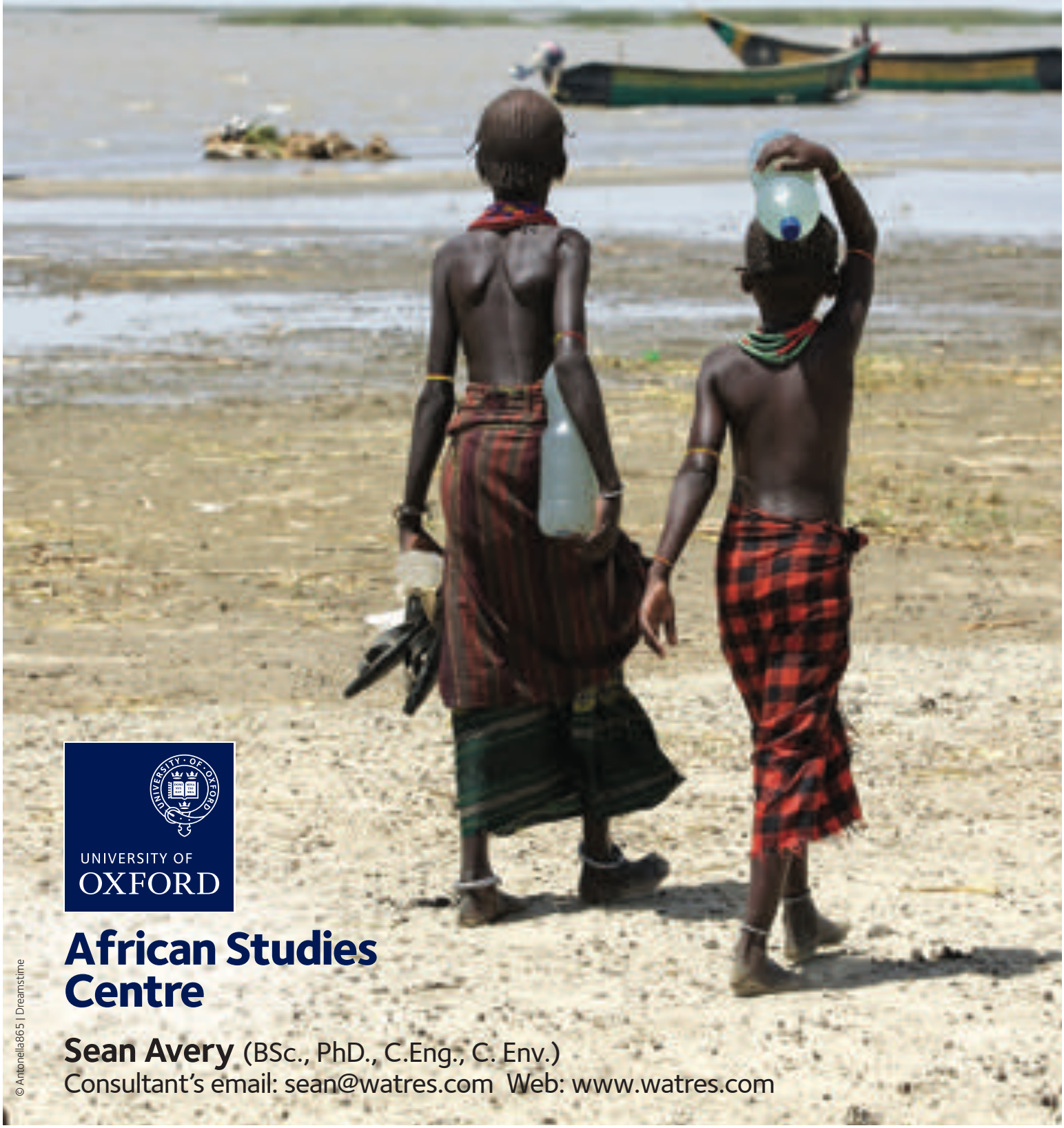
Lake Turkana & the Lower Omo:

Hydrological Impacts of Major Dam & Irrigation Development

REPORT



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LAKE TURKANA & THE LOWER OMO: HYDROLOGICAL IMPACTS OF MAJOR DAM & IRRIGATION DEVELOPMENTS

CONTENTS – VOLUME I REPORT

LIST OF FIGURES

LIST OF TABLES

LIST OF PHOTOS

VOLUME II - ANNEXES

Separate volume.

LIST OF ACRONYMS

AFDB	African Development Bank
ADB	Asian Development Bank
AFD	Agence Francaise de Development (French Development Agency)
ADF	African Development Fund
ALRMP	Arid Lands Resource Management Project, Kenya
ASAL	Arid and Semi-Arid Lands
ARWG	Africa Resources Working Group
BCM	Billion cubic metres
BGS	British Geological Survey
BP	Before Present (Present = 1950)
CEH	Centre for Ecology & Hydrology, Wallingford, UK
DFID	Department for International Development, UK (former ODA)
EANHS	East Africa Natural History Society
EAWLS	East African Wildlife Society
EEPCo	Ethiopian Electric Power Company
EA	Environmental Audit
ECHO	European Community Humanitarian Office
EIA	Environmental Impact Assessment
EIB	European Investment Bank
EPA	Environmental Protection Authority, Ethiopia
ESDC	Ethiopia Sugar Development Corporation
ESIA	Environmental and Social Impact Assessment
ESMP	Environmental and Social Management Plan
EU	European Union
EVDSA	Ethiopian Valleys Development Studies Authority
EWCA	Ethiopian Wildlife Conservation Authority
EWRA	Ethiopian Water Resources Authority
FAO	Food & Agriculture Organisation
FAS	Foreign Agriculture Service of USDA
FHI	Food for the Hungry International
FoLT	Friends of Lake Turkana, Kenya
GoE	Government of Ethiopia
GoK	Government of Kenya
ILRI	International Livestock Research Institute
IUCN	International Union for Conservation of Nature
JICA	Japan International Cooperation Agency
KAA	Kenya Airports Authority
Kengen	Kenya Power Generating Company
KETRACO	Kenya Electricity Transmission Co. Ltd.
KFS	Kenya Forest Service
KMD	Kenya Meteorological Department
KMFRI	Kenya Marine & Fisheries Research Institute
KNBS	Kenya National Bureau of Statistics
KPLC	Kenya Power & Lighting Co. Ltd
KWS	Kenya Wildlife Service
LTRP	Lake Turkana Research Project
LVFO	Lake Victoria Fisheries Organization
MALDM	Ministry of Agriculture, Livestock Development and Marketing
masl	metres above mean sea level
MCM	million cubic metres
MoA	Ministry of Agriculture, Kenya
MoE	Ministry of Energy, Kenya
MoFD	Ministry of Fisheries Development, Kenya
MoLD	Ministry of Livestock Development

MoLD&F	Ministry of Livestock Development and Fisheries, Kenya
MoU	Memorandum of Understanding
MoWD	Ministry of Water Development, Kenya
MoWI	Ministry of Water & Irrigation, Kenya
MoWR	Ministry of Water Resources, Ethiopia
MoWRD	Ministry of Water Resources Development, Kenya
NASA	National Aeronautics Space Administration, USA
NEMA	National Environment Management Authority, Kenya
NIB	National Irrigation Board of Kenya
NIVA	Norwegian Institute for Water Research
NMA	National Meteorological Agency, Ethiopia
NMK	National Museums of Kenya
OBMP	Omo-Gibe Basin Integrated Development Master Plan
ODA	Overseas Development Administration, UK (superseded by DFID)
REGLAP	Regional Learning & Advocacy Programme for Vulnerable Dryland Communities
SNNPRS	Southern Nation Nationalities and People Regional State
TBI	Turkana Basin Institute
TLU	Tropical Livestock Unit
ToR	Terms of Reference
UK	United Kingdom of Great Britain and Ireland
UMD	University of Maryland, USA
UN	United Nations
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational Scientific and Cultural Organisation
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WB	World Bank
WCMC	World Conservation Monitoring Centre
WDD	Water Development Department, Kenya
WFP	World Food Programme
WHC	World Heritage Centre (UNESCO)
WPA	Wildlife Protected Area (Ethiopia)
WRA	Water Resource Associates, England
WRMA	Water Resources Management Authority, Kenya

UNITS OF MEASURE

	Length:
mm	millimetre
cm	centimetre (1 cm = 100 mm)
m	metre (1 m = 1,000 mm)
km	kilometre (1 km = 1,000 m)
	Area
m^2	square metre
km^2	square kilometre
ha	hectare (I ha = 10,000 m^2)
	Volume
mL	millilitre
L	litre (1 L = 1,000 millilitre)
m^3	cubic metre (1 m^3 = 1,000 L)
km^3	cubic kilometre
MCM	million cubic metre (10^6 m^3)
BCM	billion cubic metre (10^9 m^3)
	Weight and Concentration
g	gram
mg	milligram
kg	kilogram (1 kg = 1,000 g)
t	metric ton (US) or tonne (1,000 kg)
ppm	part per million (milligram per litre)
mg/L	milligram per litre
meq/L	milli-equivalent per litre
μg/L	microgram per litre
	Time
s	second
min	minute
hr	hour
d	day
mth	month
yr	year
	Miscellaneous
μS	micro Siemen (electrical conductivity)
^oC	degree Centigrade (temperature)
	Money
K.Shs	Kenya Shillings
£ GBP	Great Britain Pound Sterling
USD	US Dollar
ETB	Ethiopian Birr

ACKNOWLEDGEMENTS

The Consultant wishes to thank the University of Oxford for enabling this useful further work on Lake Turkana in northern Kenya, including the Lower Omo in southern Ethiopia.

This report extends knowledge assimilated on Lake Turkana over many years and presented in reports for the African Development Bank (AFDB) (Avery, 2009; & Avery, 2010). The AFDB studies provided the first targeted assessment of the Lake Turkana's hydrology and its environs. The AFDB studies culminated in a technical assessment of the impacts of Gibe III Dam and other developments in the Omo Basin on the hydrology and lake levels of Lake Turkana, and on the lake fisheries. As the AFDB work was done under a confidentiality agreement, permission was subsequently sought by the Consultant from AFDB to publish findings. No objections were raised and the Consultant's earlier report was placed by AFDB in the public domain, accessible through the AFDB website.

The Consultant wishes to thank Dr David Anderson and Dr David Turton of the African Studies Centre at the University of Oxford, England. Their support has not only enabled the study, but has assisted the wider dissemination of important information on changes taking place in the Lower Omo and affecting Lake Turkana and its people. Thanks to their support, key findings were presented to the 14th World Lake Conference in the USA in November 2011, to the National Museums of Kenya / the Kenya Wildlife Service and the UNESCO / IUCN World Heritage fact-finding mission to Kenya in March 2012, and most recently to the environmental governance workshop hosted by the Friends of Lake Turkana in Lodwar, Kenya, in October 2012.

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This work has been possible thanks to the support of so many, as listed above, from a broad spectrum of both the local and international community. I hope the report will be useful, and I hope that there will be the opportunity to contribute further in the future.

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Postscript:

In late 2013, a condensed version of this report was prepared for publication. A CD of this 2012 report will be attached. Some typographical corrections were made, and Figures 98 to 100 were revised for consistency.

EXECUTIVE SUMMARY

1. This report was undertaken for the African Studies Centre of the University of Oxford, England, and carries forward the Consultant's previous work on the impacts of Gibe III dam on Lake Turkana's hydrology and fisheries, for the African Development Bank (AFDB) (Avery, 2009; & 2010). This study extends research into the background to development in the Omo Basin, and the Lower Omo in particular, and extends studies on climate, traditional water sources surrounding Lake Turkana, and irrigation water requirements in the Lower Omo.

2. Lake Turkana is located within northern Kenyan, within the arid and semi-arid lands that comprise 80% of Kenya's land area. Lake Turkana's surrounding areas border Ethiopia, South Sudan, and Uganda. The Omo River and Lake Turkana are the major part of a major trans-boundary basin whose large catchment breaches three of Kenya's five international borders.

3. The Lake Turkana region's people traditionally subsisted through pastoralism, an appropriate arid zone livelihood, with agro-pastoralism in the Lower Omo, and along the Turkwel and Kerio rivers, and fishing in the Lake and Omo River.

4. Although annual rainfall has increased since records began in 1921 (Figure 42 p.128), the increase is insignificant in volumetric terms, and rainfall is increasingly variable with climate change. Arid zones have always been prone to drought during which livestock can perish in large numbers. These droughts lead to destitution and conflict, with pressure increasing with dramatic population increase (4-fold in 40 years). Since the 1970s the area has been a regular recipient of humanitarian relief food. Due to Government neglect, "food aid" is practically an "institutionalised drought coping mechanism" (Snyder, 2006), dominated by international aid agencies. The consequences include dependance and loss of self-esteem, increasing sedentarisation, and exacerbating tension through in-migration of people attracted by the food relief (Avery, 2010).

5. The northern areas have thus been long been "marginalised", with a history of tension caused by colonial border constraints and insecurity, with livestock losses through drought and rustling. The Kenya Government reacted by forming a Ministry of State for Development of Northern Kenya And Other Arid Lands, within the Office of the President (Vision 2030, GoK; cited in Avery, 2010).

6. Pastoral livelihoods are today increasingly challenged by the constraints to mobility caused by increasing population coupled with reducing rangeland areas through land excisions for alternative uses (such as wildlife conservation, tourism, infrastructure, and agriculture).

7. The effective surface water drainage area contributing to Lake Turkana covers 130,860 square kilometres (Table 26, p107). Turkana is notably Kenya's largest lake, Africa's fourth largest lake, and the world's largest desert lake.

8. Lake Turkana is located in Kenya but is sustained by the inflows of Ethiopia's Omo River, which alone provides about 90% of the lake inflow (Avery, 2010). The Omo Basin is Ethiopia's second largest river system, accounting for 14% of Ethiopia's annual runoff, and being second only to the Blue Nile in annual runoff volume from Ethiopia (ibid). Lake Turkana is a closed basin, hence the inflows are totally evaporated over time, and hence the lake waters are becoming increasingly saline, being already unfit for consumption, and unsuitable for agriculture. However the lake sustains its thriving fisheries ecology, though this is less diverse than exists in other African Great Lakes.

9. The population in the Omo Basin in Ethiopia was estimated to reach 13.429 million in 2009 (Woodroofe et al, 1996), distributed as follows:

    a. 900,000 people within South Omo (ibid).

    b. 175,000 out of 900,000 people are within Lower Omo (Sogreah, 2010) (only 1.3% of the total basin population).

c. 82,000 out of 175,000 people were estimated to be directly dependant on the Omo River (ibid).

10. The 2009 census population in the three districts adjoining Lake Turkana in Kenya is:

    a. Turkana District: 650,000 people
    b. Marsabit District: 160,000 people
    c. Samburu District: 210,000 people

    Of the above combined total, about 200,000 people are within census sub-locations abutting Lake Turkana, with 90,000 people estimated within the immediate lakeshore zone.

11. Hence the directly affected combined population, in the Lower Omo in Ethiopia and around the lake in Kenya, amounts to about 170,000. Note that population is doubling every 20 years. The indirectly affected population, through the inevitable "domino effect", will be very much larger. Estimates in the literature mention 500,000 people being "affected by Gibe III".

12. Since the 1960s, the Kenya Government has encouraged people living around the lake to diversify livelihoods, in order to reduce dependence on livestock. Alternative livelihoods have included some irrigated agriculture along the Kerio and Turkwel rivers, and fishing on the lake. Fishing activities are today widespread throughout the lake, in spite of fierce winds that can create dangerous conditions for boats. The commercialisation of fishing remains hampered by the absence of fish cold storage facilities, and very poor road infrastructure with which to effectively transport product out of the region. There are also concerns that the fish flesh harbours parasites that would prevent export. The fisheries resource has become an alternative livelihood providing a valuable source of protein to people in the Lake Turkana area, although only a relatively small population proportion benefits. NGOs such as Oxfam, and missionaries, have supported the fishing sector through the sponsorship of boats and fishing gear. However, the sector is poorly regulated.

13. Various studies on the lake fisheries have been published, as follows:

    a) 1895 - 1900: The first visits to the Lake with fish records (by Donaldson-Smith).

    b) 1909 - 1915: British Museum Catalogues (Boulenger, 1909 - 1915).

    c) 1930 - 1931: Cambridge University Expedition on East African lakes (Beadle, 1932).

    d) 1930 - 1932: The Omo Expedition (Mission Scientifique de l'Omo, Pellegrin, 1935).

    e) 1972 - 1975: Lake Turkana Project - Overseas Development Administration, UK, with Kenya's Fisheries Department. Lake Turkana was the last of the world's major lakes whose bathymetry had not been measured. A specialist research vessel built in UK was transported to Kenya and launched in 1971, specifically for the study (Hopson et al, 1982).

    f) 1985 – 1988: Turkana Limnology Study – Norwegian Institute for Water Research (NIVA), and the Kenya Marine & Fisheries Research Institute (KMFRI). This was the last major fisheries study to have been undertaken on the lake itself. Recommendations were proposed on monitoring to better understand the nutrient supply of the Omo River (NIVA, Kallqvist et al, 1988).

    g) 1987 - 1989: Turkana Fisheries Study – University of Bergen, Norway (Kolding, 1989), and various later papers by Kolding.

    h) 2007: Kenya Marine Fisheries & Research Institute (KMFRI) multi-disciplinary research expedition – Lake Turkana Research Project (Ojwang et al, KMFRI, 2007).

    i) 2012: Muska et al & KMFRI – "The last snapshot of natural pelagic fish assemblage in Lake Turkana, Kenya: A hydroacoustic study" (Muska et al, 2012).

    The critical dependance of the lake's fisheries on the Omo River's hydrological fluctuations and nutrient supply was clearly established by the above studies (reported in detail in Avery, 2010). The studies stated that changes to the Omo hydrology would damage the lake's fisheries. Even Ethiopia's Omo-Gibe Basin Master Plan noted that water resource developments would adversely affect the lake's fisheries (Woodroofe et al, 1996).

14. A major study of the geothermal energy and geology of the northern sector of the Kenya Rift Valley was undertaken by British Geological Survey, with Kenya's Mines & Geological Department, from 1988 – 1992, and the project area included the Lake Turkana region (BGS, 1993).

15. Today, oil exploration is being undertaken throughout the area, with oil finds reported in the Lower Omo, and in more than one location in and around Lake Turkana. Exploration is also being undertaken in the lake itself. There are raised expectations as a result of the oil finds, and this is raising concerns within the communities.

16. The above studies provide a wealth of information on the lake, its chemistry and interesting aquatic ecology, but until recently, there was very little information on the hydrology of inflowing rivers. The principal perennial inflow source is the Omo River, but there are some springs around the lake, and the Turkwel Dam's regulated releases into the Turkwel River eventually reach the lake, albeit much diminished in volume. Otherwise, the inflowing rivers are seasonal, typical of arid areas, and difficult to monitor and quantify (Avery, 2010).

17. Studies published in 1982 (Hopson et al) reported that Lake Turkana hosts 48 species of fish, 18 of which are either endemic or Nilotic. Twelve species are riverine and specific to the Omo River. Thirty species are Soudanian, and hence are also to be found in rivers extending from West Africa to the Nile. More recent studies increased the fish species list to 60 species (Avery, 2010; citing Ojwang et al, 2007, citing FISHBASE, 2000).

18. The key environmental factors governing the fish ecology in Lake Turkana were previously reported to be as follows (Avery, 2010; citing Hopson et al, and others):

    a) Salinity of the water: This lake is one of the most saline of any lake in the Rift Valley hosting abundant and distributed fisheries, and long term salinity is gradually increasing.

    b) The lake's prevailing SE winds: These strong winds control the lake currents, which drift the algae and zooplankton to NW shores, and the wind-driven currents sustain the lake in its well-mixed and well-oxygenated condition. Hence fish biomass is denser towards the NW shores, where there are "higher diversity indices" (Ojwang et al, 2007).

    c) The lake's water temperature: This is stable, with stratification at depth. Studies presented in this report show that there is an increasing temperature trend consistent with general reported global warming (Figure 37, p124).

    d) And, most important, the annual flooding influx of the Omo River: The Omo's flood pulses stimulate fish spawning, the inflows carry nutrients into the lake (having the most effect in the northern sector), and the Omo inflow and floods govern the lake's ecology.

    Lake level change is also a key factor. This is discussed further below.

19. Naturally increasing water salinity levels are not believed to have been critical to fisheries (Avery, 2010; citing Hopson et al, 1982). However, any changes to the flood regime of the Omo River will directly impact the breeding of 70% of the lakes "more important" species (ibid). The Omo floods inundate areas within the Lower Omo valley plains and delta, from which nutrients are derived. These inundations replenish the grasslands and wetlands favoured by birds and other creatures, especially in the Lower Omo. The floods cause the lake itself to rise and inundate the lake's littoral margins. These inundations submerge terrestrial vegetation that provides valuable refuge habitat in a lake otherwise devoid of benthic vegetation (due to its salinity). The floods dilute the lake waters, reducing the salinity levels in the northern areas of the lake in particular, and the floods spread a plume of sediment rich water into the lake. The plume spreads to the central sector of the lake, and the reduced visibility caused by the plume encourages fish to migrate closer to the lake surface and towards the shores (Avery, 2010; citing Hopson et al, 1982).

20. Twenty-three of the fish species known in 1975 were considered "more important" (ibid). Of these, ten species spawn in the Omo River or in major river mouths; six species spawn in littoral zones of the lake dependant on seasonal rises in the lake from the flood season (ibid). Seven of the important species breed in the open lake. Hence the spawning of

sixteen of the lake's "more important" species is dependent on the Omo flood volumes and periods, as well as the cyclical lake rises that inundate the littoral margins of the lake (ibid). The value of the littoral zone to fisheries is dependant on the levels of livestock grazing of these zones. In recent years, the shoreline vegetation has been heavily grazed, which in turn will have negatively impacted the success of fish breeding. On the other hand, the livestock droppings are an alternative source of nutrients.

21. Lake level was not listed amongst the "key environmental factors" by the 1972 - 1975 studies edited by Hopson et al (Avery, 2010). The lake levels were expected to continue to fluctuate within two to three metres of the levels in 1972, which reflected the "natural" cycle experienced up to that time. However, the AFDB studies stated this would change dramatically with developments in the Omo Basin (Avery, 2010).

22. The Omo-Gibe Integrated River Basin Development Master Plan forecast that by the year 2024, 32% of the Omo inflow to the lake would instead be utilised to meet water demands (Woodroofe et al, 1996 – see Table 6, p54). The AFDB studies showed that this high level of abstraction would lead to a significant and permanent drop in lake level (Avery, 2009; & Avery, 2010), with significant impact on the Lake Turkana fisheries. Adverse impacts on fisheries were anticipated in the Omo-Gibe Basin Master Plan, but these impacts were not explored as the Lake Turkana portion of the Omo catchment was beyond the Master Plan's study area. The Master Plan was funded by and undertaken to Terms of Reference agreed by the African Development Bank / African Development Fund, so the exclusion of the lake from studies was agreed upon, and this was surprising given its trans-boundary nature. The Master Plan did however conclude that all developments should be subjected to full environmental and social impact assessments (ESIAs), and that environmental legislation in Ethiopia should be strengthened with such studies being mandatory. The Master Plan also recommended avoidance of the problems caused by displacement of people, as had happened with the Ethio-Korean irrigation project at Omorate in the Lower Omo. Unfortunately, the Master Plan's recommendations have not been effected, with major developments proceeding without any prior ESIAs, without any prior consultations in Kenya, and with local people in the Lower Omo forcibly coerced away from lands they traditionally inhabited and utilised (Human Rights Watch, 2012).

23. In 2011, the major excisions from the Omo National Park, Mago National Park, and Tama Wildlife Reserve, were reported, for the purpose of major commercial irrigated sugar development in the Lower Omo. This scale of commercial agricultural development had not been foreseen in the Omo-Gibe Basin Master Plan, nor was it foreseen in any of the recent studies reviewed in this report. The Kuraz sugar scheme alone will comprise over 150,000 hectares, an area equivalent to the total "irrigated area" in the entire Republic of Kenya in the year 2011 (JICA, 2012). The Kuraz sugar development alone will require a significant proportion of the Omo inflows to Lake Turkana, 28.2% at 70% irrigation efficiency, and over 40% if the schemes are inefficient – see Table 14 on p65.

24. The full scale of "irrigable" Lower Omo commercial agriculture based on previous studies of soil suitability will be less than the areas reported in studies by the Oakland Institute (see Table 4 p52, and Table 9 p58), but the areas are nonetheless huge, and represent a very significant chunk taken from the lands of the indigenous inhabitants.

25. The revised Lower Omo "irrigable" area presented in this report will require abstraction of about 33.5% of the Omo's annual flow (28.2% + 5.3% = 33.5%, Table 14, p65, assuming 70% irrigation efficiency). This will cause the lake to permanently drop 13 metres from its current sustainable level, based on average inflows (Figure 99, p225). In the event of inefficient water management practices, the potential lake level drop would be 22 metres for the same crop water requirements (Figure 99). In the event of drought and reducing Omo flows over several years, such as occurred in the 1940s and 1950s, the lake level reductions will be greater still than the above "equilibrium" figures (this is illustrated in Figure 97, p223). It should be borne in mind that the average lake depth is roughly 30 metres.

26. The above 13-metre lake level drop will reduce the lake volume to 59% of its current sustainable volume (Figure 100, p226). In the event of inefficient water management practices, the lake level drop will be greater and biomass would fall to 42% of its sustainable volume. This huge volume reduction will correspondingly reduce the fisheries

habitat and hence available biomass, and will also cause an increase in salinity through concentration of salts. As an example, it has been reported that the reduction in lake level between 1975 and 1988 resulted in 70% reduction in open-water pelagic endemic fish (Kolding, 1993), a direct consequence of falling lake level. A very recent fisheries survey was aptly entitled the "last snapshot" of Turkana's pelagic fish, stated by the authors to be in anticipation of the damage to fisheries by the Gibe III development (Muska et al, 2012). The concerns are widespread.

27. When lake level falls more than 3.1 metres below the September 1972 lake level (the bathymetric survey map zero datum), Ferguson's Gulf will be dry. The Gulf has proved to be one of the most productive fishing areas on the lake (Hopson et al, 1982; NIVA, 1988). The algal "production" measurements in the Gulf in 1988 were reported as being amongst the highest recorded. In recent years, the Gulf has been impacted by sedimentation, and the shore has been invaded by Prosopis juliflora, an aggressive alien tree, introduced by NGOs to "green the deserts". The Gulf's present-day bathymetry is uncertain. The filling of the Gibe III reservoir will drop the lake level by two metres and would on its own render the Gulf dry again. Gibe IV will have a similar effect, in turn. The irrigation abstractions will render Ferguson's Gulf dry forever more.

28. Fisheries resources depend not only on sustainable harvesting of the fish resource, but also on effective management of the dependant water resource, and on its catchment and riparian zones. All riparian zones in Kenya are legally protected, and no development, tillage or cultivation is in theory permitted. The traditional "flood recession" riverbank cultivation practices along the Omo River banks would be illegal in Kenya. From a hydrological catchment management perspective, riparian zone cultivation should be discouraged. However, enforcement is a challenge, and in Kenya, there remains widespread and often damaging exploitation of the riparian zone of lakes and rivers, often by poorer people without alternative land to access. Such practices disturb the riparian zone and are detrimental to the water resources as a whole, and they increase sediment runoff and affect water quality. Lake Turkana is no exception.

29. The lake's hydrological monitoring has been neglected in recent years, in spite of repeated recommendations concerning the importance of these measurements. However, there are rainfall records for isolated rainfall stations around the lake. Historic lake level measurements have been sporadic, and there has been no ongoing measurement of river runoff into the lake. However, there is a sufficient record, thanks to various researchers, with which to establish that the lake was once very much higher than today, and that in recent years there has been a current increasing lake level trend, a trend also shared by other regional lakes. The lake level changes are today monitored on a 10-day cycle by remote satellite equipment (USDA-FAS and others).

30. The Lake Turkana region has for years fascinated archaeologists, palaeontologists, anthropologists, and geologists, and understandably so. The formation of the Rift Valley commenced 20 million years ago (BGS, 1993). The sedimentary history provides a fascinating insight into the climate change that has occurred over the past 5 million years during which a lake has existed in Turkana. The Omo River once flowed SE to the Indian Ocean. The Rift Valley floor then dropped, and a lake formed.

31. In its history, the lake has risen and fallen dramatically in response to major climate changes. The sedimentary history shows that the lake was once an extraordinary 100 metres higher than it was in 1972, with a very much larger surface area, with the Omo delta 100 kilometres further north than it is today, and with an overflow link into the River Nile drainage (this overflow link occurred NW of the contemporary lake through the Lotagipi Swamp into South Sudan).

32. Since 6,500 BP, the lake has fallen in response to climate change, descending into increasing aridity, being "dry" 3,000 BP (Garcin et al, 2012 - see Figure 15 on p73).

33. The contemporary lake water surface elevation is about 363 metres above mean sea level. This is roughly the "equilibrium" level that can be sustained by current average lake inflows. This level is below the September 1972 "zero" metre water level of 365.4 masl, but higher than the historic low lake levels of the 1940s, 1950s, and 1988. The lake is a closed basin, but, as stated earlier, the Soudanian fish species found in the lake today interestingly originate from former times when the lake was linked to the Nile River's drainage. The fish

species in Lake Turkana are all found across rivers to West Africa, although the lake has endemic species as well, but these are all derived from the original Soudanian species.

34. In recent history, the "contemporary" lake peaked in 1896, as did other regional lakes. The lowest level for this "contemporary" period was reached in the 1940s when the lake fell 20 metres below its 1896 peak, well illustrated in Figure 57 (on p152), and Figure 97 (on p223). A similar "low" was reached in 1988. Since then, the lake has risen, the lake today being about 17 metres below its 1896 "peak".

35. Hence the lake has experienced a very wide range of "natural" level fluctuation, ranging from there being no lake at all, to a lake 100 metres higher than today. It might be concluded from this that further change is acceptable, however rapid it might be, provided such change falls within the "natural level range" of the past.

36. Runoff patterns in the Omo River have changed in the last twenty years. Forests and vegetation have been cleared in the Omo Basin through human activity, and as a consequence, runoff has become more variable, with much more rapid response to rainfall. Without effective catchment management, the overall runoff volume can be expected to increase with catchment degradation. The increased runoff rates are also accompanied by accelerated soil erosion, and increased sediment runoff into rivers for conveyance downstream. The effects of this are seen in the changes over time of the areal extent of the Omo delta. Sediments are deposited where the Omo River's flowing waters decelerate on entering Lake Turkana, and this sedimentation is a factor in the development of the delta.

37. The Omo River sustains the lake at present water levels by providing the water input needed to balance the large water volume evaporated from the lake surface. In addition, the Omo River carries nutrients and minerals into the lake, especially nitrogen.

38. The flood pulses of the Omo River have many positive effects. The floods flush the river channel; the floods replenish off-stream oxbow lakes, depressions and delta lakes; the flood volumes lead to cyclical changes in lake level within a year; the flood pulses stimulate fish behaviour and movements; the flood pulses also change lake currents, affect visibility, and these currents distribute nutrients throughout the water body of the lake. Flood pulses promote the beneficial interaction of aquatic and terrestrial ecosystems, with peak fisheries production rates being associated with peak rises in lake level (Kolding, 1993). "Flood-plain" type fisheries are considered the most productive in the tropics (Kolding, 1994; citing Welcomme, 1979; and Junk et al, 1989). Lake Turkana falls within this category of fisheries.

39. In contrast to flooding periods, falling lake levels are associated with plummeting fish stocks (ibid).

40. As Lake Turkana is dependant on the Omo River for almost 90% of its inflow, this river is the lake's "umbilical cord" (Avery, 2010). If the Omo River inflow is reduced, the lake level and associated biomass will fall, as will nutrient inflow. If the Omo river flow patterns are modified, the lake ecology will be impacted. The lake is almost entirely within Kenya, whereas the Omo River is entirely within Ethiopia. Hence management of the Omo Basin and lake water resources is a trans-boundary matter.

41. The AFDB studies collated all the readily available climatic, hydrological and fisheries data (Avery, 2010). This study has extended that database, and has increased the scope to include lake temperature change assessment from satellite data.

42. The AFDB studies assessed the impact of the Gibe III hydropower reservoir on Lake Turkana's levels, and identified the consequences on fisheries ecology (Avery, 2010). In contrast to other studies, the AFDB Consultant insisted that large-scale irrigation in the Lower Omo is a direct "benefit" and consequence of Gibe III, and that the irrigation impacts must be included within Gibe III's impacts. This "benefit" arises because Gibe III will significantly enhance natural low flows of the Omo River through regulation from the huge storage lake created by the 243 metre high Gibe III dam, thereby making irrigated agriculture feasible (ibid). The average low flows will be increased 2.5 times.

43. This study consolidates the AFDB studies with up to date information on large-scale irrigation development in the Lower Omo. This study presents revised irrigable areas based on published data, and presents appropriate computations of water demands for irrigation using FAO software, and FAO climate and soils data. This study also presents comparative data from an irrigation scheme with similar characteristics on the Tana River in Kenya, and from Kenya's National Water Master Plan update.

44. This study investigates the low flows of the Omo River and demonstrates through a flow duration analysis that without regulated flows from Gibe III, the Omo's natural low flows are insufficient to sustain large-scale commercial agriculture in the Lower Omo. This reinforces the findings of the Master Plan dated 1996. This study shows that the Omo's low flows are more critical today than at the time that the Master Plan was undertaken, due to changes in the Omo catchment, and due to abstractions to meet water demands along the river. The Omo's low flows are shown to have diminished in recent years (see Figure 94, p219). Hence, it must be emphasised again that without Gibe III's regulated flow releases, the irrigation schemes are not feasible.

45. This study notes that Kenya is investigating the potential of 10,000 hectares of irrigated agriculture at Todenyang on the NW shore of Lake Turkana, near the Ethiopia / Kenya border. Feasibility studies have not yet been done, but it is assumed by this study that the necessary irrigation water would be sought from the Omo River, and that this would require co-operation between Ethiopia and Kenya.

46. The AFDB studies noted that there are two further hydropower schemes envisaged on the Omo River downstream of Gibe III, namely Gibe IV and V, and that these schemes will add to the impacts of Gibe III (Avery, 2010). Gibe IV will create a lake similar in volume to Gibe III. Hence Gibe IV will have similar impact on the lake, and will compound the impact of Gibe III, the full extent of the lake recession being dependant on the timing of project commissioning.

47. The AFDB studies noted that the Gibe IV and V projects would not only add to the Gibe III impact on the lake, but also will intercept and attenuate the proposed Gibe III "ecological" flood releases. In effect the Gibe III "ecological" releases will be rendered redundant, although it can be assumed that similar measures would have been proposed for Gibe IV and V (Avery, 2010). Hence the scenario will alter with the addition of Gibe IV and V, but the consequences will be enhanced. This study has enquired about further studies on the Gibe IV and V projects, but none were yet available.

48. The AFDB Consultant noted that previous studies have been conducted on the Omo Basin, and in some detail, related to the specific developments, but those previous studies did not venture to assess impacts over the border in Kenya, on Lake Turkana (Avery, 2010; citing Woodroofe et al, 1996). None of those studies anticipated the magnitude of recent developments that include large excisions from the Omo and Mago National Parks and Tama Wildlife Reserve, undertaken to enable large-scale sugar plantation developments. Even Ethiopian Government bodies such as Ministry of Water Resources appear not to have been aware.

49. The AFDB study confirmed that Lake Turkana is almost entirely dependant on the Omo River, as stated by previous studies. The Gibe III hydropower project, which is still under construction today (56% built in 2012), would need the equivalent of over two metres on Lake Turkana in order to fill the huge lake created by the 243 metre high dam wall (Avery, 2010). Thereafter, the scheme will "process" 67% of the water that later reaches Lake Turkana, constantly releasing water in order to generate the power for which it is designed. The hydropower releases will be "regulated", hence, whilst the annual volume of water flow should in theory not alter, the pattern of flows will change according to the power scheme's operating rules.

50. The 243 metre high Gibe III dam will create a lake 200 square kilometres in area. The Gibe III reservoir's gross storage will be 15 cubic kilometres of water, which is roughly the mean annual runoff needed to sustain Lake Turkana (Avery, 2010). The Gibe III reservoir will forever capture all bed load sediment transported by the river to this point, and will store water for approximately a year, leading to changes in water quality (ibid). The removal of bed load sediments will stimulate erosion of the river downstream of the dam.

None of these impacts have been quantified. Note that Gibe IV will create a similar size reservoir downstream, with similar impacts.

51. Gibe III's high dam will raise the adjoining groundwater table to the height to which the lake rises. This means raising the groundwater table by about 240 metres above the previous "natural" groundwater table. Fears have been expressed that this will cause huge seepage losses underground (ARWG). AFDB cited specialist studies with which this study agrees, that the concerns of water losses from the Basin were unfounded, as any seepage would remain within the Omo river system (Sogreah, 2010).

52. Concerns had also been expressed about seismic effects that can result from the huge superimposed load that comprises the stored water volume. This remains a real possibility.

53. The AFDB Consultant commented on the proposed ecological flow and the annual ecological flood release of ten-day duration proposed as a mitigation measure for the Gibe III project (Avery, 2010; reviewing the Agriconsulting et al studies done for EEPCo). The AFDB report stated that although the "flood-pulse" intention is the correct mitigation measure for this lake's "flood-plain fisheries" ecology, the ecological flow proposals were not supported by any quantified scientific evaluation (Avery, 2010). The AFDB Report posed many questions. For instance, what is the significance of the selected ten-day flood pulse duration (ibid)? Can the river and lake ecology be sustained by a single ten-day flood pulse, or are several such flood pulses needed, and for what duration are such pulses needed (ibid)? As the "fertility" of the lake is entirely due to the pulses of nutrient inflows, what are the nutrient inflow levels at the moment, and how will they be affected by upstream storage / flow regulation (ibid)? What assurance is there that the proposed compensation flow releases will be sustained given the conflict of interest with power generation and irrigation interests (ibid)?

54. This study has concluded that the above "ecological" flood releases can no longer be contemplated in any case because floods will damage the extensive irrigation and associated infrastructure whose construction commenced in early 2011 in the Lower Omo. The Lower Omo's commercial agricultural developments have commenced without any ESIAs having been released. Hence there is no revised mitigation plan available from the Ethiopian Government with which to evaluate the cumulative impacts of the current Gibe III and large-scale agricultural developments. In this context, the Sogreah proposal to replace ecological floods by a canal-fed recharge system was interesting, although even that proposal is superseded by the large-scale irrigation now being developed (Sogreah, 2010).

55. The impacts of Gibe IV and Gibe V have been mentioned in the EEPCo reports, but the mitigation measures thereafter are not addressed. The Gibe IV and V schemes are envisaged downstream of Gibe III. It is stated in EEPCo reports that the Gibe III ecological flow releases will no longer be necessary once Gibe IV and V are constructed. In effect, there will be no more natural floods. Studies on other lakes suggest that the regulation of the annual lake level fluctuations to a stable level will be detrimental to the lake's flood plain fisheries ecology (Karenge and Kolding, 1994). Hence considerable change to the lake fisheries as it is known today is inevitable.

56. Apart from the AFDB's 2009 and 2010 studies, none of the various available technical reports addressed long-term water abstraction plans within the Omo Basin in terms of the impact on Lake Turkana. The Omo-Gibe Basin Master went no further than acknowledging adverse trans-boundary impacts. AFDB's 2010 hydrological study demonstrated that long-term potential abstractions from the Omo River could reduce the lake level by 20 metres (Avery, 2009, & 2010). AFDB presented this alarming data and emphasised the need for an integrated trans-boundary basin impact assessment.

57. The Kenya Government officially requested assistance from UNEP to collect environmental data on Lake Turkana (GoK letter to UNEP, 2011). UNEP has responded positively. UNEP sponsored a presentation on Gibe III's impacts by the Consultant to the 14th World Lake Conference in Texas, USA, in November 2011, within the UNEP/ILEC Session. UNEP has since been developing its initiative to bring together Ethiopian and Kenya professionals within a project that discusses this trans-boundary water resource (various Personal Communications with UNEP Nairobi, 2012).

58. The AFDB studies noted that no scientific quantitative studies have actually been presented to decide whether Lake Turkana should or should not be sustained, and if so, at what water level should that be (Avery, 2010)? What is the economic value of the lake to Kenya and the environment (ibid)? This position remains unchanged three years later when this report was produced.

59. A study dated 1986 argued that sustainable development in Ethiopia could only be achieved "through the adoption of an integrated, conservation-based strategy for the development of the valleys and basins of Ethiopia". The Omo-Gibe Integrated River Basin Development Master Plan, funded by the African Development Bank / African Development Fund, was published in 1996. The "principal goal" stated in the Terms of Reference was to prepare "a master plan for development…with the minimum possible adverse environmental impact." The Omo Basin has been almost as "marginalised" within its national context, as has been Lake Turkana within Kenya, so the "needs" cannot be disputed.

60. The AFDB studies referred to a World Bank Concept Note that described the importance of development within the Omo Basin, but which stated in regard to Lake Turkana that there is "no significant use of the lake's waters" (Avery, 2010, citing World Bank, 2004). The same "Note" considered that it would be relatively easy to obtain a "no objection" from the Kenya Government, and that if there was donor funding involved, Kenya "can benefit from the Project" (ibid).

61. Gibe III and other developments in the Omo Basin are consistent with the Master Plan funded by AFDB / ADF, and are supported by the above World Bank Concept Paper's proposals. In 2009, the Kenya Government signed its MoU with Ethiopia to buy power, with Gibe III's production in mind. Hence the Kenya Government is also supportive of the Gibe III Project.

62. In 2012, the World Bank announced its funding for a major power transmission line from Ethiopia to Kenya. This announcement has been greeted with protests from Friends of Lake Turkana (FoLT). It is believed that the feasibility of the ambitious 1,045 kilometres long powerline depends on power generated at Gibe III. FoLT are right to protest. The consequences of Gibe III and other Omo Basin developments cannot be lightly dismissed as the World Bank suggested in 2004. What would be the appropriate compensation due for destruction / damage to the Lake Turkana resource? What compensation would be due for the displacement of affected communities? How would compensation be paid? All such issues should be addressed as prerequisites for all such project funding, and urgently, as impacts are happening already. The recent large-scale developments commenced without published ESIAs and trans-boundary consultations, which infringes World Bank "safeguard" policies. Human Rights Watch has published findings of human rights abuses (Human Rights Watch, 2012). World Bank is in partnership with the African Development Bank and French Development Agency for the powerline. The powerline is inevitably linked to the Gibe III generation contribution to Ethiopia's power grid. Thus, being enjoined, responsibility is shared by all three international donors.

63. The Gibe III Project commenced construction without benefit of an environmental and social impact assessment (ARWG). Studies were presented three years after construction commenced, and were not independant, and investigated within Ethiopia only (Salini, 2009; Agriconsulting & Mid-Day 2009, for EEPCo). "Positive" impacts on the lake's hydrology were claimed (ibid). This claim was without basis, and was at variance with the adverse effects on the lake fisheries anticipated in the Omo Basin Master Plan. The challenging trans-boundary issues reported in the Master Plan were beyond the geographical scope of that report, and hence were not addressed further at that time, unfortunately.

64. Concerns have been expressed that there is past global experience that ecological flow rules may be disregarded / amended to suit other more pressing national needs (Avery, 2010; Sogreah, 2010). For instance, an environmental audit of the Gibe I project, undertaken by Ethiopian professionals, reported that although compensation flow releases had been stipulated for that scheme, no compensation flows were being released. There is potential for a conflict of interest with the needs for power generation, and its economics, as stated earlier and in other reports (ibid; Sogreah, 2010).

65. The AFDB studies overcame the absence of river flow data for the hydrological assessment of Lake Turkana by computing river discharges from lake level fluctuations (Avery, 2010). That study successfully utilised satellite radar altimeter readings of the lake level, which are observed at 10-day intervals. Hence the AFDB Consultant demonstrated a very useful tool for ongoing lake inflow monitoring. The current study has developed the AFDB work, and demonstrates the effectiveness of the lake water balance model through further hydrological analysis.

66. The AFDB studies confirmed the vulnerability of the lake to catchment degradation and especially the proposed water developments within the Omo Basin. The scale of irrigation development has since crystallised. These are at a far larger scale than expected, and are progressing apace, and as forecast by AFDB, the lake will diminish, as will biomass and fisheries (Avery, 2010). Whether this is of consequence should have been the subject of a separate study and consultations with the Kenya Government and stakeholders, as recommended by AFDB, such a study being based on a proper economic valuation of Lake Turkana and its resources (Avery, 2010). The consequences on people that depend on the lake cannot be dismissed lightly.

67. In order to make reasoned decisions, the following is concluded and recommended:

    a) The hydrological study presented in this report is conclusive in regard to immediate changes expected from Gibe III and the known scale of the Lower Omo commercial agricultural developments. It also includes speculation about Gibe IV and V. The hydrological assessments in this report can be refined as a useful monitoring tool, and more work could be done on climate change, but the changes are certain.

    b) The bathymetric survey produced by Tullow Oil in 2011 / 2012 needs to be obtained in order to refine the evaporative model used in these studies.

    c) The lake climate temperature change studies should be continued with future projections made on temperature change. The effect of increased temperature on increasing lake evaporative losses, and increasing crop water consumption needs, should then be refined, and ecological effects postulated.

    d) AFDB and Sogreah both independently strongly recommended re-establishing a river gauging station on the Omo River at Omorate (Avery, 2010; Sogreah, 2010). This recommendation is important and is reiterated here. A gauging station will be required upstream of the Kuraz irrigation offtake point, and at the intake itself to measure both offtake and downstream release towards the lake.

    e) The AFDB study also recommended that the lake level gauge near Ferguson's Gulf be restored to routine monitoring status, with an immovable permanent reference datum (Avery, 2010). This has been done. The gauge was not visited and no data has yet been obtained during this study. However, it has been requested. This will need to be followed up, and the measurements can be usefully correlated with the independent satellite monitoring.

    f) The flood patterns of the Omo River need to be studied in terms of flow volume and duration. The impact of changes due to catchment degradation need to be addressed, as the presence of dams can assist by regulating the flashy and damaging runoff that results from catchment degradation.

    g) The cumulative impact of the proposed Gibe IV and V schemes will need to be reviewed once studies are available (Avery, 2010).

    h) The cumulative impacts of the ongoing large-scale irrigation developments in the Lower Omo need to be reviewed once the ESIA study is released by Ethiopia's Sugar Development Corporation.

    i) In view of the massive water abstractions planned in the Lower Omo, there is need for appropriate climate data collection to enable accurate crop water computations.

    j) The potential water utilisation within the Omo Basin needs to be constantly reviewed in the light of the proposed Gibe IV and V schemes, and other schemes, and the impact on Lake Turkana's levels can then be refined based on this information (Avery, 2010).

k) A scientifically proven and appropriate method of assessing ecological flows in the Omo River needs to be chosen and utilised (Avery, 2010). Some ecological flow release below the Kuraz sugar diversion intake is a fundamental necessity.

l) The AFDB studies recommended that the status of Lake Turkana's fisheries resource today needed to be reviewed, as changes will have taken place since the detailed studies were done over 30 years ago (Avery, 2010). The fisheries resource is in "a perpetual state of change", undergoing "unpredictable and drastic transformations" (Kolding, 1993), and will have been impacted by catchment degradation since the authoritative studies of that time, by changes in runoff and sediment runoff patterns, and by population pressure and associated increased and poorly regulated fishing, and increased livestock grazing of littoral zones.

m) The full impact of changes within the Omo Basin on fisheries should be evaluated (Avery, 2010). The changes in hydrology are inevitable. These will alter the fisheries ecology, as it is known today. Studies need to evaluate the emerging scenarios.

n) A full evaluation of the economic value of the lake as a "resource", and its contribution to microclimate, was recommended by the AFDB studies (Avery, 2010). This is still needed to assist planning the lake's future. There is need to value the compensation that will be due upon destruction / damage to the resource.

o) The lake's influence on the ground water level needs to be considered as well.

p) A thorough socio-economic and livelihood survey of the lake-dependant communities should be concluded once the full impact of development proposals is quantified (Avery, 2010).

q) An updated integrated basin-wide environmental & social impact assessment is needed (Avery, 2010). There is need to value the compensation due to those displaced by the developments.

r) It would sensible for the EIA studies to evaluate the consequence of a dam-break situation, especially as the Gibe III dam is being constructed in a seismically active zone, and will store a massive volume of water equal to a depth of two metres on Lake Turkana (Avery, 2010). This recommendation was included in the KETRACO ToR (KETRACO, 2010) and thus should have been included in the report presented in 2012 (Panafcon / DHV, 2012, report not yet released).

1 INTRODUCTION

1.1 The Context

This report is concerned with Lake Turkana in Kenya's northern Rift Valley. Lake Turkana is Kenya's largest lake, Africa's fourth largest lake, and the world's largest desert lake. The lake is located within Kenya's most arid lands with its northern shores bordering Ethiopia. In more humid times, most recently about 6,500 years ago, this lake was deeper and overflowed into the River Nile basin. Since those humid times, the region has undergone dramatic climate change, becoming much drier. The lake became a closed basin, and through relentless evaporation, the lake water's have become increasingly saline. The lake is popularly known as the "Jade Sea" on account of its unusual colouration (caused by its algal flora). It is ecologically unique and hosts Kenya's only archaeological national park, in recognition of which the lake's national parks are inscribed on the UNESCO World Heritage List.

The ecology sustains diverse fisheries utilised by local people. 90% of the lake's freshwater inflow and nutrients are provided by Ethiopia's Omo River, the "umbilical cord" for Kenya's Lake Turkana (Avery, 2010). Hence any study of Lake Turkana hydrology necessarily embraces Ethiopia's important Omo Basin.

In 1996, the Ethiopian Government prepared its Omo-Gibe Basin Master Plan (Woodroofe et al. 1996). The Omo Basin's water resources were studied up to the Kenya border where the Omo River forms its ever-changing delta on reaching Lake Turkana.

The location of the Omo-Gibe Basin within the various Ethiopian river basins is illustrated in Figure 1 on p16. Although the Basin is clearly not amongst Ethiopia's largest, this Basin enjoys some of Ethiopia's highest rainfall in its highlands, and conveys the second largest annual runoff of any river system in Ethiopia, accounting for 14% of Ethiopia's annual runoff (Woodroofe et al, 1996). Only the Blue Nile (Abbay) carries larger flows. Hence the Omo-Gibe Basin is a very significant potential hydropower and irrigation resource within Ethiopia, and a logical target for development.

Construction of a cascade of hydropower schemes commenced on the Omo River with the Gibe I hydropower scheme commissioned in 2004. The Gibe II hydropower project followed, and was commissioned in 2010, with Gibe III's construction having commenced in 2006. The Gibe III hydropower project has ever since been mired in ongoing international controversy. The construction commenced without any prior environmental and social impact assessment, Kenyan stakeholders were not consulted, and the main dam construction contractor was sourced without a competitive tender process.

An early large-scale irrigation project was attempted many years ago at Omorate, in the Lower Omo, not far from the Omo delta on Lake Turkana. Known as the Ethio-Korean project, this scheme was abandoned in 1991. In early 2011, large-scale irrigated sugar development commenced in the Lower Omo upstream of Omorate. This new development is on a scale far in excess of what was envisaged in the Ethiopian Government's 1996 Omo-Gibe Basin Master Plan, and was not reported in Ethiopia's Ministry of Water's projections dated 2007. This irrigation development was also not mentioned in the several technical reports prepared in connection with Gibe III during 2010. Even the UNEP Gibe III draft technical report dated 2012 omitted mention of this development (UNEP, 2012). The emerging concern is that major developments are commencing without prior environmental & social impact assessment (ESIA), and without engagement with key stakeholders, including people in Kenya. Implementation of the Kuraz scheme is well under way, with the Omo temporarily dammed and flows being almost entirely diverted at times, such as in February 2012. These happenings were reported by the Consultant in a presentation to the UNESCO / IUCN / National Museums of Kenya fact-finding Workshop at the Kenya Wildlife Service Head Quarters in Nairobi, in March 2012 (UNESCO, 2012), attended by various Kenya Government and NGO representatives.

The 175,000 hectares Kuraz sugar plantations and factories in Lower Omo are being established largely on areas recently de-gazetted from the Omo and Mago National Parks, and

the Tama Wildlife Reserve. Utilisation of protected areas for commercial agriculture was not foreseen in the Omo-Gibe Basin's Master Plan. As well as hosting interesting diverse fauna and flora, the national parks and wildlife reserve were also contributing to the livelihood of indigenous peoples through traditional agro-pastoral practices co-existing within the parks, although these activities were not encouraged. There are claims that local people are being displaced to accommodate the Government developments, claims which are denied by the Government. There are disturbing reports that these population displacements are being achieved through coercion amounting to human rights abuses (Human Rights Watch, 2012).

Significant potential impacts on Lake Turkana were briefly mentioned in the 1996 Omo Basin Master Plan, but these were not studied in detail. A decline in fisheries was expected, and this was excused on the basis that a fisheries decline was expected anyway due to over exploitation in Kenya (Woodroofe et al, 1996). Since 2006, when Gibe III's construction commenced, various international media objections to Gibe III were issued, and these included a formal objection from Friends of Lake Turkana (FoLT) to the African Development Bank (AFDB). The Ethiopian Government prepared its belated ESMP and Downstream ESIA in 2009, three years after dam construction commenced (Salini, 2009; and Agriconsulting et al, 2009). The European Investment Bank (EIB) commissioned an independent study in 2009, as did the African Development Bank. These studies further explored impacts of Gibe III, as the available ESIA studies were not independent and were deemed an insufficient basis to justify supporting the Gibe III project. The EIB studies focussed on the downstream area between the dam and the lake, whilst the AFDB studies focussed on the lake itself. The World Bank had also commissioned independent studies, and had withdrawn its interest in the Gibe III project as the procurement process used to engage the dam contractor did not comply with World Bank procurement rules (Mitchell, 2009).

AFDB commissioned two separate studies in 2009, encompassing both the lake hydrology and socio-economic environment. Reports were presented in late 2009. Based on recommendations, further complementary studies were commissioned in 2010 on fisheries, irrigation and the environmental baseline. In 2010, final reports on hydrology and socio-economic environment were presented (Avery, 2010; Kaijage & Nyagah, 2010).

The AFDB studies presented Lake Turkana's baseline conditions, with the focus being on hydrology and the lake's important hydrology dependant fisheries (Avery, 2009; & 2010). The socio-economic studies confirmed that the lake is a marginalised area, the predominant livelihoods being pastoralism, agro-pastoralism and some fishing (Kaijage & Nyagah, 2009; & 2010). The studies confirmed the harsh arid environment in which people subsist in extreme poverty. The studies highlighted the poor infrastructure of the area, very low literacy levels, and very poor understanding of potential changes arising from Gibe III.

For the first time on hydrological studies on Lake Turkana, satellite lake level measurements were used to model water inflow to the lake (Avery, 2009; & 2010). This was very useful, as Omo River flows had not been measured at Omorate for many years. The model enabled the derivation of flow inflow sequences and an assessment of the potential impact on Lake Turkana's water levels arising from the Gibe III hydroelectric power project in Ethiopia. In conjunction with this, the AFDB study reviewed irrigation development within the Omo Basin with regard to potential reductions in the Omo River flows, and the impacts of developments in the Omo Basin on the lake's hydrology were forecast, and were reported to be a very significant concern (Avery, 2009; & 2010). These concerns about changes to lake cycles and levels have since been evaluated jointly by UNESCO's World Heritage Centre and IUCN, and this evaluation contributed to UNESCO's recommendation that the Lake Turkana National Parks World Heritage site be listed "endangered" (UNESCO, 2012). The recommendation was not adopted, but the concerns remain to be addressed, and to follow up, IUCN is planning a field visit to Ethiopia to further explore the concerns.

In mid 2010, the Ethiopian Government announced that a funding agreement had been signed with Chinese banks for ongoing work on Gibe III. The consequence was that the EIB and the AFDB interest in funding Gibe III was rendered redundant. The respective studies were "wound up" or concluded. This unfortunately meant that some very useful study momentum in the form of independent professional studies was lost, and a raft of recommendations was never followed up.

The cascade of Omo River developments, past, present and future, is illustrated in Figure 2 on p16.

The geographical location of the Gibe III catchment within Ethiopia is illustrated in Figure 3 on p17.

1.2 The Assignment

The African Studies Centre of the University of Oxford commissioned this "assignment" to assist consolidate the very useful hydrological work on Lake Turkana that had been initiated by the African Development Bank in 2009 and 2010. This assignment was a short consultancy, but the project has achieved the following:

1. This report presents a review of previous studies in Lower Omo, in particular the Omo-Gibe Basin Master Plan. This report presents an update of the hydrological work presented to the AFDB, and updates the assessment of impact on lake levels based on the recent disclosure of the extent of irrigation development in the Lower Omo. The published irrigation areas are reviewed, with revised water demands freshly calculated.
2. In November 2011, thanks to an invitation from UNEP Nairobi, updated hydrological findings were presented to the 14th World Lake Conference in Austin, Texas, in the USA.
3. Close dialogue has been maintained with UNEP throughout in connection with UNEP's work establishing a trans-boundary project on the Lake Turkana Basin.
4. Close dialogue has been maintained with a range of local and international scientists with interests in furthering the knowledge base in Lake Turkana.
5. Communication has been maintained with various interested groups such as the African Development Bank, Friends of Lake Turkana, Turkana Basin Institute, International Rivers, Human Rights Watch, Oxfam, to name a few. The aim has been to provide sound technical information on the lake hydrology and expected changes.
6. Technical information has been provided in response to enquiries from journalists.
7. In January 2012, a field trip was undertaken on the lake. The entire lake was explored, including the Omo Delta and each of the three islands. Due to insecurity in the lake, the field expedition established temporary camps on each of the three islands.
8. In March 2012, the Consultant was invited by the National Museums of Kenya to make a technical presentation on Lake Turkana to the UNESCO / IUCN Mission Stakeholders fact-finding Workshop (sponsored by National Museums of Kenya, Kenya Wildlife Service, IUCN and UNESCO). The presentation aimed to provide the hydrological baseline for the lake, and to provide data on the changes that are taking place, and the concerns that arise from these. Comments were also made on "protected" areas. The Consultant also submitted detailed written comments to the IUCN / UNESCO team. These inputs were acknowledged in the team's Mission Report (summary details are included in the Annexes).
9. In April 2012, the Consultant visited the eastern lakeshore and Loiyangalani.
10. In June 2012, the Consultant made a presentation to one of the East African Wildlife Society's annual Imre Loefler Lectures (at the Muthaiga Country Club in Nairobi – details included in Volume II of this report - Annexes).
11. In October 2012, the Consultant presented to the workshop on "Integrating Environmental Governance, Land and Socio-Cultural Rights", held in Lodwar, Turkana, and organised by Friends of Lake Turkana. The presentation was on the impacts of Gibe III and large-scale irrigation on Lake Turkana.
12. A range of interesting lines of further study has been initiated. This includes climate change assessments based on satellite-based measurements of lake water temperature.

Water Resource Associates previously studied temperature change in the African Great Lakes (for FAO), and these results have a bearing on fisheries ecology.

1.3 Methodology

This work is based on a relatively short time input spread over a 12-month period.

The methodology was simple:

1. Using the AFDB hydrological studies on Lake Turkana as the platform, desk research was extended to increase the baseline knowledge of:
    a. The background to the Gibe III and associated developments, using the AFDB / ADF funded Omo-Gibe Basin Integrated River Basin Development Master Plan as the basis underpinning the Basin's development. This study has set out to critically review the current development processes against the benchmark established within this comprehensive Master Plan document. This study has set out to reinforce the Master Plan's recommendations directly pertinent to the ongoing developments.
    b. There are many criticisms voiced in the media, and this study tries to constructively relate such criticisms to the Ethiopian Government's own Master Plan, rather than pander to "media paranoia".
    c. The Lake Turkana and Lower Omo demographics and challenges: Key data was sought on population, livelihoods and water resources.
2. A field campaign was planned to enhance familiarity with the lake, its islands, and its lake dependant communities (the fisher-folk). Water quality data was collected, and visual field evidence of dramatic historic climate change was inspected and photographed.
3. Water demands within the Omo-Gibe Basin were rationalised, especially taking account of the recent commencement of large-scale irrigation developments in the Lower Omo.
4. Hydrological impacts on Lake Turkana were re-modelled, utilising the satellite radar altimetry based model derived through the AFDB hydrological work. A simple "equilibrium model" was added for clarity of presenting impacts on the lake.
5. Views were shared with local advocacy groups and NGOs.
6. Links were made with the international scientific community, especially those with knowledge on tropical lakes.
7. This detailed report was prepared, and ideas for future collaboration, including publication, were formulated.

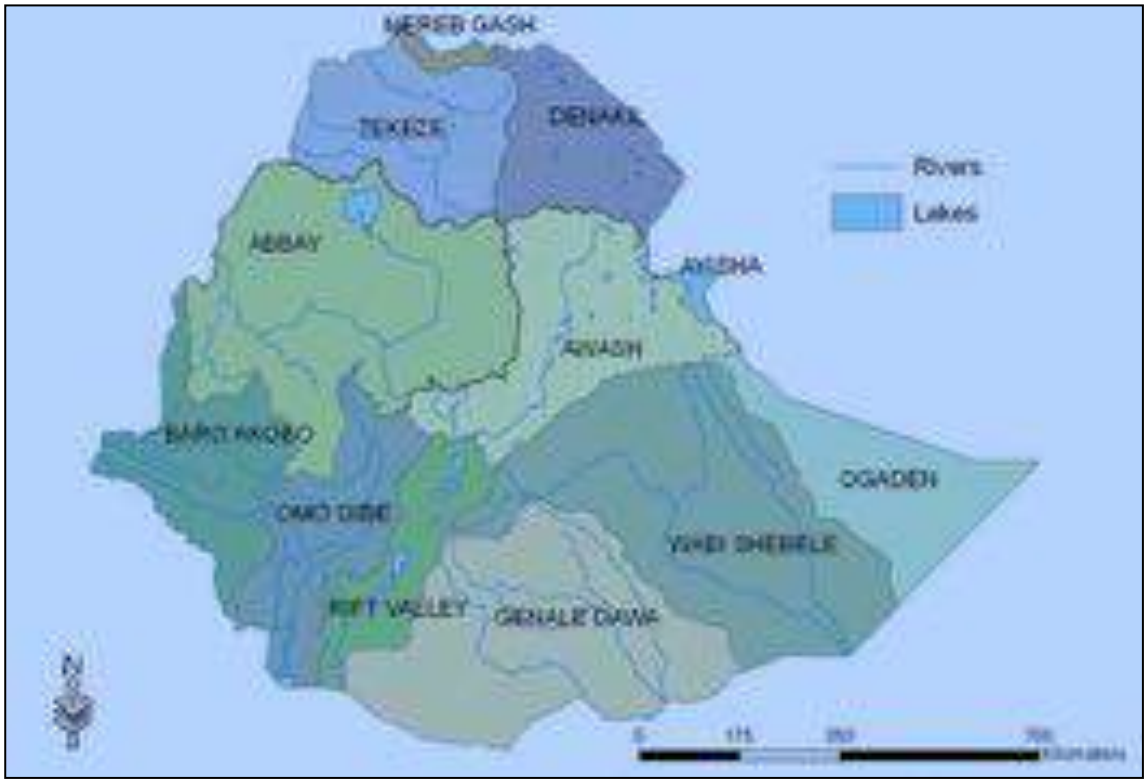


Figure 1: The river basins of Ethiopia

Source: IWMI 2007.

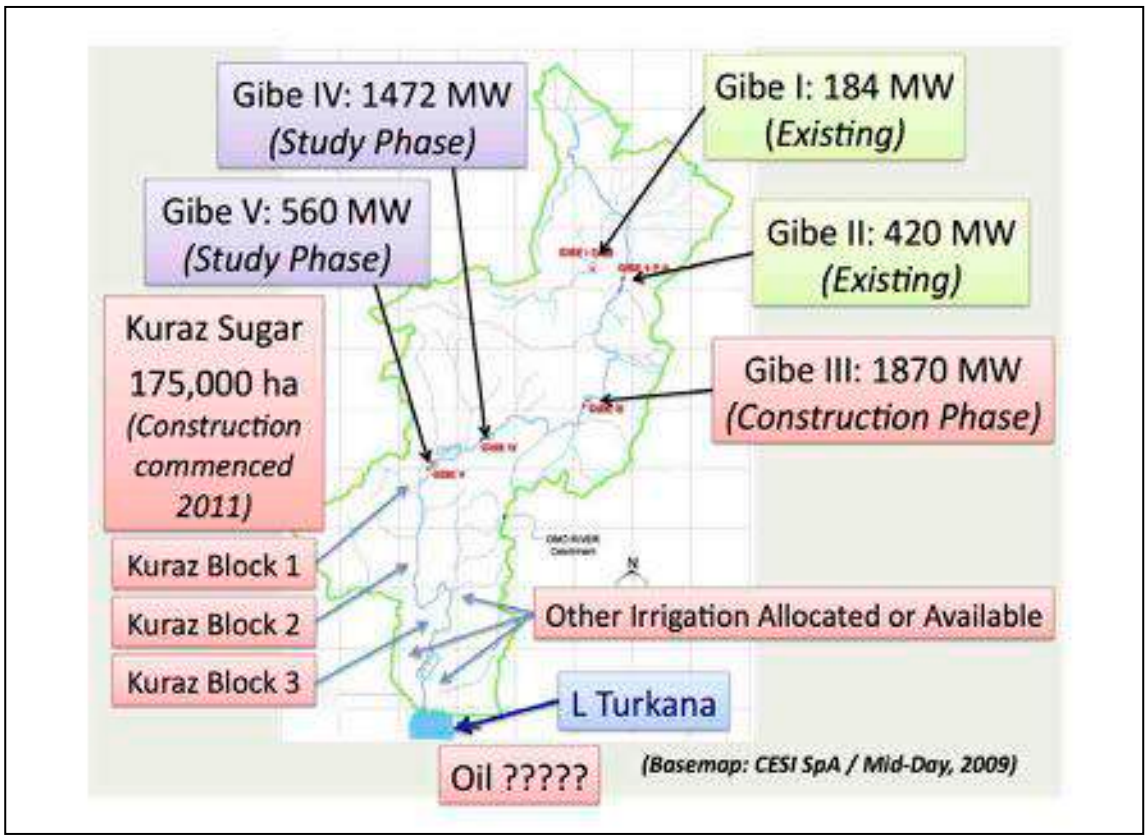


Figure 2: The Omo River's cascade of major schemes

Figure 3: Gibe III's catchment within Ethiopia

Reproduced from Salini & Studio Pietrangeli Report 500 HYD RSP 001A, Jan 2009.

2 DEVELOPMENT PLANNING IN THE OMO BASIN

2.1 Introduction and Summary Overview of Findings

This Chapter presents the background material in connection with the Gibe III project, and irrigation projects downstream of Gibe III. The consequence of these developments is the catalyst for this project to update previous studies.

Major development activity is distributed through the Omo Basin as shown earlier in Figure 2.

The Ministry of Water Resources of the Federal Democratic Republic of Ethiopia issued its XV-volume Omo-Gibe River Basin Integrated Development Master Plan Study in December 1996 (the Master Plan) (Woodroofe et al, 1996). The Master Plan was the first and only comprehensive study of its kind for this basin, and it encompassed the entire basin within Ethiopia. The preparation of the Omo-Gibe Basin Master Plan was financed by AFDB / ADF, to Terms of Reference agreed by AFDB / ADF, with a study horizon of thirty years (ibid).

The Omo-Gibe basin hydrology was studied, with runoff sequences produced by rainfall / runoff modelling. The basin's water resource potential was evaluated, with hydropower potential and irrigated agriculture being the principal project focus. Two major hydropower schemes already under study by international consultants, (including Gilgel-Gibe), were excluded from the Master Plan, so the study was not "fully" integrated.

The major departure apparent today from the Master Plan is the emergence of "sugar" as a crop for large-scale development in the Lower Omo. Nor was the present magnitude of commercial irrigation development envisaged in the Master Plan. Sugar "potential" was not mentioned in either the Master Plan or in other recent studies. Full feasibility studies and ESIAs have not yet been availed by the Government of Ethiopia. The sugar developments are being implemented on land areas excised from two national parks and a wildlife reserve. These were "protected areas" and hence presumed by the Master Plan and other studies to be immune from such development.

The Master Plan includes many poignant recommendations on social and environmental assessments, including citing past bad experiences in implementing irrigation projects in the Lower Omo, (the Ethiopian-Korean Scheme at Omorate), which, if heeded, would have avoided the many accusations being levied against the Ethiopian Government today. Some of these recommendations are included in the review below.

The Master Plan conducted "more detailed" environmental impact assessments, at pre-feasibility level, at a number of schemes including the Lower Omo Large-scale Irrigation Project. Other schemes included the Bako Irrigation Project, Bako Dam Project, and the Gojeb Dam Project. It was made abundantly clear in the Master Plan that the dam projects were necessary to store water in order to "uplift" the river low flows, as the natural low flows alone were otherwise insufficient to sustain the proposed irrigation schemes. It was also clearly stated in the Master Plan that full feasibility studies including environmental and social impact studies would need to be undertaken.

Although Lake Turkana was beyond its study area, the Master Plan did comment on the adverse effects of the potential Lower Omo irrigation developments on the lake, and stated the importance of trans-boundary dialogue. Adverse effects on fisheries were anticipated, but the Master Plan unfortunately negated the importance of these adverse effects by stating that fisheries was "declining anyway" due to over-exploitation. It is worth noting that the irrigation development that is taking place today is encompassing far greater land areas than envisaged in the Master Plan, and hence the environmental and social impacts are proportionately very much higher than had been anticipated, with more water being abstracted, and with wildlife conservation being effectively totally abandoned.

The following sections review in more detail the Master Plan, and recent studies of Gibe III, and what has been published on the irrigation projects. What has emerged is that the many issues being raised in the "outcry" were anticipated in the Master Plan. It is unfortunate that the Ethiopian Government has not embraced the recommendations of its own Omo-Gibe Basin

Master Plan to strengthen its legislation in mandating full ESIAs prior to proceeding with major development. It is also unfortunate that the Ethiopian Government did not heed the Master Plan's recommendations for trans-boundary dialogue, as the Omo-Gibe Basin is a resource shared with Kenya. Gibe III is the foremost example of the above failures, as it commenced construction without any prior ESIA. The next example is the excision of national parks and large-scale irrigation development in the Lower Omo, which will abstract large volumes of water from the Omo River. The Master Plan envisaged 54,570 hectares of irrigated agriculture. The present plans represent a 6-fold increase in area compared to the Master Plan. The consequence is a proportionate increase in environmental and social impact, with the considerable social impact exacerbated by the increase in indigenous population since the Master Plan was published. There has been a deluge of valid objections and outcry, and it is significant to note that no single international donor is providing funding, and the Kenya Government has lodged its concerns through the UNESCO World Heritage Centre (WHC, 2012).

2.2 Omo-Gibe Basin Master Plan Study, December 1996

2.2.1 Omo-Gibe Basin Master Plan - Terms of Reference

The Master Plan was undertaken according to the Terms of Reference (ToR), dated October 1991, and approved by AFDB / ADF. The ToR include the following references and statements (Woodroofe, Vol. II, TA1):

- "…The Ethiopian Highlands Reclamation Study (EHRS), 1986, argued that sustainable development could only be achieved through the adoption of an integrated, conservation based strategy for the development of the valleys and basins of Ethiopia…" (ibid, ToR Item 1.0.3).
- "…Additionally, many developments in the past in various basins have been undertaken without the benefit of an overall planning framework, and without due consideration for the possible adverse effects of such developments on the environment…" (ibid, ToR Item 1.0.4). It is ironic that many years later, construction of the Gibe III hydropower project commenced without any prior ESIA.
- "…In view of the foregoing, therefore, the GoE (Government of Ethiopia) has concluded that planned development strategies should be formulated for the basins of the country, and that only by such an approach, where a Master Plan for multi-sectoral development is prepared, can the inefficient use of resources and the risk of environmental damage be avoided or minimised…" (ibid, Item 1.0.5).
- Whilst the approved ToR stated that "...the study will cover the whole basin area…", Lake Turkana was excluded as the study area lower extremity was at the border, namely "Latitude 4-33N" (ibid, Item 3.1.1).
- "…The South Omo of the basin is rich in wildlife including zebra, gazelle, eland, lion, and even rhinoceros…" (ibid, Item 3.3.4). It would be highly unlikely that any rhinoceros existed in the Basin for some years.
- "…both the Omo River delta as well as Lake Rudolph is considered productive for fishing…" (ibid, Item 3.3.5).
- "…The arid Lower Omo basin is inhabited by nomadic pastoralists such as the Geleba and Mursi who depend principally on their herds and flocks of cattle, goats, sheep and donkeys as well as camels for survival. They do however practice growing sorghum on residual soil moisture along the banks of the Omo…" (ibid, Item 3.4.5).
- "…The "principal goal of the study" was to prepare a master plan for development "…with the minimum possible adverse environmental impact…" (ibid, Item 4.1.1).

- Under "Social Study", the Master Plan team was tasked with coming up with "…an understanding of the basic transformation of the socio-economic processes at different levels of the system in order to conceive, plan and implement the essential transformation of the socio-economic system…" (ibid, Section 4i). This is interesting as it means there was an agenda for social transformation agreed with AFDB / ADF, although it is not clear what is meant by "essential transformation".

2.2.2 Omo-Gibe Basin Master Plan - Water & irrigation

The Master Plan made the following comments in regard to basin potential and water demand (the need for storage dams to support large-scale irrigation in the Lower Omo is shown):

- "…The main potential use of the basin's water resource is for the irrigation of some 67,000 ha of land in Lower Omo..." (Woodroofe, Vol. XI, F1, p83). These schemes are all located between the southern end of the Omo and Mago National Parks and the Omo delta, and are located either side of the Omo River (Woodroofe, Vol. XI, F2, Figure 9.3). Hence no agricultural development was foreseen within national parks or wildlife reserves. Following further study, the potential area selected for feasibility study was reduced to 54,570 hectares.
- "…. By the construction of storage dams…the estimated minimum flows of the main stem river will be increased…" (ibid, Vol. XI, F1, p83). The Master Plan determined that meeting downstream irrigation needs would require an increase in minimum flows through construction of storage dams (ibid, p83). This was part of the Master Plan's "integrated" river basin planning.
- "….The annual water demands for all sectors…for the years 2009 and 2024…correspond to...approximately 21.5% and 32% of the annual outflow to Lake Turkana…" (ibid, p79 and p83). Hence the Master Plan envisaged significant consumptive usage of the Omo River waters, and these figures were utilised in the later AFDB Turkana lake impact studies (Avery, 2010).

2.2.3 Omo-Gibe Basin Master Plan - Environmental impact assessment

2.2.3.1 Environmental policy and legislation

The Master Plan stated that "an environmental impact assessment (EIA) on the proposed water resource developments in the Basin" had been conducted during the "Master Planning Phase" (Woodroofe, Vol. XI, F1, p84). These comprised pre-feasibility level EIAs for a number of projects, with full EIAs called for at feasibility study stage (ibid, Vol. II, Part 2, TA7).

The Master Plan's Technical Appendices include an EIA chapter with the following interesting observations on policy and legislation strengthening, land tenure, and local participation, all of which remain applicable today (Woodroofe, Vol. II, Part 2, TA7):

- "…Although Ethiopia lacks a comprehensive environmental policy, the underlying cause of environmental degradation in the Basin are also a reflection of national weakness in respect to natural resource tenure and land use rights…" (ibid, Vol. II, Part 2, TA7, p57).
- "…Five issues have special relevance to environmental management and should be incorporated in Government Policy:
  - A national land use policy and strategic policy in land use planning;
  - Integration of social, cultural and gender issues with sustainable resource and environmental management;
  - Environmental economics, macro-economic policy and economic development;
  - Rural land and natural resources tenure and access rights;
  - People's participation in sustainable development and the management of natural man-made and cultural resources and management…" (ibid).
- "…Defects in extant environmental or natural resource legislation...Areas particularly in need of attention include:

- provision for empowerment of communities,
- provision for appropriate environmental appraisal tools such as IEIAs, EIAs, environmental auditing, monitoring and evaluation,
- environmental standards applying to water, land and atmospheric resources…" (ibid).

"…There is particular need for a national law that mandates the use of EIAs to assess the impacts of proposed interventions…" (ibid, p58).

- On "Land tenure", the Master Plan states "…The land tenure system should ensure security of tenure by minimising opportunities for manipulating access to land by local, regional, or national political leaders…" (ibid, Section 6.3, p59).
- On "Local level participation" the Master Plan states "…Natural resource conservation and management on a sustainable basis usually requires that people do certain things and refrain from doing others. Their support is essential, and participation in policy-making, law-making, and planning is one way to enlist support for policies, laws and plans. Once understood and accepted by people, law enforcement and plan implementation are likely to meet with less opposition than imposed laws and plans…" (ibid, Section 6.5, p59).

2.2.4 Omo-Gibe Basin Master Plan – Ecology Survey

The Ecology Survey addresses "deforestation and conservation of biodiversity". The Report points out that Ethiopia "is one of many nations of the world which is facing growing environmental pressure and abuse". The Report refers to species loss, and even "total ecosystem losses" in the country. The Report notes the important role Ethiopia can play in biodiversity conservation, citing the biodiversity of the Omo-Gibe Basin, and the very high proportion of endemic species in Ethiopia.

The Master Plan proposed the addition of the following four policies to strengthen the existing Ethiopian Valleys Development Studies Authority's (EVDSA) portfolio of policies (ibid, Vol. VIII, C3, p40):

- "…RB/E62. Traditional methods of agriculture, agroforestry, forestry, range and wildlife management which use, maintain or increase biodiversity shall be encouraged, along with the involvement of communities in the conservation and management of diverse ecosystems in such ways that they benefit from the measures adopted.
- RB/E63. Diverse natural habitats shall be protected and, in order to provide additional protection, environmentally sound management shall be promoted in the surrounding areas.
- RB/E64. The rehabilitation of damaged ecosystems and the recovery of threatened and endangered species shall be promoted.
- RB/E65. Improved methodology for evaluating the impact of development projects on biodiversity, including the costs of losing biodiversity, shall be promoted. Environmental impact assessment, with public participation, shall be required for projects that threaten biological diversity…" (ibid).

The Ecological Survey referred to work by the World Conservation Monitoring Centre (WCMC) dated 1991. The Master Plan stated "…Deforestation, soil erosion and human encroachment into protected areas are described by WCMC as the main threats to biodiversity in Ethiopia…". It was recommended that remaining forested areas be afforded "…the highest protection possible as a matter of urgency…" (ibid, p22, citing Osborne, 1991).

The Ecological Survey was a brief study, and no mention was made of the Lower Omo delta wetlands, although it was stated there are no wetlands in the "command area" of the proposed Lower Omo irrigation project. The Survey notes the need for detailed information on biological resources.

The Ecological Survey stated: "…Social aspects of wildlife were considered, but a study of local attitudes to wildlife needs to be taken further…" (ibid, Section 1.2).

The "natural regions" of the basin progressed from "Steppe" in the SW corner of the Basin, to "Woodland Savannah" to "Broadleaved Forest" in the mid to upper Basin, with small patches of "Woodland Savannah" and "Coniferous Forest" in the NE corner of the Basin (ibid, Figure 2.1).

The Survey noted less pressure at that time on riverine vegetation in the Lower Omo, but that destruction was occurring, notably at Omorate (ibid, Section 3.5.3).

2.2.4.1 Omo-Gibe Basin Master Plan combined forestry – biodiversity programmes and environmental education for riverine areas

The Master Plan recommended "special attention to managing riverine ecosystems" (Woodroofe, Vol. VIII, C3, Section 3.5.4). "Consideration should be given to designating strips of land (perhaps 500 metres wide) on either side of specified stretches of the larger rivers in the Basin as conservation areas" (ibid).

2.2.4.2 Lower Omo irrigation projects: Pre-feasibility Study 'Social Impact'

The Master Plan earlier explored the potential development of 67,000 hectares in Kuraz Wereda, Lower Omo, all located south of the Omo and Mago National Parks. A reduced area of 54,670 hectares was then subjected to pre-feasibility study (Woodroofe, Vol. V, Section 3 Lower Omo Irrigation, Table 1.1, p1).

The selected Lower Omo Irrigation Project was based on water pumped from the river. The annual rainfall of the area is reported to be 400 millimetres, and temperatures are reported to regularly reach 40^{o}C (ibid, p3).

The Master Plan assessed the "social impact". The following extracts capture the range of effects anticipated in 1996 (useful to compare with the very much larger scale of irrigation development that recently commenced):

- "…The construction of the Lower Omo Irrigation and Drainage Project will not require major population relocations as there are no permanent residents in the proposed irrigation area..." (ibid, p44).
- "…However, there are indigenous people (mostly agro-pastoralists) who depend heavily on the natural environment of the area for their livelihood…" (ibid).
- "…The project could substantially alter and disrupt their traditional way of life and could seriously threaten their existence..." (ibid).
- "…Expropriation of land would directly affect indigenous people through loss of grazing land…" (ibid).
- "…The physical barrier of irrigated land close to the river could also prevent them watering their cattle…" (ibid).
- "…workers will need to be brought in from elsewhere...this migration and setting up of new urban areas has the potential to impact greatly on indigenous people…" (ibid).
- "...Significant demographic changes in population size and ethnic composition will take place, bringing the potential of ethnic tension and conflict between "settlers" and "locals"…" (ibid).
- "…"Competition for resources due to population increase could also occur…" (ibid).

The Master Plan draws from previous experience, stating:

- "…There were major disturbances during the initial establishment of the Ethio-Korean Joint venture farm…" (ibid).
- "…Local people were not consulted about the project, nor were they compensated when land they traditionally viewed as theirs was annexed…" (ibid, p44-45).

In conclusion (Woodroofe, Vol. V, Section 3, Lower Omo Irrigation, p42):

"…the Lower Omo irrigation can bring considerable benefits at the national and regional levels. However, for the project to be implemented successfully there is need for discussions and negotiations with the various groups living in the area to ensure that:

- The riverine land used for flood retreat cultivation is affected as little as possible.
- Dry season grazing rights and access to the river are protected.
- Acceptable compensation to individuals and communities is provided for land used by proposed schemes.
- Local people are assisted in meeting their own development priorities in return for their land being used for national development.

A deal whereby local groups can use some of the proposed irrigation land for food crops may be one of the most effective ways of obtaining co-operation…"

(ibid, Vol. V, Section 3, p42).

2.2.5 Lower Omo Irrigation Projects: Pre-feasibility Study 'Environmental Impact'

The following pertinent excerpts are quoted using the exact same section headings adopted in the Master Plan (Woodroofe, Vol. V, Section 3, p45-56):

Loss of grazing land (Annex A4.2):

- "…A major impact of the project will be the loss of traditional grazing lands to irrigated agriculture…" (Woodroofe, Vol. V, Section 3, Lower Omo irrigation, p45).
- "…the density of cattle will increase outside irrigated farms, which could lead to over-grazing, land cover deterioration and soil erosion…" (ibid).

Loss of agricultural land (Annex A4.3):

- "…Some of the areas will be lost that are watered by the annual flood which are currently used for flood retreat cropping. This could be a cause of serious friction with indigenous people. Flood retreat agriculture is generally quite productive, so a valuable resource will be lost…" (ibid).

Forestry and Wildlife (Annex A4.4):

- The project command area "does not contain extensive forests" (ibid).
- "…woody biomass resources will come under tremendous pressure from farmers, herdsmen and timber merchants to meet traditional demands and a growing urban demand…" (ibid).
- Wildlife was reported "generally scanty". Wildlife was under pressure at that time. Former hunting areas had become "virtually useless" due to unlicensed hunting (ibid). The recent excision of the Lower Omo national parks and reserves for commercial agriculture is indicative that Government attaches little value to wildlife as a natural resource / heritage.

Water resources (Annex A4.5):

- "…The construction of the project will cause altered water flows, the most obvious of which will be substantial changes in the low flow regime..." (ibid).
- "…This could bring a corresponding loss of habitats for fish and other aquatic organisms…" (ibid).

Impact on aquatic resources (Annex A4.6):

- "…Experience gained from other irrigation projects show they have significant effects on aquatic resources…" (ibid).
- Various "effects" were elaborated including: Proliferation of aquatic weeds in canals and watercourses; Retarded drainage and large evaporation losses; Mosquitoes; Changes in water chemistry due to agro-chemicals; Raised nutrient levels leading to destruction of aquatic biota…" (ibid).

- The Master Plan warns that excessive chemical runoffs often occur, with potential adverse impacts that include "depreciation of downstream water quality" and "increased vulnerability of the ecosystem". Also mentioned are potential "biological concentration of toxic substances along food chains, and alteration of the ecosystem" (Ibid).

Impact on public health (Annex A4.7):

- "…The irrigation project will alter ecological conditions in the area and create an environment favourable for breeding disease vectors..." (ibid). The potential spread of malaria and bilharzia (schistosomiasis) is specifically mentioned.
- "…The expected increase in population could increase the spread of human diseases…" (ibid).

Increased use of agrochemicals (Annex A4.10):

- "…Experience on similar projects in the country indicate that correct amounts of fertiliser and pesticides are not being used, and excessive chemical runoffs can occur…" (ibid, p46).
- "…The major potential adverse impacts of this improper use of agrochemicals include depreciation of downstream water quality, increased vulnerability of the ecosystem, and physical harm to humans and livestock…" (ibid).

Recommendations (Annex A5.2):

In conclusion, it was stated in the Master Plan that the environmental effects "may be acceptable" (ibid, p47), but that "the impact of such large-scale irrigation would require a detailed EIA at the feasibility planning stage" (ibid, p47). The scheme area being evaluated at that time was only 54,570 hectares, a fraction of the area now being developed. Hence the environmental and social concerns at that time will be much greater today, not only because of the much larger scale of the development now being undertaken, (hence larger loss of land accessible to local people), but also by the local population increase since 1996, (forecast in the Master Plan to be double in twenty years).

Various recommendations were made (ibid, p47). These included: Collection of baseline data on the indigenous peoples; Investigation of land use, and impacts of loss of land on indigenous people; Study of potential for disease; Investigation of potential for soil erosion, and river conditions; Investigation of the potential for water quality deterioration, and weed plant proliferation; Investigation of the effects on the groundwater table, and potential water logging (ibid).

There was one recommendation specific to Lake Turkana:

"…"Identification and assessment of the project's effect on the hydrology of the river and downstream users, including aquatic ecosystems and flood plain ecology especially at Lake Turkana if the low flow regime of the river substantially changes…" (ibid).

It is pertinent to emphasise that the Lower Omo Irrigation Project area envisaged at the time of the Master Plan was 1/6th of the area now being developed. The warnings then were clear, yet the present much larger developments have proceeded without any evident transparent independent ESIA process, nor any essential consultation with Kenyan stakeholders, all of which is contrary to recommendations made in the Ethiopian Government's own Basin Master Plan (which ironically was funded by the AFDB / ADF).

2.2.6 Omo-Gibe Basin Master Plan: Trans-boundary impacts

The Master Plan Technical Reports include the following interesting statements on trans-boundary impacts, which remain applicable today:

- "…The Omo-Gibe is classed as an international river as it feeds into a lake which is shared between two countries (Ethiopia and Kenya)…" (Woodroofe, Vol. XI, F1, p84).
- "…Reductions in the flow of the Omo River are likely to have an adverse effect on the potential of the lake fishing..." (ibid, Vol. XI, F1, p84).

- "…Any reduction in lake level would also result in the bed of the Omo River becoming more incised. This would lead to the present delta drying out and a further delta developing downstream…" (ibid, p84).
- "…The development of irrigation and agriculture generally in the Basin would also probably lead to the increased use of fertilisers and pesticides. The former can have both detrimental and advantageous effects, with problems due to algal bloom and increased productivity due to the addition of nutrients…" (ibid, p84).
- The Master Plan states that "the widespread use of pesticides", for instance in developing large areas of cotton-growing, "…are wholly detrimental on the fish population of the lake…" (ibid, p84).
- "…This means that in the international context a bilateral agreement should be reached between the two countries (Kenya and Ethiopia) before either country changes the natural flow of the river...Any major change in the river's regime as, for instance, by the construction of a dam for the development of hydro-power, or, more significantly, by the development of large-scale irrigation in the south of the Basin, would be almost certain to raise issues internationally…This is, of course, a subject for consideration by the Government of Ethiopia, and not for this project…" (ibid, p85).

Hence, in conclusion, the impact issues on Lake Turkana had been correctly anticipated in the 1996 Master Plan, but they were stated to be beyond the scope of that study, hence they were not assessed at that time. However, the Master Plan did recommend a bilateral agreement before the river flows are altered.

In connection with the reduction in lake fisheries, the Master Plan claimed the following: "…the lake is reportedly already over-fished and reductions in (fish) yield are likely no matter what developments take place in the Omo-Gibe Basin…" (ibid, p84). This statement should have been challenged, as it appears to be offering "carte-blanche" to developments in the Omo Basin irrespective of the impact on Kenya's fisheries. The Master Plan's statements about pesticides detrimental to lake fish are alarming.

The AFDB study warned that that the Master Plan's irrigation estimates "might be an under-estimate" (Avery, 2009; & 2010). The Master Plan proposed feasibility studies for 54,570 hectares of potential irrigated agricultural land. Kuraz Sugar Development alone is at least 150,000 hectares. As the Master Plan did not plan irrigation development within national parks and reserves, the inclusion of the Kuraz Sugar project adds appreciably to the scale of commercial irrigation development foreseen in the Master Plan (see Table 9 on p58 later in this report).

2.2.7 Hydropower

The Omo-Gibe Basin Master Plan investigated hydropower potential, apart from the Halele-Werabesa Scheme and Gilgel Gibe Project already being studied by international consultants. Hence Gibe III was not specifically encompassed within the Master Plan.

2.3 The Omo Basin and irrigation – "An early candidate for development" (World Bank)

In 2004, World Bank prepared a Concept Paper (Background Note for FY04 CEM) entitled "Ethiopia's Path to Survival and Development: Investing in Water Infrastructure". This Paper discussed Ethiopia's "struggle for food security and development", and stated: "The Omo Basin has important potential for development, including both irrigated and rain-fed agriculture". The Paper did acknowledge potential impacts on Kenya's Lake Turkana but dismissed these on the basis that "there is no significant use" of the lake's waters and suggested that impacts on Kenya could be compensated by agreed sharing of benefits arising from development in the Omo Basin.

The following extracts are quoted from the World Bank Concept Paper (World Bank, 2004a) and an associated Background Note (World Bank, 2004b):

- "…Over 80 percent of the country's population is mired in a declining subsistence agriculture economy producing less than their minimum subsistence requirements…" (World Bank, 2004b).
- "…The basic problem is that in Ethiopia, irrigation is an extremely rare and neglected sector..." (ibid).
- "…The highlands are affected by massive land degradation arising from deforestation and cultivation of steep slopes with ineffective or inadequate watershed treatment, and uncontrolled grazing of livestock on steep slopes…" (ibid).
- Due to the high soil losses, much of the land in the highlands "…has been rendered more or less unproductive…and could lead to a collapse of the farming system in many areas..." (ibid).
- From several perspectives, it is stated: "…Ethiopia's investment in water resources development should best focus on its lowland river basins…" where: "…There is an abundance of potentially productive land that can benefit from irrigation at lower per hectare costs than the highlands..." (ibid).
- "…All of Ethiopia's major river valleys offer significant opportunities for large-scale irrigated agriculture in their lower reaches…" (World Bank, 2004a).
- "…The lowland river basins feature several risk factors that are largely manageable. These include…Remoteness…Health risks and perceptions of the lowlands as hostile / uninhabitable…Trans-boundary water basin issues and complexities…" (World Bank, 2004b).
- "…The Omo Basin (irrigation potential of 348,000 ha) could be an early candidate for development for the following reasons…There is no significant use of the Omo River by any other country and the river enters Lake Turkana within the boundaries of Ethiopia. While most of the lake lies within Kenyan territory, that is a sparsely inhabited semi-desert pastoralist region with no significant use of the lake's waters. It should therefore be relatively easy to negotiate a "no-objection" from Kenya should that be required for multilateral / bilateral funding. Assuming a multi-purpose (hydroelectric / irrigation) dam / dams on the Omo, Kenya could also benefit from it…" (ibid).
- "…The Omo River is particularly important, both for its annual flow and its irrigation potential, and its being one of the principal basins where there is unlikely to be any objection by downstream countries…" (World Bank, 2004a).
- "…Overall, the irrigation potential of the Omo Basin could support livelihoods equivalent to 1.6 million – 1.75 million households. At an average 5 persons per household, this could support some 8 million persons above the poverty line…" (ibid).

- "…Potential Projects…Dam: Omo river…could provide the principal structure for the irrigation of 200,000 - 300,000 ha…." (ibid).
- "…Research needs include research on…What are the social problems that might arise in terms of population displacement / re-integration, etc., and how might these be effectively addressed?..." (World Bank, 2004b).

It is not surprising that the Omo Basin was promoted as "an early candidate for development". Water is without doubt one of Ethiopia's key natural resources. The country is the main water tower for the River Nile, and development of the country's water resources is an inevitable response to the country's escalating needs.

In line with the Ethiopian Government's own stated intentions supported by other donors such as AFDB / ADF (EVDSA, 1991), the World Bank encouraged Ethiopia to develop its lowland basins, including the Omo Basin, in which the World Bank confirmed significant irrigation and hydropower potential. The World Bank suggested that large-scale irrigation potential may be realised through the provision of a storage dam. The World Bank's Concept Paper is aware of potential conflicts, and mentions the need for research into "social problems", but overall the Concept Paper attaches no significance to the traditional use of the lands it proposed be developed.

3 REVIEW OF OBJECTIONS TO GIBE III & RELATED STUDIES

3.1 Introduction to the "Downstream Impacts" of Gibe III

Development of the Omo River's hydropower potential is expected to include the following "cascade" of existing and future hydropower plants (Salini et al, 2008):

- Gibe I - existing scheme upstream of Gibe III
- Gibe II - existing scheme upstream of Gibe III
- Gibe III - under construction since 2006
- Gojeb and Halele / Werabesa - foreseen upstream of Gibe III
- Gibe IV and V - foreseen downstream of Gibe III

In addition, as part of the Basin's integrated development, some large-scale irrigation development in the Lower Omo was envisaged, facilitated by the storage created by the dams.

Gibe III Hydropower Project has been under construction since 2006, being the third project in the hydropower "cascade", and fourth and fifth hydropower projects are envisaged further downstream (Gibe IV and V).

The Gibe III dam will be 243 metres high, generating 1,870 MW of electrical power. The dam is the fourth highest hydropower dam in the world currently under construction (EEPCo). The construction works were 32% complete in June 2009 (ibid). In mid 2012, the construction works were over 50% complete. The project is delayed, as the Updated Power Master Plan originally envisaged dam filling and power coming online in 2011 (EEPCo, 2006).

Hence the Omo Basin is already undergoing radical change. The hypothesis of hydropower operation stated by the Gibe III designers is: "…20% of the Gibe III flows will be regulated by upstream plants discharging a constant flow 95% of the time…" (Salini 300 POW R SP001 B, 2008). Hence river flows will be regulated throughout the Omo Basin.

An Environmental & Social Management Plan (ESMP) was not submitted for Gibe III until 2009, three years after construction commenced (Salini & Mid-Day, 2009b). The "Downstream ESIA" study was also reported in 2009 (Agriconsulting & Mid-Day, 2009). The above studies were undertaken by Salini's team and were thus not "independent". The "Downstream ESIA" only studied as far as the Kenya border, and hence Lake Turkana was excluded, and no consultations were conducted within Kenya.

Various media reports have claimed that the new dam will have catastrophic effects downstream, which have not properly been considered.

Based on Salini data, key hydrological characteristics for Lake Turkana as regards Gibe III have been reported as follows (Avery, 2010):

- Influx needed to sustain Turkana's lake level = 19 km^3/yr
- Gross water storage to fill Gibe III Reservoir = 16.3 km^3
- The length of Omo River downstream of Gibe III = 600 km
- Mean annual inflow into Gibe III Reservoir = 12 km^3

Hence the water volume to fill Gibe III reservoir would deprive the lake of 85% of its normal annual inflow in one year (ibid). The Gibe III fill volume is almost 7% of the volume of water presently stored in Lake Turkana, which is significant (ibid). Gibe IV will require a similar volume to fill its reservoir, and will compound the Gibe III impact.

If as has been claimed, there was 50 to 75% loss of Gibe III's storage due to seepage underground, this would amount to up to 9 km^3/yr of water (which is almost 50% of the inflow needed to sustain the lake) (ibid).

If the claimed "losses" were substantiated, the inflows to the lake would be reduced, and the lake would shrink in size, as claimed. However, these claims on losses were considered improbable and unsubstantiated in earlier reports (Avery 2009; & 2010; Sogreah, 2010).

The "Downstream ESIA" study (Agriconsulting & Mid-Day, 2009) gives monthly discharge graphs for the "before" and "after" Gibe III scenarios – see Figure 4 on p29. As would be

expected with any hydroelectric power scheme, these graphs show that the distribution of flow is to be regulated by controlled discharge through the turbines and outlets in the dam. Compared to the "natural" regime, there will be higher low flows, and lower high flows, whilst the annual volume is reported to be much the same. About 67% of the lake's total flow will be controlled by discharges allowed from Gibe III. The Salini ESMP stated: "…Major benefits would be induced by the regulation of river flow in the downstream lower Omo valley in terms of public health…permanent availability of water with stable water levels allowing for development of commercial irrigated agriculture…" (Salini & Mid-Day, p61).

In response to adverse media publicity, EEPCo issued the proposed mitigation measures reproduced in Volume II of this report (EEPCo, May 2009).

EEPCo have stated: "…The lake is characterized by high rate of fluctuations which is currently reducing at an alarming rate due to climate changes…" (ibid).

Amongst the various benefits listed, EEPCo stated: "…there will be sustainable flow and positive hydrological balance to Lake Turkana…" (ibid). The "Downstream EIA" also makes reference to the benefits of flood regulation in regard to reducing "catastrophic" flooding in the Lower Basin (Agriconsulting & Mid-Day, 2009). The average low flow of less than 200 m^3/s in the Omo River will be increased to 500 m^3/s (Figure 4, on p16).

The AFDB Final Report addressed all the hydrological concerns raised (Avery, 2010). These are explored further in this report, but the AFDB conclusions will be summarized here:

1. The mitigation measures lacked a scientific basis with which to evaluate the effectiveness of the proposed mitigation measures.
2. Furthermore, the development of Gibe IV and V would render EEPCo's proposed ecological flow mitigation measures redundant.
3. There would be enhanced abstractions from the river consequent upon the uplifted "sustainable" flow provided through Gibe III's regulated flows, and lake levels will fall.

Hence the AFDB study findings did not support the EEPCo claims of a "positive water balance". The AFDB study foresaw lake levels falling permanently in proportion with downstream abstractions (Avery, 2010). In addition, the AFDB study warned that the regulated flow sequence would adversely affect the lake's fisheries, and hence should not be claimed to be "positive" (ibid).

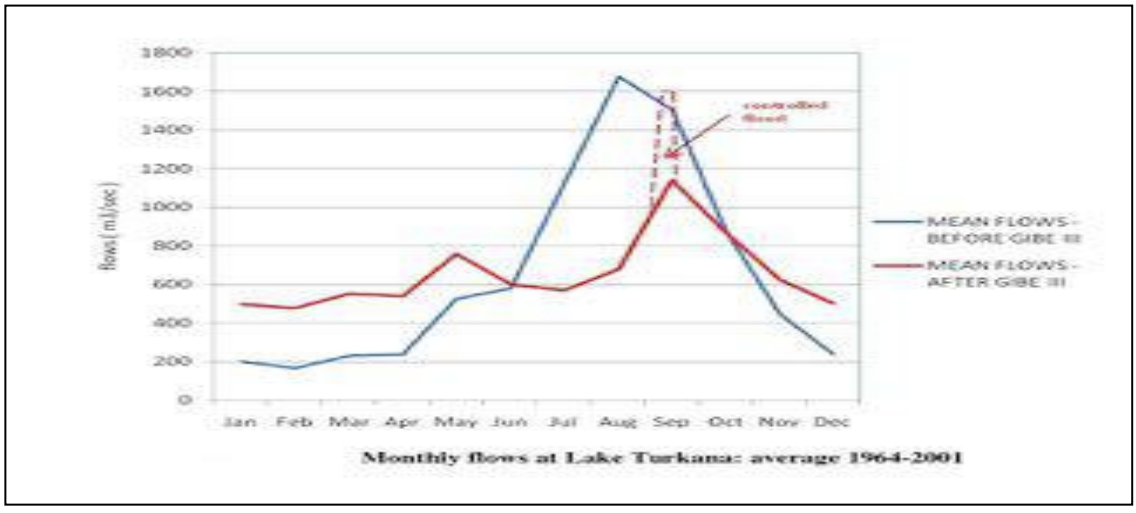


Figure 4: Proposed regulated flow sequence from the Gibe III hydropower project

Source: EEPCo (Agriconsulting & Mid-Day, 2009).

3.2 Africa Resources Working Group (ARWG 2009)

The key issues targeted in a report by ARWG were listed in the AFDB report as follows (Avery, 2010; citing ARWG, 2009):

(1) "…Radical reduction of inflow to Lake Turkana, since the Omo River provides up to 90% of the total input to the lake…" (ibid).

"…Estimates as high as a 10 - 12 metre drop in lake level are realistic; even the most minimal drop in lake level (e.g., 5 metres) would cause cessation of flooding in the Omo delta altogether, and large scale retreat of much of Lake Turkana. Radical reduction of Lake Turkana waters, with sharply rising salinity conditions, would lead to a decline of aquatic ecosystems – including fish stocks, the loss of potable water for human populations and livestock, and the destruction of significant commercial interests (fishery, tourism, etc.) at the lake. A possible 50 - 75% leakage of waters from the reservoir, due to multiple fractures in the basalts at the planned reservoir site, with only a portion of these waters ever re-entering the Omo River system, would produce an even greater reduction of inflow to Lake Turkana…" (ibid).

(2) "…Risk of seismic activity in the Gibe III project region, with the possibility of a major seismically determined event – including earthquake and massive landslide potential... " (ibid).

"…The seismic danger is actively discounted within the 2006 Environmental Impact Assessment released by EEPCo, and omitted altogether in the "Downstream" EIA (in the following pages, "the EIA" refers to the "Downstream EIA", unless the 2006 document is specified)... " (ibid).

(3) "…Major tri-country trans-boundary economic, political and ecological repercussions, involving south-western Ethiopia, north-western Kenya and south-eastern Sudan…" (ibid).

(4) "…Elimination of the riverine forest and woodland, due to at least a 57% to 60% reduction of river flow volume, with accompanying destruction of forest biodiversity and virtually all riverine associated economic activities, including human settlement…" (ibid).

(5) "…Cessation of all recession cultivation (or "flood retreat" cultivation), along the lower Omo River and throughout the Omo delta, resulting in economic collapse for tens of thousands of agro-pastoralists who are directly dependent upon such cultivation for their survival, and massive impoverishment for a far greater number of the lower Basin's indigenous population dependent on these cultivation systems for food products through trading relations. Moreover, there is no rain fed cultivation "alternative", as the EIA states. At least 200,000 indigenous pastoralists and agro-pastoralists within the lower Omo basin will face livelihood devastation from such losses…" (ibid).

Several other reports and presentations have assessed the Gibe III Project. These are reviewed in subsequent sections that follow.

3.3 African Development Bank - Gibe III Independent Feasibility Study by Mitchell (Mitchell, 2009)

In April 2009, Mitchell submitted a desk study to the African Development Bank entitled "Gigel Gibe III Economic, Technical and Engineering Feasibility" (Mitchell, 2009). This report "…presents results of an independent study of the feasibility of completing construction and beginning operations at the Gilgel Gibe III hydro-electric project in Ethiopia's Omo Basin…" (ibid, p1).

Mitchell's report draws on findings of an earlier report to World Bank by Mitchell to assess the feasibility of the World Bank providing financial assistance to the Gibe III project. Mitchell states in his report to AFDB: "…Citing a lack of transparency and the absence of a competitive bidding process in the selection of the prime contractor, the World Bank opted not to proceed with a full review of the funding application for Gibe III…(ibid, p1)". The World Bank has had no further input in regard to the Gibe III project.

Mitchell has made some interesting observations. He stated that there was "…need for a new approach to risk management at EEPCo…" and that this was "…underscored by the fact that research activities to support the preparation of (Mitchell's) report were repeatedly hindered by EEPCo's website. EEPCo's main website www.eepco.gov.et was found to be propagating "Silent love China" computer attacks that attempt to install Trojan software on visitors' computers and steal passwords…" (ibid). Mitchell went further to suggest the possibility that EEPCo had been breached by deliberate acts of espionage by government agencies within the Peoples' Republic of China (ibid). This is extraordinary, especially in view of the subsequent entry of Chinese banks to finance the Gibe III project.

Mitchell listed a number of "negative externalities as costs to populations who will bear disproportionately negative economic and quality-of-life impacts as a result of Gibe III". The negative externalities included the following:

- Increases in disease (schistosomiasis and malaria being cited).
- Water losses due to evapotranspiration from the lake created by Gibe III, translating into reduced flows to Lake Turkana, a lake which is already stressed by recession and increasing alkalinity, the lake being a source of potable water and fish, reportedly supporting 300,000 people, many of whom have no alternative livelihood. The reduced flows will shrink the lake and alter the lake chemistry.
- Eliminating periodic inundations of the Omo River basin will disrupt food supplies for downstream communities that have developed sophisticated agricultural practices dependant on existing water supplies and flow cycles.
- Inadequate local participation in the dam's permitting, licensing and funding processes.

Subsequent commentators have stated that evaporative losses from the Gibe III reservoir will be insignificant. Mitchell unfortunately did not mention consumptive use through consequential irrigation that takes advantage of regulated flows. Mitchell mistakenly assumes Lake Turkana's water is potable, and also erroneously states the lake is in recession. The lake water is not potable by WHO standards due to its dangerously high fluoride levels, and the lake levels are currently in a rising phase (Avery, 2009, & 2010). Nonetheless, Mitchell raised valid concerns.

3.4 Mott MacDonald & Sogreah Consultants – EFTA, July 2009

Mott MacDonald & Sogreah Consultants (with AG Consult as sub-consultant) were engaged by the European Investment Bank (EIB) to perform the study "Gibe III Hydropower Project, Economic Financial and Technical Assessment (EFTA)" (Mott MacDonald & Sogreah, 2009). This review "did not include a review of the environmental and social aspects and downstream impacts in Kenya which are the subject of separate reviews" (ibid, Page iii).

The following excerpts, especially those on Turkana, are included:

- "…According to Salini, Gibe III did not appear on the Ethiopia Master Plan due to the inaccessible nature of the site…." (ibid, Volume 1, Page ii).
- "…this project has been fast tracked, and as such has not undergone the traditional studies associated with a large hydro project…." (ibid).
- "…Some US$ 40 million of environmental and social impact mitigation costs are included for Gibe III…" (ibid, Page vi).
- "…It is worth noting that the downstream ESIA generally does not include costs for impacts on Lake Turkana. Within the downstream ESIA the definition of the study area is defined for the terrestrial and aquatic ecology as the "Omo River downstream of the dam site until its mouth into Lake Turkana". For the downstream area, mitigation measures make reference to a fishery resources monitoring plan, which will monitor any changes to the aquatic environment including Lake Turkana from construction of the reservoir upstream. The EFTA Consultant recognises that AFDB has recently contracted a specialist to analyse and research the Project's potential impacts to Lake Turkana…" (ibid, p24).
- "…The Project cannot compromise adequate flows of water to Lake Turkana (currently under study) by abstracting additional amounts water for downstream agriculture without carefully studying and discussing its effect with relevant stakeholders..." (ibid, p38).
- "…the possibility of leakage from the Omo Basin to the rift valley is very remote..." (ibid, Volume 2, p87).
- "…The groundwater has low salinity, lower than 500 mg/l total dissolved solids (TDS), except in some deep aquifers and the lacustrine deposits of the lower Omo plain where active evaporation and accumulation of fine sediments is common…" (ibid).
- "…There is also the risk posed by negative public perceptions of the project due to concerns on the effect on Lake Turkana and the livelihood of the local population..." (ibid, Volume 3, Page ii).
- "…The AFDB and EIB already recognise the risk posed by environmental and social issues and have begun to address this with further studies…" (ibid, p14).
- "…The impact of the project on Lake Turkana is a main source of negative criticism. Lake Turkana only receives limited mention in the ESIA and was not a focus for the ESIA studies or public consultation and disclosure plan activities. The study that has recently been initiated by AFDB to understand better the potential impacts should be useful for the project staff to engage with individuals and NGOs who cite Lake Turkana as a major concern…" (ibid, p15).

The study team clearly foresaw large-scale water abstraction for irrigation to be associated with the Gibe III project, and the team considered it essential that impacts on Lake Turkana be discussed with Kenya.

3.5 African Development Bank: Hydrological Impacts on Lake Turkana, November 2009 (Avery, 2009) & November 2010 (Avery, 2010)

The African Development Bank Draft Report entitled "Assessment of Hydrological Impacts of Ethiopia's Omo Basin on Kenya's Lake Turkana Water Levels" was presented in November 2009 (Avery, 2009).

This AFDB report was the first targeted hydrological study to have been done on Lake Turkana. The report aimed to assist the AFDB's mediation discussions with Friends of Lake Turkana (FoLT). Friends of Lake Turkana (FoLT) had submitted an official complaint objecting to AFDB's intentions to provide finance for the Gibe III power station. Previous studies have alluded to impacts on Lake Turkana without providing any basis that can be used to assist decision-making. The AFDB study aimed to overcome these deficiencies.

The AFDB report compiled all available data on the lake hydrology, and presented a comprehensive baseline, including the lake's all-important fisheries. The AFDB Report established a water balance model based on satellite radar altimeter lake levels from 1992 to date. This model was used to predict the effect of reduced lake inflows consequent upon abstraction from the Omo River.

Based on modelling, the AFDB study confirmed that significant impacts were expected on Lake Turkana due to Gibe III, and due to consequential large-scale irrigation opportunities. Such impacts have been alluded to in previous studies, notably the 1996 Omo-Gibe Integrated Basin Master Plan, but no attempt was made to quantify or discuss these impacts.

AFDB made extensive reference to the comprehensive Omo-Gibe Basin Master Plan. With the Master Plan water demand forecasts as a basis, AFDB demonstrated that extrapolated very long-term water consumption could cause lake levels to fall up to 40 metres. Thus the disturbing future spectre of an "African Aral Sea" scenario emerged, with the lake reducing potentially to two smaller more saline lakes.

The AFDB Report carried out extensive reviews of design documentation provided by the Gibe III dam team. AFDB noted that such studies were limited to the Omo River up to Lake Turkana, and did not consider effects on the lake itself. The lake is in Kenya, and this was deemed by the Gibe III design team to be beyond the project area of interest.

The AFDB Report stressed the dependance of the lake fisheries on the Omo hydrology, and cited scientific references confirming that changes to the Omo hydrology / inflows would inevitably adversely affect the lake fisheries, and hence would affect the livelihood of those people dependant on fisheries.

This AFDB study was consolidated, incorporating valuable comments received from Friends of Lake Turkana (FoLT) and a representative from the Kenya Marine & Fisheries Research Institute (KMFRI). Whilst the Final Report and AFDB socio-economic studies were in progress, the Ethiopian Government announced its financing agreement with Chinese banks on Gibe III. This announcement rendered the AFDB interest in the project redundant. This meant that the AFDB studies were brought to a close, which was unfortunate, as there was no indication that the new donors would require similar professional studies as a necessary pre-requisite to participation.

AFDB's Final Report on hydrology was dated November 2010. The concerns reported in November 2009 remained the same (Avery, 2010). The 2010 Report also included key findings from parallel studies initiated by AFDB in response to recommendations of the November 2009 report. These special studies covered fisheries, socio-economics, irrigation, and land use change.

In addition to the above hydrology report, AFDB also presented its "Socio-Economic Analysis and Public Consultation of Lake Turkana Communities in Northern Kenya" (Kaijage & Nyagah, 2009; & 2010). Summary findings are presented later in this report.

3.6 African Development Bank: Draft Baseline Survey of Lake Turkana Basin, Irrigation & Agriculture Component (Maina, AFDB, May 2010)

This draft report provided a baseline derived from existing Consultant's and Kenya Government reports. It covered the Turkwel, Kerio and Omo Basins. As with other reports at this time, the large-scale irrigation plans in Lower Omo were not captured. This draft AFDB report anticipated only 7,300 hectares of irrigated area downstream of Gibe III, of which 5,000 hectares comprised commercial plantation (mainly cotton – see Table 2 of Maina, 2010).

Maina's draft AFDB Report repeated oft-quoted assessments on the Lake Turkana water quality, as follows: "…The lake water is generally not suitable for drinking by either humans or livestock. The water is characterised by high pH (8.6 - 10.6), high content of sodium and potassium, and high content of total dissolved solids. The lake water also has high amounts of silt and organisms. This makes the water not potable, not fit for long periods of livestock watering and unfit for irrigation. The water quality is not homogeneous…" (Maina, 2010). The above water assessment probably derives from Kenya's Range Management Handbook for Turkana, which makes very similar statements.

A summary of findings was included in the Final AFDB Hydrological Impact Report (Avery, 2010).

3.7 Salini & Pietrangeli – Gibe III Impact on Lake Turkana Lake Levels, March 2010 (Salini & Pietrangeli, 2010)

This belated report for EEPCo finally addressed the impact on Lake Turkana levels, something that every earlier EEPCo report had neglected. Judging by its timing, this report was produced to pre-empt / counter the AFDB study findings. The AFDB findings had been produced in a confidential report dated November 2009. The Salini & Pietrangeli report utilises the same satellite data source and some curiously similar methodology. It would not be unreasonable to assume that Salini & Pietrangeli had access to the AFDB Report, although this is not acknowledged in the references they listed.

In its introduction, the Salini & Pietrangeli report states:

- "…The lake area is scarcely inhabited…" (ibid p2).
- "…the lake utilisations are mainly sightseeing and tourism (1,000 visitors in 1988), recreation (sport fishing) and fisheries…" (ibid, p2). Local people would accord "fisheries" top priority, certainly above "sightseeing, tourism and recreation", plus the lake is used to transport goods in an area lacking good road infrastructure.
- "…the runoffs regulated by Gibe III are expected to sensibly reduce the lake level fluctuations…" (ibid, p2). The use of the term "sensibly" implies there is a need to reduce lake level fluctuations, but no references are cited to support this.
- "…The power plant regulation will reduce the annual oscillation of the water surface. This effect is considered positive and may benefit the lacustrine habitat as a consequence of more regulated river flows and consequently more stabilised lake levels…" (ibid, p2). Salini & Pietrangeli calculated that the annual lake fluctuation of 0.95 metres would dampen to 0.25 metres (ibid, p38).

Ecologists will vigorously reject the above claims that the dampening effect on lake levels is "positive". It is well known that diversity is a consequence of natural variations, and that regulation leads to diminished diversity. In effect, the "positive" hydrological effects claimed by

the EIA reports will instead adversely affect the lake's current diverse ecology (Avery, 2010, citing Kolding).

The 2010 Salini & Pietrangeli report omitted to mention the effects of abstraction from the Omo on lake levels. As pointed out earlier in this chapter, EEPCo's ESMP for Gibe III stated that "permanent availability of water with stable water levels" would allow for "development of commercial irrigated agriculture" (Salini & Mid-Day, 2009b, p61). The consequential impacts should have been included in Salini & Pietrangeli's 2010 report; as otherwise, the impacts of Gibe III are only partially and selectively assessed.

3.8 African Development Bank: Baseline Study of Lake Turkana: Limnology and Fishery (Kamau, AFDB, 2010)

This draft report provided a baseline based on previous published data and Government statistics. The report re-iterated the various aspects of lake ecology that would be affected by Gibe III, and states that the ecological releases must be assured.

The draft report's conclusions were:

- "…There are major gaps in the limnological studies of the Lake Turkana which makes it difficult to establish the current status of the general lake ecology and also the fisheries potential of the lake..."
- "…On the other hand the lake experiences a lot of challenges which are fundamentally linked to the harsh climatic conditions of area. Although the potential of the fishery is not known, its market chain is not well established to ensure maximum benefit to the local community. The high percentage loss in fish catch exemplifies the poor development of the fishery sector…"
- "…The fishery ecology is also delicate owing to the fact that it's not fully understood yet it's known that the Omo River is critical to the maintenance of some fish species for their breeding and population development. The increasing population in the Lake basin poses a threat to the lake as well. As the population increases more people will venture into fisheries. There is also the promotion of the fisheries by non-governmental organizations due to the security it offers to the communities' livelihoods…"

Key findings were incorporated in the Final AFDB Hydrological Impact Report (Avery, AFDB, 2010).

3.9 Sogreah Consultants – Independent Review of Gibe III ESIA, March 2010

The Sogreah Consultants' report was entitled "Independent Review and studies regarding the Environmental & Social Impact Assessments for the Gibe III Hydropower Project" (ESIR Report - Sogreah, 2010). This is a thorough report into the Omo Basin, with many similar findings reported by AFDB and others. Like many other such reports, the report deals only superficially with Lake Turkana. The report's most significant weakness lies in its under-estimation of the potential for large-scale irrigation in Lower Omo. This means that the ESIR Consultant has grossly under-estimated the overall impact of Gibe III on Lake Turkana.

Various useful excerpts are included below:

- "…The ESIR Consultant considers the Gibe III project as a major opportunity to initiate the economic development of the Lower Omo, one of the least developed region of Ethiopia…" (Sogreah, 2010, Page a),

- "…and recommends that any financial support to Gibe III development is closely linked to the simultaneous socio-economic development of the Lower Omo region, in order to maximize the benefits from the river flow regulation... (ibid).
- "…The downstream impact zone (Omo river, Omo delta and eventually Lake Turkana) will be more severely affected by the Project. The alteration of river hydrology, with a regulation of the seasonal flows, will severely affect the flood recession agriculture practiced along the riverbanks and in the flood plain by the local population. The suppression of the seasonal submersion of the floodplain will also affect its ecosystems, particularly the grazing lands fundamental for livestock and the spawning areas essential for fisheries. Overall, around 82,000 people could be affected…" (ibid).
- "…Furthermore, the reservoir impoundment may have also significant impacts on the hydrology of Lake Turkana in Kenya, thereby raising trans-boundary concerns…" (ibid, p2).
- "…the issues involved on Lake Turkana are yet to be covered by an appropriate agreement between the two countries…" (ibid, p4).
- "…Compared to the present situation, water losses for Lake Turkana during Gibe III operation will be limited to 20 Mm^3/year from reservoir evaporation and 80 Mm^3/year from the irrigation of about 10,000 ha proposed in the ESIA-DS. This total of 100 Mm^3/year abstracted from the natural inflow to Lake Turkana (23,000 Mm^3/year) represents only 0.4% of the Lake's annual inflow…" (ibid, Page d). Note that elsewhere, the ESIR Consultant determined that 79,000 hectares of land would be "suitable" for irrigation – see below. The ESIR Consultant was not made aware of the 175,000 hectare Kuraz scheme being planned by the Ethiopia Sugar Development Corporation.
- "…The ESIR Consultant estimates that maximum 82,000 people are directly dependent on the river, to various extents…" (ibid, p65). The ESIR Consultant was disputing claims by ARWG that "at least 200,000 people are heavily dependant on the Omo" (ibid).
- The ESIR Consultant estimated there is almost 100,000 hectares of pasture in the four relevant Weredas in the Lower Omo, and that "an estimated 16,000 people benefit from natural flooding of pasture land from the river" (ibid, Page e).
- "…Land evaluation indicated that whilst there is no land presently highly suitable, there are some 30,600 ha of 'moderately suitable' and 33,300 ha 'marginally suitable' land. 21,400 ha are now 'unsuitable'. With remedial measures such as surface and subsoil drainage, crevasse infilling and leaching with gypsum, provided these are economically viable, then some 5,000 ha would become 'highly, 60,000 ha 'moderately' and 14,000 ha 'marginally' suitable…" (ibid, p30). The total 'suitable' would be 79,000 ha. This is much larger than the 10,000 ha referred to in the DS EIA, but still far short of the large-scale development now taking place. The potential irrigation area in the Lower Omo in Figure [3] of Sogreah's report looks a replica of Figure 3 in Vol. XI, F2, of the Omo-Gibe Basin Master Plan.
- The ESIR Consultant makes a range of recommendations that agree with the earlier 2009 AFDB report (Avery, 2009). The principal criticism of the ESIR Consultant's report lies in the allowances for irrigation abstraction, which are inconsistent, and did not include the large-scale plans of the Sugar Development Corporation and others. The 10,000 hectares used by the ESIR Consultant for assessing the irrigation abstraction impact on Turkana is a fraction of present day reality, and was even far less than the 79,000 hectares found "suitable" in this same report – see above (Sogreah, p30). The omission of large-scale irrigation is surprising as such development was reported to be an expected consequence of Gibe III in the earlier EFTA Report (reviewed above). Sogreah was part of the team that produced the EFTA Report.

Perhaps one of the most interesting parts of the ESIR Consultant's report is the Consultant's discussion of an alternative to the proposed "ecological flood" releases from Gibe III. The Consultant analyses the high costs of ecological releases in terms of power generation losses. There is an understandable global scepticism attached to such releases, shared by this Consultant. It is generally believed it will never happen, as it will be financially punitive.

Other reports have noted that the construction of Gibe IV will render the ecological releases from Gibe III redundant (Avery, 2010). Furthermore, it will be obvious that flood releases will be incompatible with the large-scale irrigation development now taking place along the banks of the Lower Omo. Floods that spill from the Omo banks will damage the irrigation infrastructure, and

this of course will be avoided. Hence, the entire discussion of ecological flood releases is academic.

Sogreah offered an interesting alternative to ecological flood releases, namely a barrage on the Lower Omo feeding a network of canals to replenish the groundwater stocks of the Lower Omo flood plains and depressions. Of course, this alternative scheme to replenish the flood plains is rendered redundant by the large-scale irrigation plans of the Ethiopian Government, which were unknown to the ESIR Consultant. It was nonetheless an interesting suggestion, although the quantity of water and effects on the lake were not mentioned.

3.10 Ethiopian Wildlife Conservation Authority – September 2011

In September 2011, the Ethiopian Wildlife Conservation Authority (EWCA) prepared its report entitled "Existing Challenges: Plantation Development versus Wildlife Conservation in the Omo-Tama-Mago Complex".

The following extracts are notable:

- "…The lower Omo Valley of Southern Nation Nationalities and People Regional State (SNNPRS) is one of the last unspoiled wilderness biodiversity hotspot areas located in the southwest Ethiopia. Wildlife protected areas (WPAs) in the area include: Omo, Mago National Parks, Tama and Chelbi Wildlife Reserves, Murule and Welishet Sala Controlled Hunting Areas…"
- "…Currently, the WPAs in the lower Omo valley are under greater conservational problems and the wildlife populations and their natural habitats have been negatively affected by a combination of human activities including cattle grazing and poaching (illegal hunting) and seasonal settlement…"
- "…The situation may become more serious due to the development of Kuraz sugar cane development project…"
- The total area excised from National Parks and Reserves for sugar plantation was reported by EWCA to be 135,285 hectares, broken down as follows:

  "…Omo National Park:
  - 1968: Established (4,068 km^2).
  - 2002: Land sought for sugar plantation (150,000 hectares) - see Figure 5 overleaf, p38.
  - 2003: Re-demarcated, reduced to 3,438 km^2, 63,000 hectares (630 km^2) in SE corner excised for sugar…"

  "…Mago National Park:
  - 1970: Established.
  - 2003: Re-demarcated, reduced to 3,438 km^2, 30,000 hectares (399 km^2) in SW part of the park excised for sugar…" - see Figure 6 overleaf, p38.

  "…Tama National Reserve:
  - 1970: Established (1,472 km^2).
  - Located either side of Omo National Park, including the buffer zone between Omo NP and Mago NP.
  - 2008: Demarcated, 42,285 hectares (423 km^2) on left bank of Omo excised for sugar. This is the entire river frontage of the Reserve, and forms a barrier separating the Reserve from Omo National Park…" - see Figure 7, on p39.

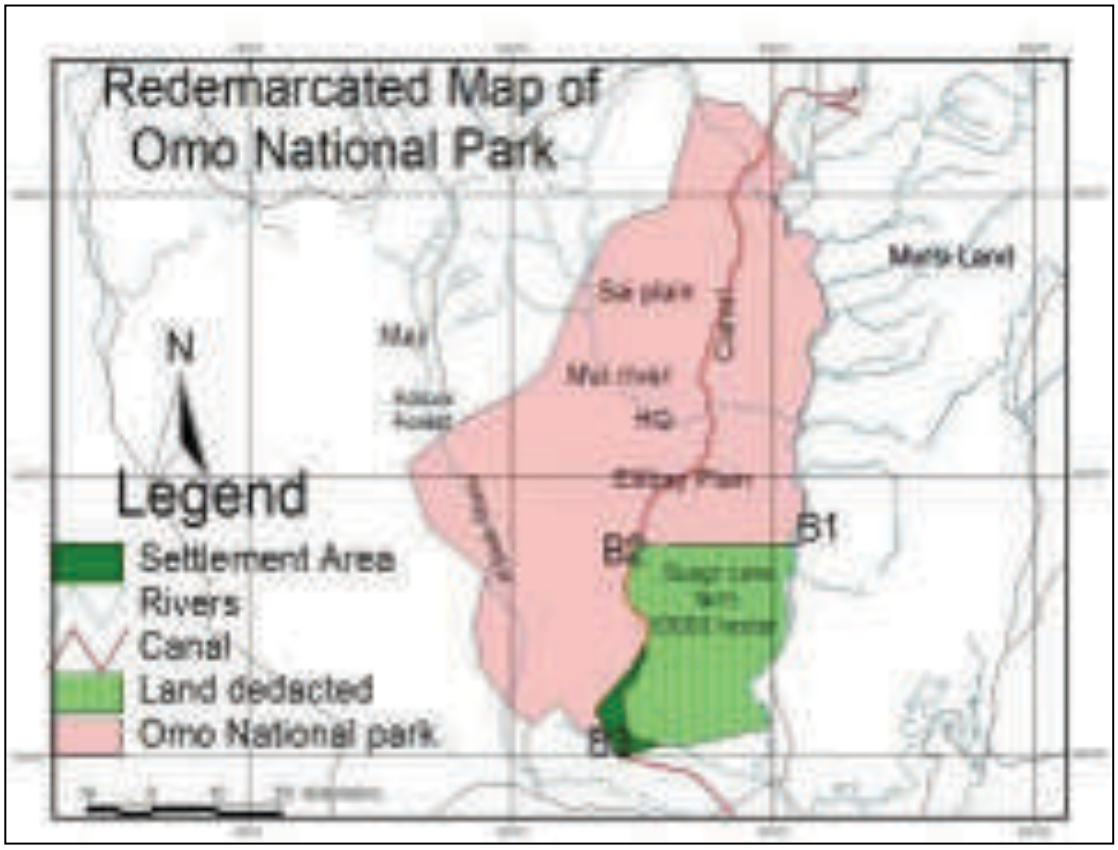


Figure 5: Omo National Park with 63,000 hectares sugar farm excision

Source: EWCA 2011.

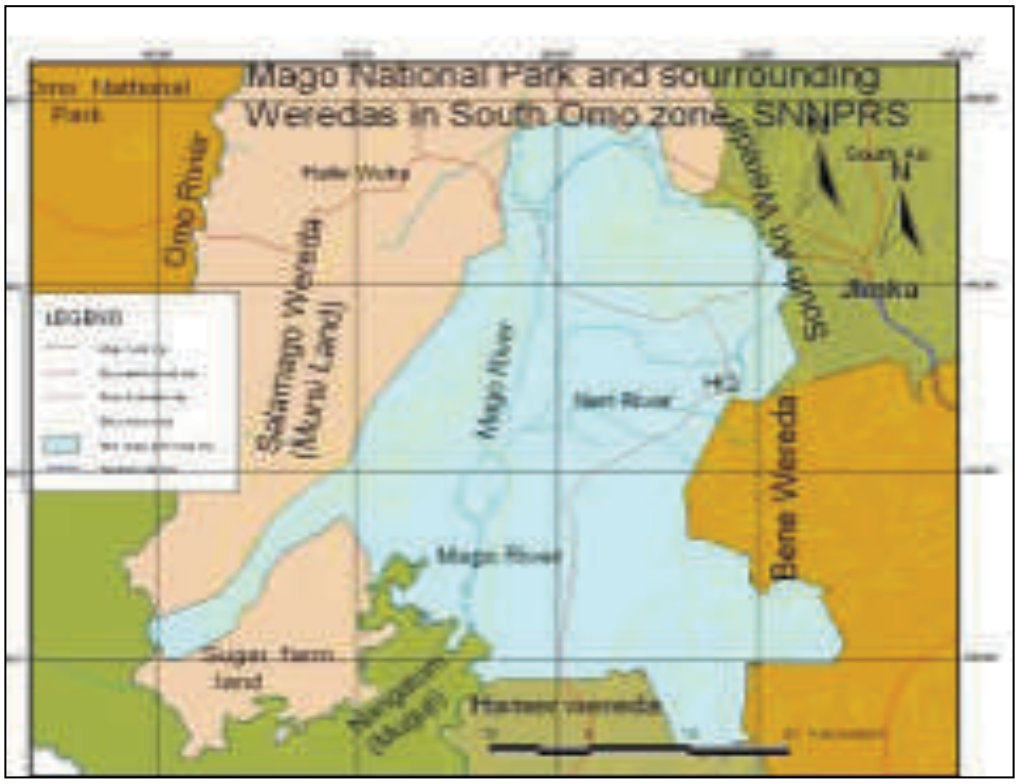


Figure 6: Mago National Park with 30,000 hectares sugar farm excision

Source: EWCA 2011.

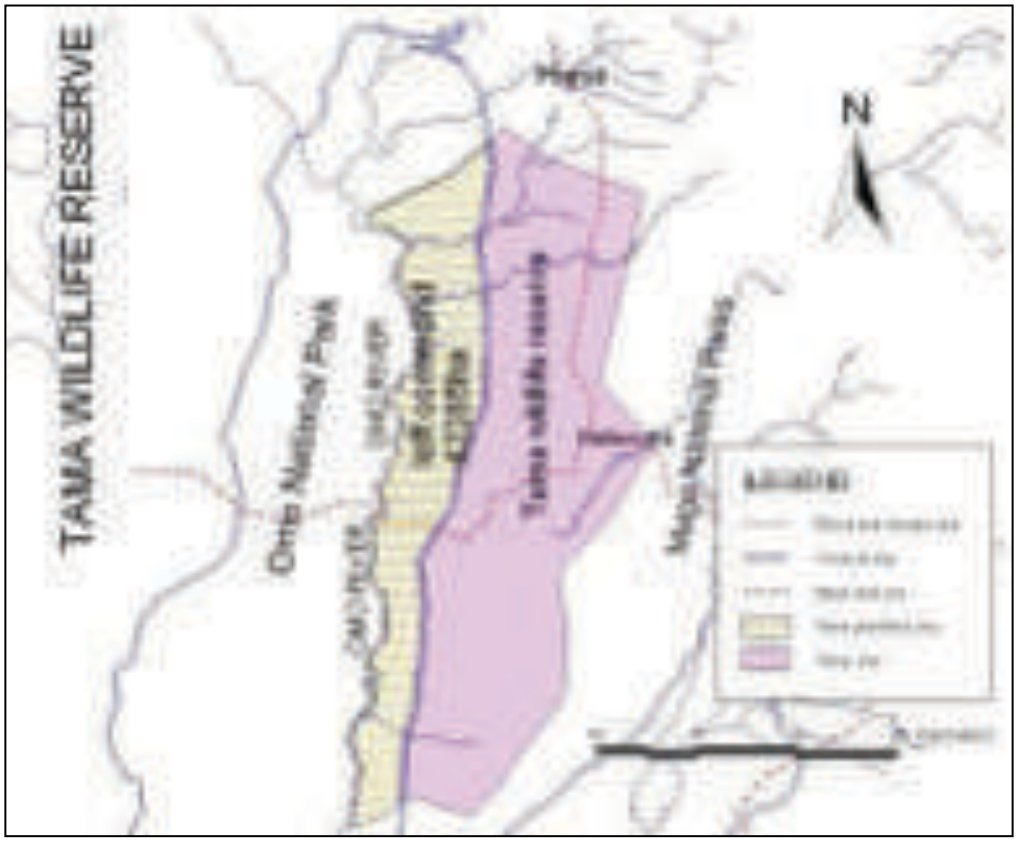


Figure 7: Tama Wildlife Reserve and 42,285 hectares "Left Command" sugar farm excision

Source: EWCA, 2011.

3.11 Oakland Institute: Land investment deals and Lower Omo

In its "Land Deal Brief" dated September 2011, the Oakland Institute addressed concerns associated with accelerated commercial agricultural development in Lower Omo, citing abuses and disregard for indigenous peoples, and large excisions from national parks. The Oakland Institute urged action before it is too late. Various pertinent abstracts are included below:

"…Since 2003, Ethiopia's Lower Omo Valley, one of the most culturally unique areas of Sub-Saharan Africa, has been thrust into the international spotlight due to the launch of the controversial Gibe III hydroelectric project. Unfortunately, the massive commercial agriculture developments and resulting state sponsored human rights violations – all made possible by Gibe III dam – have escaped international attention…" (Oakland Institute, 2011).

The Oakland Institute stated: "…Since 2008, 350,000 ha of land has been earmarked for commercial agricultural production in the Lower Omo Valley…" (ibid). The Oakland Institute also reproduced tables and a map showing the breakdown and distribution of the various agricultural schemes. These will be presented later in this report.

The Oakland Institute quoted the late Prime Minister Meles Zenawi, who in early 2011 summed up as follows: "…In the coming five years there will be a very big irrigation project and related agricultural development in this zone. I promise you that, even though this area is known as backward in terms of civilisation, it will become an example of rapid development…" (ibid).

The Oakland Institute stated that 500,000 indigenous people "rely on the waters and adjacent lands of the Omo River and Lake Turkana" (200,000 in Lower Omo; 300,000 in Turkana).

The Oakland Institute referred to "human rights violations in the name of agricultural development", citing reports since early 2011 that "development of sugar plantation infrastructure has been accompanied by abuse from the Ethiopian Defence Forces (EDF) against local populations, instilling a sense of fear regarding any opposition to sugar plantation plans". The Oakland Institute stated that the EDF behaviour was consistent with discoveries by journalists uncovering oppressive behaviour in other parts of Ethiopia.

The Oakland Institute included reference to "sacrificing national parks", being the excisions from the Omo and Mago National Parks, described earlier in this report in the EWCA Report. The Oakland Institute referred to 130,000 hectares excised land, with a further 150,000 hectares "prime natural habitat" being cleared for commercial agriculture, all with "detrimental impacts on the livelihoods of the South Omo indigenous peoples". The Oakland Institute referred to "disregard for areas of outstanding ecological or cultural value as Ethiopia rushes to convert land to industrial agriculture". The Oakland Institute described this as "a travesty in the name of development", and expressed concerns that "without significant and timely intervention, the rich cultural traditions of these people will be gone forever, raising immediate questions about their future livelihoods and identity".

The Oakland Institute quoted figures suggesting that 150,000 jobs will be created through sugar plantation development, but considered this to be high (ibid).

3.12 14th World Lake Conference, Austin 2011 – Presentation on impacts on Lake Turkana

UNEP invited the Consultant to present to the 14th World Lake Conference, Austin, Texas, in November 2011, within the Session entitled "Global Programs and Strategies on Assessment and Management of Lakes and Their Basins: UNEP-ILEC Collaboration". The presentation was entitled "Hydrological Impacts of Ethiopia's Omo Basin on Kenya's Lake Turkana" (Avery, 2011).

Background was presented for the Omo Basin and its cascade of development projects. Since 2009, the Gibe III hydropower project has been the subject of a flurry of studies. The presentation showed that recently emerging associated very large-scale commercial agriculture development has raised concerns to a higher level.

The following consequences of Gibe III and large-scale irrigation were reported at the Conference:

- Gibe III filling would alone cause an approximate 2-metre drop in Lake Turkana's water level, possibly reducing the lake below the historic lowest lake level on record. There would also be dampening of lake level cycles of fluctuation. Both the dampening of cycles, and the reduction in lake level, would have disastrous consequences for lake fisheries (Pers.Comm., Kolding, 2011). The lake level would recover in time, but the dampened cycles would remain, hence the ecology would permanently change.
- The Kuraz Irrigation scheme crops will need 19% of the Omo's annual flow. This amount of water on its own will lead to a permanent 5-metre lake level drop based on an assumed flow sequence 1993 - 2008 (which includes an unusual 1997 / 1998 El Nino). If this is combined with Gibe III filling, the lake level drop will be compounded. The situation will be further compounded by the addition of other irrigation developments being promoted in the Lower Omo.

The above findings have been revised in this report as the reported crop water usage provided by the Sugar Development Corporation was the "net" crop water requirement and did not include the losses that will occur when applying the water. As the Lower Omo is dry, windy and hot, the losses will be appreciable.

3.13 UNEP – Gibe III impact on L. Turkana

UNEP prepared the following draft report in early 2012: "Ethiopia's Gibe III Dam: its Potential Impact on Lake Turkana Water Levels" (UNEP, 2012).

A draft of this report has been circulated on the Internet, although the report evidently had not completed its peer review (Pers.Comm.,UNEP). The reaction of various scientists to the UNEP Report findings was extremely negative (Pers. Comms). The main points of comment are:

- The UNEP report presents a hydrological model that predicts lake levels from satellite derived rainfall and evaporation. This approach is an academic exercise insofar as Lake Turkana is concerned as the lake levels are directly measured and do not need to be derived through uncertain modeling. The AFDB studies did the reverse, which was to use the known satellite derived lake level changes to derive the Omo river's inflow sequence. This was more useful as it was the Omo flows that are not measured. The UNEP report's science is interesting, but the report's background research is poor, there was confusion over catchment area, and it is puzzling that UNEP in 2012 is repeating impact studies already reported by others three years ago. Instead of embarking on its own duplicate Gibe III impact studies, UNEP could instead have usefully carried forward detailed recommendations of the AFDB and EIB studies.
- UNEP provided a useful review of the Gibe III site, but the UNEP report otherwise conveys a surprising lack of on-the-ground familiarity. A photograph is included in the Executive Summary purporting to be "overlooking Lake Turkana", but the image is actually Lake Ziway in Ethiopia.
- The UNEP report to a large extent repeats findings reported by others in 2009, but unfortunately draws wrong conclusions. The most unfortunate conclusion is the following: "The variability in the lake levels due to regulated inflows after the dam is commissioned is found to be within the lake's natural variability". This statement not only arises from partial and selective analysis, but it is misleading and has precipitated written objections from knowledgeable scientists (Pers.Comm.Kolding, 2012, to UNEP).
- The UNEP report's above conclusion overlooks the fundamental ecological dependance of the lake on the Omo River hydrological cycles, and the very significant detrimental consequences of a change in the Omo River hydrological cycles on Lake Turkana's fisheries. These potentially dire consequences have been flagged up in earlier reports (Pers.Comm. Kolding, 2011; Avery, 2009; & 2010).
- The UNEP report's greatest omission is its failure to include the consequential impacts arising from the large-scale irrigation downstream in Lower Omo. The irrigation plans were announced in early 2011. The feasibility of downstream irrigation will depend on the enhanced low flows consequent upon regulated releases from Gibe III, and later from Gibe IV. The omission of consideration of this indirect impact of Gibe III is puzzling, as warnings about large-scale abstractions downstream have been made in previous reports, for instance as early as Sogreah's report in 2009, and AFDB's report in 2009, plus enhanced commercial irrigation downstream is specifically promoted in EEPCo's Gibe III ESMP. Furthermore the potential impact of these abstractions was presented during the UNEP / ILEC Session of the 14th World Lake Conference in November 2011 (Avery, 2011).

In response to the various comments, UNEP appears to have put the report on hold, as it has since not been formally presented. The report should either be expanded into a cumulative impact assessment, or it should confine itself to an academic hydrological modelling exercise unrelated to Gibe III.

3.14 KETRACO - ESIA of impact of Gibe III on Lake Turkana's ecosystem

3.14.1 Kenya – Ethiopia Power Line

In 2006, Kenya's power utilities (Kengen & KPLC) signed a Memorandum of Understanding (MoU) with Ethiopia's power utility (EEPCo) for "joint development of generation facilities in Ethiopia and interconnection of the two power systems" (EEPCo, 2006), and funding requests were submitted to the African Development Bank.

Ethiopia's Power Master Plan Update foresaw two possible "generation connection" points for Kenya. The first was the Genale Dawa cascade (830 kilometres from Nairobi, generation capacity 720 MW). The second was Gibe III (1,200 kilometres from Nairobi, generation capacity 1,800 MW) (Ibid). The vision of a powerline connecting Ethiopia to Kenya will open a gateway for Ethiopia's power to the southern and central African countries.

The Power Master Plan stated in 2006 that "the HVDC link with Kenya will be, at this current stage, associated with the development of Gilgel Gibe III power plant, as this plant is committed to be in service by 2011".

In June 2012, the International Development Association (IDA) of the World Bank and its partners AFDB (African Development Bank) and AFD (French Development Agency) agreed to finance the power transmission line from Sodo in Ethiopia to Kenya. This will involve construction of 1,045 kilometres of bipolar 500KV HVDC overhead transmission line and towers (World Bank, 2012). The length of the powerline differs in different documents.

An objection launched by the Friends of Lake Turkana is included in the press release included in the Annexes (FoLT, 2012).

The World Bank Safeguards Appraisal (World Bank, 2012) does not mention that Gibe III is the power generation point that will feed the Sodo Sub-Station to which the Kenya powerline will connect. Hence the Appraisal disregards the ongoing controversy shrouding Gibe III (a project World Bank declined to fund because its procurement procedures did not fulfil World Bank guidelines).

3.14.2 Panafcon / DHV ESIA – Impact of Gibe III on L.Turkana, 2012

In 2010, the Kenya Electricity Transmission Co. Ltd. (KETRACO) issued its Terms of Reference for the assignment described in the Data Sheet "Consultancy Services for Carrying out Environmental & Social Impact Assessment of proposed Gibe III Hydroelectric Power Project: Downstream of Gibe III: Kenyan Perspective" dated July 2010 (KETRACO, 2010). These Terms of Reference were drafted whilst the AFDB studies were still ongoing.

KETRACO is the Kenyan utility responsible for the proposed power transmission line from Ethiopia to Kenya (project funded by World Bank, AFDB and the French Development Agency (AFD). By commissioning an ESIA to look into the impacts of Gibe III on Lake Turkana, KETRACO acknowledged that Gibe III is the "generation point" for the proposed powerline, and recognised the concerns concerning Gibe III, and considered these should be subject to study.

The KETRACO ToR state the following (KETRACO, 2010):

"…An Environmental and Social Impact Assessment (ESIA) focusing on upstream dynamics has been undertaken by the EEPCo. CESI of Italy and Mid-Day International (MDI) Consultants carried out other studies in 2006. Other experts have criticized the Methodology and conclusions of some of these studies. The project has commenced and the construction is on going…"

"…Kenya has a legitimate concern with developments on the Omo River because it is a trans-boundary resource. The Omo River is the only perennial tributary feeding the Lake and is

estimated to provide at least 80% of its inflow. Despite this, the Government of Kenya was not identified as a major stakeholder in the environmental and social impact assessment process. As such the ESIA done by the Ethiopian Government concentrated on the Ethiopian side with minimal mention on possible impacts on the Kenyan side…"

"…These Terms of Reference define the requirements for consultancy services for undertaking a full Environmental and Social study for the proposed project on downstream of the Gibe III dam…" (KETRACO, ToR, Item 1.1, July 2010).

The KETRACO ToR included a summary of the World Bank Safeguard Policies in its Appendix G, as follows:

- OP/BP 4.01 Environmental Assessment: This safeguard policy is triggered if "the downstream perspective is likely to have potential (adverse) environmental risks and impacts on its area of influence". The safeguard policy states, "the Bank supports, and expects borrowers to apply, a precautionary approach to natural resource management".
- OP/BP 4.04 Natural Habitats: This safeguard policy is triggered if the project has the potential to cause significant conversion (loss) or degradation of natural habitats whether directly (through construction) or indirectly (through human activities induced by the Gibe III Hydroelectric Power Project: Downstream Perspective).
- OP/BP 4.36 Forests: This safeguard policy is triggered where the project has potential impact on the health of forests.
- OP 4.09 Pest Management: This safeguard policy is triggered by risks through increased pesticide usage through the project.
- OP/BP 4.11 Physical Cultural: This safeguard policy is triggered where physical cultural resources are threatened.
- OP/BP 4.10 Indigenous Peoples: This safeguard policy aims to "… foster full respect for the dignity, human rights, and cultural uniqueness of indigenous peoples…"
- OP/BP 4.12 Involuntary Resettlement: This safeguard policy aims to minimise involuntary resettlement.
- OP/BP 4.37 Safety of Dams: This safeguard policy states steps to be taken to ensure dam safety.
- OP 7.60 International Water: This safeguard policy is triggered because the Gibe III dam is on the Omo River, which "flows through two or more states". The policy strives to protect relations between the Bank, its borrowers and the states.
- OP 7.60 Disputed Areas: This safeguard policy is triggered where the project is a "disputed area".

In 2011, KETRACO commissioned Kenyan Consultant Panafcon in association with international Consultant DHV to undertake the study entitled: "The Impact of Gibe III on Lake Turkana Ecosystem". The scope of services largely replicates what was already done by AFDB in 2009 and 2010.

The Final Report prepared by Consultants Panafcon / DHV is understood to have been submitted in early 2012. At the time of writing this report, it had not been released into the public domain.

The former AFDB Consultant met with the Panafcon / DHV team in February 2011, at their invitation, and a copy of the AFDB Hydrological study was provided to the team after permission was obtained from AFDB. The report was at the same time forwarded to KETRACO, as agreed with the AFDB. No acknowledgement was received.

The former AFDB Consultant kept in touch with Panafcon / DHV, and was expecting to attend the final stakeholder workshop. Panafcon / DHV advised that the Workshop was cancelled by KETRACO, and Panafcon / DHV were instructed to instead submit their Final Report.

3.15 UNESCO's World Heritage Committee & IUCN – L. Turkana World Heritage sites "endangered" by Gibe III, 2012

Kenya's Sibiloi and Central Island National Parks were inscribed in 1997 on the World Heritage List as "Lake Turkana National Parks". World Heritage status places conservation obligations on Kenya (the State Party), and World Heritage Centre teams may periodically be invited by the State Party to conduct missions to inspect and verify that obligations are being met.

In 2011, the World Heritage Centre (WHC) and IUCN jointly issued their warning that the Lake Turkana National Parks (the property) might be endangered by developments in the Omo Basin, in particular the Gibe III dam. The World Heritage Centre and IUCN requested cessation of construction of Gibe III dam on the Omo River pending reports from the State Parties of Ethiopia and Kenya (WHC, 2011).

The State Parties issued their reports in 2012, and a World Heritage Centre / IUCN team was invited on a fact-finding mission to Kenya. The team visited in March 2012, and later issued its Mission Report in which the following was stated (WHC, 2012):

- "…On 31 January 2012, a report was submitted by the State Party of Kenya in response to Decision 35 COM 7B.3…" (UNESCO, 2012, p10).
- "…In the report, the State Party expresses its concern about the potential impacts of the Gibe III dam on the property and notes that it is of the opinion that no adequate scientific proof has been provided by the State Party of Ethiopia that adequate mitigation measures have been taken and that this has to be addressed urgently to avoid irreversible damage to the property..."
- "…The report further notes that this issue is of trans-boundary nature and that a solution has to be found together with the State Party of Ethiopia…"
- "…On the same date, a report was also received from the State Party of Ethiopia in which it notes that the Gibe III dam will not result in consumptive use of water, and hence water levels in Lake Turkana will return to normal once the reservoir is filled. It notes that irrigation development is not part of the Gibe III project. It concludes that all Environmental Impact Assessments (EIA) carried out indicate that the Gibe III dam will not have significant impacts on the environment…" (ibid, p10-11).

The joint World Heritage Centre / IUCN team issued various suggestions, and their final recommendation was that Lake Turkana National Parks be inscribed on the "List of World Heritage in Danger". The draft submitted to the Committee is included in Volume II of this report - Annexes. The final recommendation was however rejected by the Committee, and the team has been instructed to arrange a fact-finding visit to Ethiopia. The invitation from Ethiopia is awaited.

It is pertinent to emphasise that the World Heritage Centre / IUCN team is recognising the significant impacts that will arise from Gibe III and the large-scale sugar development. It is also significant to note that the State Party Ethiopia refrained from mentioning the consequence of large-scale irrigation on "the property". This means that the State Party's response was unfortunately selectively inconclusive, as Gibe III cannot be distanced from beneficial irrigation downstream.

The Consultant played a role in providing information to the joint UNESCO WHC / IUCN team during its Mission to Kenya in March 2012 (acknowledged in the UNESCO Mission Report). At the invitation of the National Museums of Kenya, the Consultant made a presentation to a fact-finding Stakeholders Workshop in Nairobi. Summary details are included in Volume II of this report - Annexes.

3.16 Human Rights Watch – Abuses in Lower Omo Valley, June 2012

In June 2012, Human Rights Watch launched the following report in Nairobi:

"What Will Happen if Hunger Comes? Abuses against the Indigenous Peoples of Ethiopia's Lower Omo Valley" (Human Rights Watch, June 2012).

The Report includes the following summary:

- "…The Ethiopian government is forcibly displacing agro-pastoral indigenous communities in the Lower Omo Valley to make way for 245,000 hectares of state-run sugar plantations, linked to the development of the Gibe III dam, which will provide much needed hydropower to Ethiopia. The cost of this development to indigenous groups is massive: their farms are being cleared, prime grazing land is being lost, and livelihoods are being decimated. Government security forces are forcing them to move through violence and intimidation. The Ethiopian government has failed to meaningfully consult, compensate, or discuss with these communities alternative means of livelihoods…"
- "…Human Rights Watch calls on the Ethiopian government to suspend the construction of Gibe III and the associated sugar plantations until these projects can be carried out in a manner that is consistent with national laws and international human rights standards. Human Rights Watch also urges Ethiopia's donors, including the World Bank, to press for appropriate social and environmental impact assessments and calls on prospective investors to refrain from any investment activities in areas where land title is contested until all violations are investigated and remedied…" (Human Rights Watch, 2012).

In addition to seeking prosecution for human rights violations, the report repeats the findings of previous reports concerning the recommendations for proper cumulative environmental and social impact assessments that include full consultation. The most interesting contribution of the report is its map showing the full extent of the proposed agricultural developments in the Lower Omo. This map will be studied in more detail elsewhere in this report.

3.17 Ethiopia Sugar Corporation "Response to Accusations" – June 2012

In response to accusations made by Human Rights Watch (HRW), the Ethiopia Sugar Corporation has stated:

- Coercion to force people to move is denied.
- HRW is reproducing data produced earlier by others, notably Survival International, International Rivers, Oakland Institute.
- The potential sugar plantation area is 150,000 hectares, possibly extending to 175,000 hectares, not 245,000 hectares as stated by HRW.

The Sugar Corporation stated the following benefits would arise from the sugar project:

> "…The people of the Lower Omo Valley had long been marginalized and deprived of any development undertaking. Apart from living in a naturally endowed environment the people have never been provided with education, health and other basic services and lived in a harsh condition. Roads and other communication infrastructures are non-existent and they have a very little contact with the outside world. With no education and no contact they lived being victims of natural disasters and harmful cultural practices which gives them nothing except remaining to be an amusement for foreign tourists. Presently the situation is changing with the government's policy to foster equitable distribution of resources to citizens residing in any part of the country. Thus followed the introduction of development activities to the region of which the sugar development project is one. Thanks to the sugar development project institutions and infrastructures, which were non-existent in the past,

have began to be in place. Roads, electricity, potable water, schools, health stations, veterinary centres etc began to be available to the people. Even from the outset of the project, 1,392 pastoralists, organized in SMEs, have managed to get job. Out of the above pastoralists 249 youth have already been made permanent workers of the project. The number will increase along the progress of the project. Moreover, the pastoralists will benefit out of using by-products of sugar cane for animal feed and also start sedentary farming which leads to zero-grazing system…"

In addition, 118,000 jobs will be created.

3.18 Summary of various report findings

The African Development Bank reports remain the only reports that considered the overall Omo Basin water abstraction impacts on lake levels. The 2012 WHC / IUCN team cited the report submitted to the AFDB as a key reference (in its Mission Report, UNESCO, 2012, citing Avery, 2010). The team recommended that the Lake Turkana National Parks be listed "endangered" as a consequence of developments in the Omo Basin. The recommendation was rejected by the World Heritage Committee which met in Russia in June / July 2012, and instead recommended that a fact-finding mission be sent to Ethiopia first. The invitation to visit is awaited, and UNESCO is pressing for this.

In contrast, the 2012 UNEP draft report does not mention the impact of the large-scale sugar developments announced in the Ethiopian press in 2011. This conspicuous omission has been noted by many scientists (Personal Communications) and has been reported by Human Rights Watch (Human Rights Watch, 2012). The Panafcon / DHV report on Gibe III's impacts on Lake Turkana has not been released by KETRACO, but is understood not to have included the impact of large-scale sugar developments either (Pers.Comm, DHV).

There is an oft-quoted argument that the sugar developments are independent of Gibe III. Such arguments deny reality, as large-scale irrigation abstractions can only be reliably contemplated thanks to the regulated flow releases made possible by the substantial water storage provisions of the lake that will be formed by Gibe III, and later by Gibe IV. The Ethiopian Government's Omo-Gibe Basin Master Plan specifically stated that storage dams were required to "uplift" the low flows of the rivers through "regulation". This need is confirmed by various Consultants reports (Avery, 2010; Mott MacDonald & Sogreah, 2009). Even EEPCo's Gibe III ESMP has stated that regulated flows will provide the opportunity for commercial agriculture downstream (Salini & Mid-Day, 2009).

It will also be shown in this report that the irrigation needs of the Kuraz sugar scheme will otherwise empty the river of its natural flow during periods of low flows, a situation that is environmentally and socially unacceptable. Such schemes should only be contemplated once regulated flows are available, and the schemes should not commence without provision for adequate compensation and ecological flow releases. A startling image of the river in February 2012 is included below. This shows the effect of diversion of water into the sugar scheme upstream, with the river reduced to little more than a trickle, as the Gibe III storage is not yet operational.

Photo 1: Omo River downstream of the Kuraz irrigation intake - February 2012
Source: Human Rights Watch (Human Rights Watch, 2012).

4 IRRIGATION WATER DEMAND IN THE OMO

4.1 Summary of reported irrigation potential water demands

This chapter includes an updated chronology of the various assessments of irrigation potential in the Omo Basin. It expands what was presented in the study prepared for the AFDB (Avery, 2010).

Assessments of irrigation potential have varied wildly since 1990. A summary is included in Table 1, with more detail provided in the sections that follow later in this chapter. Up to 445,320 hectares potential has been referred to.

Table 1: Published Omo irrigation potential

Date	Area hectares	Source of data on irrigation areas	Comment on area encompassed within the Basin
1990	445,320	WAPCOS (1990)	Omo-Gibe Basin
1992	250,000	EVDSA Master Plan ToR (1)	Omo-Gibe Basin
1994	265,000	OBMP Reconnaissance	Omo-Gibe Basin
1996	74,300 31,780 106,080	OBMP Medium scale (2) OBMP Small scale (2) Total	Omo-Gibe Basin Omo-Gibe Basin Total
1997	445,300	FAO (1997)	Omo-Gibe Basin
2004	348,000	World Bank (2004)	Omo-Gibe Basin
2007	100,000	MoWR	Omo-Gibe Basin
2007	67,928	IWMI (2007)	Omo-Gibe Basin
2009	100,000	MoWR (Pers. Comm.)	Omo-Gibe Basin
2009	153,000	CESI & Mid-Day (2009)	Lower Omo
2010	79,000	Sogreah (2010)	Lower Omo
2010	7,300	AFDB (Maina, 2010)	Lower Omo
2011	175,000 (3)	Sugar Corporation (Kuraz)	Kuraz Scheme - Lower Omo
2011	445,501	Oakland Institute	All Schemes – Lower Omo
2012	208,655 (4) 31,780 (2)	Medium / Large - Table 9 Small-scale - Table 7	Omo-Gibe Basin

Notes on table:

1. *Terms of Reference for Omo-Gibe Basin Master Plan total basin potential.*
2. *OBMP = Omo-Gibe Basin Master Plan (Woodroofe et al, 1996).*
3. *Reported by Bloomberg (data collected by W.Davison from the Sugar Corporation).*
4. *This study.*

The Ethiopian Government's announcement in early 2011 of large-scale commercial irrigation development in the Lower Omo increased the potential for water abstraction from the Omo by a large margin, as this included large excisions from former protected areas (WPAs).

In addition, Kenya has recently announced plans for an irrigation development on the NW shores of Lake Turkana at Todenyang (Daily Nation, August 2012), although the water source has not been identified. The various other potential crop water usages have been estimated by this study and have been included in the table.

4.2 WAPCOS, 1990

A desk study identified 445,320 hectares of prospective irrigation area within the Omo-Gibe River Basin (WAPCOS, 1990).

4.3 FAO assessment, 1997

FAO presented the following assessments in the Omo-Gibe Basin area within Ethiopia:

1. Catchment area in Ethiopia 76,545 km^2 (FAO, 1997).
2. Omo-Gibe annual runoff 16.1 km^3/yr (ibid).
3. Omo-Gibe Basin irrigation potential area 445,300 hectares (ibid).
4. Gross water requirement 4.01 km^3/yr (ibid).

The above irrigation potential required 25% of the Omo-Gibe Basin's annual runoff (ibid).

FAO further stated: "…While the total water requirement is only one-fourth the annual runoff, the development of the irrigation potential would require important storage works…" (ibid). The unit irrigation rate was however very low considering that the bulk of the irrigation would be in the very dry Lower Omo. Hence the FAO estimated gross water requirement was too low for the envisaged 445,300 hectares.

The lake that is created by Gibe III dam fulfils the storage requirement, and will be further enhanced by Gibe IV's storage.

4.4 World Bank Concept Paper, 2004

The World Bank Concept Paper stated: "…The Omo Basin in the southwest produces an annual flow of some 17 BCM with considerable potential, estimated at 348,000 hectares…" (World Bank, 2004).

4.5 IWMI report, 2007

This IWMI document summarises data on water resources and irrigation development in Ethiopia.

Turkana is listed within the IWMI report's tabulation of "lakes and reservoirs in Ethiopia", but with no basic hydrological data (the IWMI report's Table 3).

IWMI presented the following data on the Omo-Gibe Basin:

- Catchment area 79,000 km^2 (IWMI, 2007, Table 2).
- Runoff 16.6 km^3/yr (ibid).
- Potential irrigable land 67,928 hectares (ibid).

The potential irrigable land is based on Ministry of Water Resources data and "this figure could be much higher given the vast land area of lower Omo" (IWMI).

4.6 MoWR data, 2009

In 2007, the Irrigation and Drainage Development Studies Department of Ethiopia's Ministry of Water Resources (MoWR) assessed the "irrigation potential" of the Omo Gibe Basin as 70,275 hectares (MoWR, 2007).

In 2009, AFDB reported "recent" communication between AFDB and MWR (Ministry of Water Resources) giving the irrigation area to be in the region of 100,000 hectares (Pers.Comm, AFDB / MWR, 2009 – reported within Avery, 2010).

The MoWR data did not foresee the 175,000 hectares Kuraz sugar development announced in 2011.

4.7 CESI SpA & Mid-Day International report, 2009

In their Gibe III study, CESI Spa & Mid-Day (CESI, 2009) presented the irrigation area information in Table 2 derived from "respective Wereda Agricultural and Rural Development Offices". The small-scale scheme data bears little correlation with the Omo-Gibe Master Plan. The large-scale potential is 70% of the actual figure known today. The "existing" figures compare poorly with other data presented later in Section 4.14 on p56.

Table 2: Irrigation schemes in the Omo Basin (after CESI SpA & Mid-Day)

Small-scale Irrigation Schemes		Large-scale Irrigation Schemes	
Existing hectares	Potential hectares	Existing hectares	Potential hectares
667	10,100	-	142,900

Source: CESI SpA & Mid-day Int., Table 5.47, Report 300 ENV R CS 002C, 2009.

4.8 AFDB reports, 2009 - 2010

At the start of the AFDB studies in 2009, there was no new information on large-scale agricultural development / irrigation. Data from MoWR provided an expectation of 100,000 hectares, which was similar to data presented by Sogreah in 2010 (see Avery, 2010, Section 1.5), but this figure is much less than the Lower Omo's publicised agricultural development area today.

A parallel AFDB irrigation study by Maina commissioned in 2010 (Maina, 2010) assessed the water demand from 7,300 hectares only. This figure did not reflect the correct situation in the entire basin, nor did it tally with the Master Plan expectations (Avery, 2010).

The final AFDB hydrological report (Avery, 2010) included a table of water demand forecasts extracted from the Omo-Gibe Integrated Basin Master Plan (reproduced in Table 6, p54). The bulk of the projected basin water demand was for irrigation, the equivalent approximate areas

being 2009:75,000 hectares, 2024:106,400 hectares. The Master Plan did not anticipate that areas of national parks would be excised and developed for agriculture. The Master Plan studies were based on irrigation development taking place south of the Omo and Mago National Parks only. Hence the Master Plan under-estimated areas compared to what has since transpired.

4.9 Sogreah report, 2010

Consultants Sogreah assessed the existing population dependance on the waters of the Omo River in the South Omo – see Table 3 below. Sogreah used satellite imagery to assess the area of flood recession agriculture, and the Sogreah estimates are the bracketed numbers in the following table's Col.4. Sogreah estimated that 82,000 people depend directly on the river (47% of the area's population) – discussed in Section 3.9 on p35.

Table 3: South Omo population affected by Gibe III

Wereda Col.1	Affected No. Kebeles / Total No. Col.2	Total Population Col.3	Population Engaged in flood Recession Agriculture Col.4	Population Engaged in Grazing Land Flooded by Omo River Col.5	Population Percentage Dependant on Omo River Col.6
Hamer	9 / 20	61,349 [1] (43,505) [2]	13,000 [1] (< 200 ha) [3]	-	45%
Dasenech	11 /20	54,610 [1] (46,479) [2]	15,557 [1] (4,000 – 5,000 ha) [3]	-	54%
Nyangatom	3 / 35	28,695 [1] (22,117) [2]	1,793 [1] (<300 ha) [3]	-	3%
Selamago	40 / 42	28,888 [2] (19,332) [2]	35,929 [1] (< 200 ha) [3]	15,159	94%
Total	63 / 107	173,542 (131,433)	66,279 [1]	15,159	47%

Notes on Table:
1: Sogreah, 2010 (p.34 of Sogreah's report).
2: Agriconsulting et al, 2005 data (p.75, Table 3.15).
3: Flood recession areas estimated from satellite imagery (p.37 of Sogreah's report)

Sogreah looked into potential irrigation areas downstream of Gibe III in the Lower Omo. Sogreah concluded after review, that with "remedial measures": 5,000 hectares out of 99,716 hectares is "highly suitable", 60,000 hectares is "moderately suitable", and 14,000 hectares is "marginally suitable".

Sogreah's total 99,716 hectares is similar to the MWR figure of 100,000 hectares.

The Sogreah revised total "suitable" area was therefore 79,000 hectares (Sogreah, 2010). The Sogreah assessment falls far short of what is actually happening, and did not include the areas being excised from wildlife protections areas (WPAs) at that time.

Sogreah estimated about 100,000 hectares of "pastures" in the four listed Woredas in Lower Omo. They estimated that 16,000 people benefit from grazing lands flooded by the Omo River.

4.10 2011: The Oakland Institute report

The "land investment deals" reported in Table 4 below by the Oakland Institute were a revelation when compared to recent expectations of irrigation development in the Omo Basin. The Oakland Institute drew attention to the large national park excisions for sugar plantation reported by the Ethiopian Wildlife Conservation Agency in 2011 (EWCA, 2011). A very much larger area of land under irrigation was now in prospect, as excision from wildlife protection areas (WPAs) for commercial agriculture was not anticipated by any of the earlier studies, nor was such excision planned within the Basin Master Plan, for obvious reasons.

The Oakland Institute's figures are far higher than the potential suitable area established by the Master Plan and the recent Sogreah studies. Some inaccuracies in the Oakland Institute's data have since been reported, notably that the 245,000 hectares for sugar were corrected by the Ethiopia Sugar Development Corporation to be a maximum 175,000 hectares.

Flintan presented data obtained from the Embassy of Ethiopia in Stockholm reproduced in Table 5 overleaf, dated 2010 (see also map showing areas in Figure 11). The total area in Table 5 is numerically comparable to the Oakland Institute's data in Table 4, as it does not include the excised areas from the Omo and Mago National Parks, and Tama Wildlife Reserve. Although the land was "available for investment', as stated above, the suitability for irrigable agriculture is not clear from these figures, plus some of the land has since been allocated, for instance South of Omo NP there is overlap with land since allocated to Kuraz Sugar Block III in Figure 10.

Table 4: Land investment deals in South Omo

Table 1: Details of land investment deals in South Omo			
Name	**Size (ha)**	**Purpose**	**Investor**
Block 1	82,600	sugar	State-owned
Block 2	81,250	sugar	State-owned
Block 3	81,300	sugar	State-owned
Daniel Fasil Bihon*	5,000	cotton and grains	Diaspora
Lucci*	4,003	cotton	Ethiopian
Mela*	5,000	cotton	Ethiopian
Whitefield Cotton Farm*	10,000	cotton	Indian
Reta*	2,137	cotton and grains	Diaspora
Rahwa*	3,000	cotton and grains	Ethiopian
Tsegaye Demose Ag Development*	1,000	cotton, sesame and soybean	Diaspora
Tamil Hadgu*	5,000	cotton, seeds	Diaspora
Adama*	18,516	cotton	Diaspora
Other agricultural investments	57,695	NA	NA
Land available from Fed land bank	*89,000*		
Total agricultural investment lands	**445,501**		
* contracts available at http://media.oaklandinstitute.org/land-deals-africa/ethiopia			

Source of table: The Oakland Institute (Oakland, 2011).

Table 5: Agricultural investment areas delineated in South Omo *(after Flintan)*

District	Hectares delineated for investment	Location
Dasanech	76,409	West of Omo - Figure 11 (blue shaded SW corner)
Nyangatom	71,473	South of Omo NP - Figure 12
Hamer	16,292	South of Mago NP – see Figure 11, also Figure 10
South Ari	16,451	North of Jinka (blue shaded in Figure 10)
Total	180,625	

Source: Table from Flintan (2011) – Source: Embassy of Ethiopia, Stockholm, 2010.
For map of the tabulated areas – see Figure 11 *on p60.*
Note: Nyangatom area S of Omo NP overlaps with Kuraz Sugar Block III in Figure 10 *on p59.*

4.11 2012: Todenyang Irrigation Project & Kenya's plans for irrigation

In August 2012, the Kenya Government announced its "20 billion shilling irrigation project at Todenyang". Kenya's *Daily Nation* newspaper reported as follows (*Relief Web* dated 25 August 2012):

- "…Prime Minister Raila Odinga has launched a Todenyang Irrigation Scheme in Turkana County, a project designed to promote irrigated agriculture integrated with livestock, fisheries, aquaculture and ecotourism in the region.
- The success of the Kshs 20 billion project covering 10,000 hectares of Turkana dryland is expected to improve food security and nutrition of the local population.
- The Israeli Ambassador to Kenya, His Excellency Gil Haskel and other officials from the Embassy accompanied the Prime Minister to witness the progress of the initiative…"

The project is "designed to promote irrigated agriculture integrated with livestock, fisheries, aquaculture and ecotourism in the region" (ibid).

The source of water for the project has not been mentioned.

The options for obtaining the fresh water needed for irrigation include the Omo River (abstracted upstream of the zone of the saline influence of the lake water), rainwater harvesting, groundwater, and desalination of lake water. There are possibilities of co-operation with Ethiopia, as linking with the canals planned in the Lower Omo is a possibility that might be investigated. The proposed main irrigation water conveyance canals are marked on Figure 10 on p59, and these canals are shown reaching the lake.

The remote location of Todenyang will limit the marketing of agricultural produce to outlets beyond the area. However, the project should improve associated infrastructure, which is to be welcomed. Poor road infrastructure in particular has generally hindered development of this area.

Strengthening the irrigation sector in Kenya is "a key in the national policy (Vision 2030)" to "increase domestic production", to "increase export" and "to decrease import or relief supply" (JICA, 2012).

In 2011, the entire irrigated area in Kenya amounted to 165,800 hectares (ibid). This area for the entire country equates roughly to the size of the Kuraz irrigation project alone on the Lower Omo.

4.12 Omo-Gibe Basin Master Plan's Terms of Reference dated 1992

The Terms of Reference for the 1996 Omo-Gibe Basin Integrated Development Master Plan Study (the Master Plan) referred to "estimated 250,000 hectares identified as having potential for irrigation development" (MoWR 1992, ToR Item 3.3.3).

The Master Plan adopted the "Ethiopian criteria" to classify irrigation schemes according to area cultivated, as follows (Woodroofe et al, 1996):

- Small scale: < 200 hectares.
- Medium-scale: 200 to 3,000 hectares.
- Large-scale: > 3,000 hectares.

4.13 Water demand from irrigation in the Omo-Gibe Basin Master Plan

The water demand projections of the 1996 Omo-Gibe Basin Master Plan are summarised in Table 6 (after Woodroofe et al, 1996).

The Master Plan forecast utilising 32% of the Omo River's discharge into Lake Turkana to meet the total Omo Basin water demand in the year 2024, with irrigation abstraction comprising 94% of the total water demand. Note that the Master Plan adopted an irrigation efficiency 45%, which is very low for commercial agriculture by today's standards; hence the forecast water usage might at first sight appear to be too high. On closer inspection, the Master Plan assumed a potential evapotranspiration rate of only 1,551 mm/yr in its Lower Omo Irrigation Projects Pre-feasibility Study report, which is much too low. A value of 2,300 mm/yr is more likely, as proposed by Sogreah (Sogreah, 2010), and as also derived by this study using the FAO's "Cropwat" software. Hence the Master Plan's low irrigation efficiency assumption is to an extent offset by the unrealistically low evapotranspiration rate. For more discussion on this, see Section 10.4, p116 later in this report.

Table 6: Water demand in the Omo Basin

Year	Domestic Water Demand MCM / yr	Commercial & Industrial Water Demand MCM / yr	Livestock Water Demand MCM / yr	Small Scale Irrigation Water Demand (1) MCM / yr	Medium & Large Scale Irrigation (2) MCM / yr	Total Water Demand MCM / yr
1976	71.3	4.1	28	419	60	580
2009	113.0	8.7	29	1,509	1,914	3,573
2024	258.3	23.9	28	1,509 (3)	3,523 (4)	5,341 (5)

Source: Woodroofe et al, Vol. XI, F1, 1996. Table Source: Avery, 2010 (AFDB Study).

MCM / yr = million cubic metres per year = $m^3 x\ 10^6$ / yr.

(1) Small-scale irrigation rate: 1.5 L/s/ha – see Section 4.14 on p56 (@ Efficiency 45%).

(2) Medium and Large-scale irrigation rate: 1.5 L/s/ha – see Section 4.15 on p57).

(3) 2024 Small-scale irrigation area = 31,782 hectares (see Table 7 *on p56).*

(4) 2024 Medium & Large-scale irrigation area = 74,300 hectares (see Table 8 *on p58).*

(5) 2024 Total Water Demand = 32% of Omo River annual inflow to Lake Turkana.

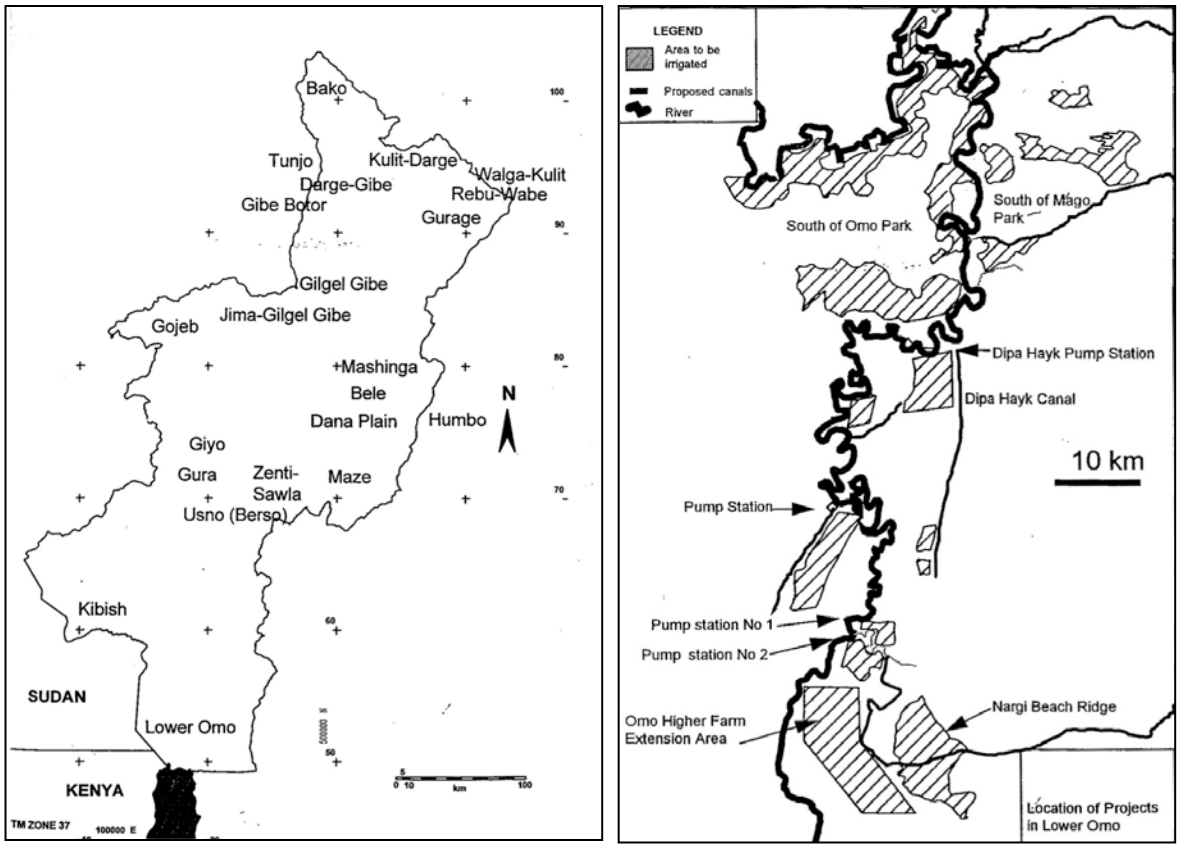


Figure 8: Potential irrigation areas studied by the Omo-Gibe Basin Master Plan

Graph on LHS. Source: Woodroofe, Vol. XI, F2, Figure A1, p41.

Figure 9: Lower Omo Irrigation Project as envisaged in 1996

Graph on RHS. Source: Woodroofe, Vol. XI, F2, p37 and p52.

4.14 Small-scale irrigation in the Omo Basin

Table 7 below conveniently summarises the Master Plan's assessment of "existing", "potential", and "combined" (existing + potential) areas, for small-scale irrigation throughout the Omo Basin. The combined total small-scale irrigation 31,782 hectares area is slightly less than 50% of the estimated 74,300 hectares "medium / large-scale" irrigation potential (see later in Table 8 on p58.

The Master Plan dealt with small-scale irrigation separately, but unfortunately this study did not have access to the Master Plan volume dealing with this aspect. It is stated in the water demand volume of the Master Plan that 1.5 L/sec/ha was adopted as the applicable unit water demand for all irrigation including small-scale irrigation. This figure is gross, inclusive of losses assumed by the Master Plan (overall irrigation scheme efficiency 45% referred to in parts of the Master Plan).

Hence in terms of water demand, the "small-scale" component is significant and it should not be overlooked, although the Master Plan assumed that the potential would be achieved by the Year 2009. The "potential" area was 3-times "existing" (Year 1994). The water demand based on the Master Plan assumptions would be 48 m^3/sec (31,782 ha x 1.5 L/s/ha). This has a significant effect when it is considered that the Omo low flows at Omorate can fall below 100 m^3/s for significant time periods (see the Omo River flow duration curve in Figure 94 on p219).

This study attempted to verify the hectarage under small-scale irrigation. Flintan stated: "In South Omo by 2000 it was calculated that 58,103 hectares were under crop production… (small-scale agriculture and settlement)" (Flintan, 2011, p35). This figure is for South Omo only, and is consistent with the entire basin small scale irrigated area forecast in the Master Plan, and is also consistent with the recession agriculture areas presented by Sogreah for Lower Omo – see Table 3 on p51. It would be useful to verify the small-scale irrigation area today in the entire basin, for the purpose of assessing water demand and impacts on available water downstream.

Table 7: Omo Basin Master Plan "Small-scale Irrigation" estimates

Wereda	Irrigable Area		
	Existing (ha)	Potential (ha)	Total (ha)
Ameya	500	2000	2500
Bako Tibe	200	74	274
Bako Gazer	0	5000	5000
Bena Kule	2350	0	2350
Boloso	0	150	150
Cheliya	0	48	48
Dedo	0	370	370
Dano	6	200	206
Daramalo	2500	0	2500
Ezana Welene	4	0	4
Gera	0	6000	6000
Goba Seyo	0	135	135
Gofa Zuria	0	90	90
Goma	0	53	53
Gudeya Bila	10	0	10
Hamer	250	40	290
Humbo	100	0	100
Sub totals	5820	14160	19980

Wereda	Irrigable Area		
	Existing (ha)	Potential (ha)	Total (ha)
Kersa	10	0	10
Konteb	0	400	400
Limu Kosa	6	0	6
Mursi Bodi	1100	0	1100
Nono	74	3000	3074
Omo Sheleko	100	300	400
Omo Nada	41	131	172
Seka Chekorsa	60	100	160
Sekoru	0	500	500
Sike	0	400	400
Sodo Zuria	0	240	240
Soro	0	1300	1300
Telo	0	100	100
Tiro Afeta	0	120	120
Wenchi	440	280	720
Weliso	1100	2000	3100
Sub totals	2931	8871	11802
TOTALS	8751	23031	31782

Source of table: Omo-Gibe Master Plan, Vol. XI, F1, p60, Table 3.5 (Woodroofe et al, 1996).

4.15 "Medium-scale" and "Large-scale" irrigation areas in the Omo Basin

The Omo-Gibe Master Plan study's "reconnaissance phase" investigated a potential 265,000 hectares, distributed throughout the Basin as shown in Figure 8 on p55. Following further study, the schemes listed in Table 8 below were selected by the Master Plan as "potentially suitable for irrigation", with the potential area having been narrowed down from 265,000 hectares to 74,300 hectares, which following soil survey was then reduced further to only 54,670 hectares. This did not include any potential within the "protected areas" (WPAs - national parks and wildlife reserves).

Hence, since the bulk of the "medium" and "large-scale" potential water demand was envisaged in the Lower Omo, and since the development has not been implemented, this demand is entirely "additional" insofar as the Omo flow regime into Lake Turkana is concerned. It is worth repeating that the Master Plan determined that 94% of the basin water demand would be from irrigation, and that the bulk of this was foreseen in the Lower Omo.

"Small-scale" irrigation was separately studied (Section 4.14 above on p56), and is not insignificant.

In 2011, 135,285 hectares were reported excised from the Omo National Park, Mago National Park, and the Tama Wildlife Reserve, for sugar plantation – see Section 3.10 on p37 above (EWCA, 2011). For the purpose of this report, it is assumed that this land has been established as "suitable for irrigated agriculture". The areas excised, and the extent of the proposed commercial agricultural developments, are all conveniently shown on Figure 10 on p59, along with the proposed irrigation conveyance canals leading to the lake (shown as dashed blue lines).

In 2012, the Kenya Government announced 10,000 hectares of irrigation development near the NW shore of Lake Turkana, at Todenyang (reported earlier). The water source and water demand was not reported, but the Omo River is a possible source.

An "evolution" of potential irrigation areas is tabulated in Table 9 below on p58. This table is based on areas for which the agricultural soil potential had been established through the Omo-Gibe Integrated Basin Master Plan, with the addition of the very recent substantial sugar development areas. The Kuraz plantation potential totals 161,285 hectares, which is close to the reported 150,000 hectares (also reported possibly extending to 175,000 hectares). The total basin potential (including 10,000 hectares at Todenyang) amounts to 208,655 hectares, which is very much less than the 450,000 hectares "investment area" reported recently by Human Rights Watch (Human Rights Watch, 2012). A distinction needs to be made between irrigated agriculture, and land used for other non-water consumptive agricultural purposes.

Table 8: Omo-Gibe Master Plan "Medium" and "Large-Scale" irrigation areas

Location	Area (hectares)
Bako-Gibe	400
Kulit-Darge	1,600
Walga-Kulit	5,300
Lower Omo	67,000 (1)
TOTAL	74,300

Note (1): Spread through 6 schemes, area later reduced to 54,570 ha – see Table 9 *below.*
Source of irrigation areas: Woodroofe et al, Vol. XI, F2, p53, 1996.

Table 9: Omo-Gibe Basin potential "Medium" and "Large-Scale" irrigation areas

Name of Farm Area (5)	Existing Irrigated Area (Ethio-Korea) (3)	Potential Before Soil Survey (M.Plan)	Potential After Soil Survey (M.Plan)	Excised Area (2) (EWCA)	Kuraz Sugar Potential (4) (ESDC)	2012 Potential Irrigable Area (5)
	ha	ha	ha	ha	ha	ha
Upper Omo (M.Plan) (1)						
Bako-Gibe	-	-	400	-	-	400
Kulit-Darge	-	-	1,600	-	-	1,600
Walga-Kulit	-	-	5,300	-	-	5,300
Lower Omo Excision						
Omo NP / Tama Excision (2)	-	-	-	135,285	135,285	135,285
Lower Omo (M.Plan)						
Omo Higher Farm	-	10,000	8,700	-	-	8,700
Dip'a Hayk	-	5,000	5,880	-	-	5,880
Omo Rate E (Ethio-Korean) (3)	1,400	-	-	-	-	1,400
Omo Rate West	-	10,000	4,020	-	-	4,020
South of Mago	-	8,000	8,000	-	-	8,000
South of Omo NP (Kuraz)	-	26,000	26,000	-	26,000	26,000
Nargi Ridge	-	8,000	2,070	-	-	2,070
Kenya Basin	-	-	-	-	-	-
Todenyang	-	-	-	-	-	10,000
Total	1,400	67,000	54,670	135,285	161,285	208,655

Note (1): Woodroofe et al, Vol. XI, F2, p53, 1996 – see Table 8 *above.*
Note (2): EWCA (2011) – see Section 3.10 on p58.
Note (3): Woodroofe et al (Ethio-Korean Scheme reported "abandoned" in 1991).
Note (4): ESDC = Ethiopia Sugar Development Corporation.
Note (5): Location of Schemes: See Figure 9 *on p55, and* Figure 10 *on p59.*

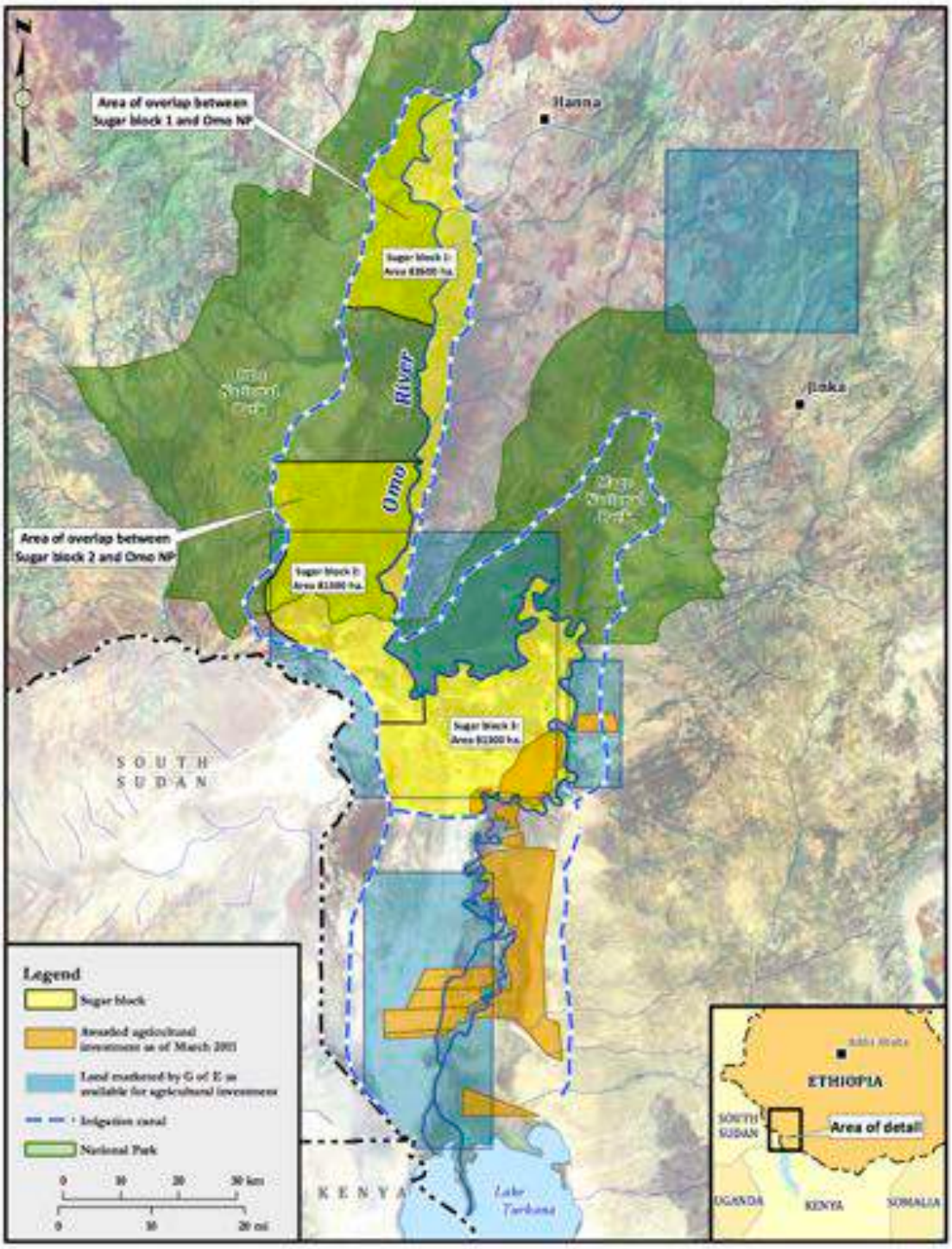


Figure 10: Lower Omo planned agricultural development, 2012

Source: Human Rights Watch (Human Rights Watch, 2012).

Figure 11: South Omo agricultural investment areas, 2010

Source: Flintan, 2011 (sourced from Ethiopian Embassy, Stockholm).

4.16 Potential irrigation water demand in the Omo Basin

4.16.1 Crop water requirements in the Lower Omo

The potential areas suitable for irrigation are tabulated above in Table 9 (p58). In the absence of published feasibility studies, crop water requirements and water demands are estimated below.

The Omo-Gibe Basin Master Plan derived average crop water application rates based on an assumed mixed cropping pattern of maize, sesame, cotton, groundnut, and banana (Woodroofe et al, Vol. V, p11), as follows (ibid):

- ET = 1,551 mm/yr, 65% Effective Rainfall, 145% cropping intensity: Crop water need = 0.237 L/s/ha average over 12 months (Gross 0.527 L/s/ha at the pump assuming 45% losses).
- Ethio-Korean JV Project: 1.15 L/s/ha effective 24-hour gross pump rate.

By way of comparison, other studies are reviewed here:

- Maina (AFDB study) adopted 2 L/s/ha. This is a "gross" water requirement (Maina, 2010) (6,307 mm/yr).
- Sogreah analysed four potential cropping patterns, of differing cropping intensity and pattern, with average net water application rates over 12 months as listed below (predominant crops being sorghum and maize, with some beans, vegetables, tomato and banana):
  - Pattern 1 (100% cropping intensity): Crop water need = 0.24 L/s/ha
  - Pattern 2 (100% cropping intensity): Crop water need = 0.31 L/s/ha
  - Pattern 3 (120% cropping intensity): Crop water need = 0.35 L/s/ha
  - Pattern 4 (150% cropping intensity): Crop water need = 0.43 L/s/ha

  Gross irrigation water requirements were calculated assuming 70% efficiency (Sogreah, 2010).
- Kenya's National Irrigation Board (NIB) studied the rehabilitation of the Hola irrigation scheme on the Tana River (NIB, 2004). Climate and river conditions are comparable. Two options of high intensity (200%) mixed cropping were investigated at Hola (Option 1: Predominant crops cotton and maize, with onion, groundnut, soya bean, green gram, and passion fruit; Option 2: Predominant crops maize and rice, with cotton, soya bean, onion, maize, groundnut, green gram). Both options were based on a 12-month cropping period and a similar average crop water requirement, as follows:
  - Option 1: 0.63 L/s/ha
  - Option 2: 0.60 L/s/ha

  Gross water requirements were then determined assuming an overall scheme efficiency 40%.
- Kenya's Development of The National Water Master Plan 2030 (NWMP 2030) includes an updated map of the entire country showing contours of the "iso-annual irrigation water requirement", for an "average year", for a "typical cropping pattern", and for "efficiency 60% (JICA / NK, April 2012). The annual irrigation water requirement for the Lake Turkana area (and extending to the Lower Omo) is the highest in Kenya, at the rate 20,000 m^3/ha/yr. This equates to 0.634 L/s/ha, virtually identical to the Hola data above. (Note that the NWMP 2030's Hola iso-annual irrigation requirement is slightly lower than in Turkana, at 15,000 m^3/ha/yr, but this is offset by the NWMP 2030's assumed higher efficiency assumption).

The above Lower Omo Irrigation Project Pre-feasibility Study net crop water need is very low when compared to the Sogreah and NIB Hola data for similar cropping intensity. The NIB Hola data compares directly with the later Kenya NWMP 2030 computations. Research by this study

into the underlying assumptions has established that the Lower Omo Pre-feasibility Study adopted evapotranspiration of 1,551 mm/yr, whereas Sogreah assumed 2,293 mm/yr. It has been shown elsewhere in this report that 1,551 mm/yr is much too low for the Lower Omo, and that the Sogreah figure is more reasonable for the locality, and that it is directly comparable with Kenyan data in northern Kenya. It has been noted elsewhere in this report that the figure 1,551 mm/yr is lower than the equivalent figure for the Gibe III catchment, which is improbable (see Section 10.4 on p116).

4.16.2 Irrigation system efficiencies

Feasibility studies for the proposed agricultural developments in the Lower Omo have not been seen by this study. Hence, the irrigation methodology to be adopted is unknown. Indicative scheme efficiencies are to be found in FAO documents included in this report below.

Irrigation water is abstracted from the river and conveyed to the scheme, either by canal or by pipeline. Pipelines are usually associated with water that is pumped, or where topography is not well suited to gravity canals. Gravity systems tend to adopt canals, and the canals can either be "earthen", where soils are impermeable, or the canals may need to be lined, where soils are permeable. The "conveyance efficiency" can vary hugely from 60 to 95% (see Table 10 overleaf on p63).

Once water reaches the crop area, either one, or a combination of one or more, of the following water application methods may be used:

- The irrigation water can be applied through simple gravity "flooding" of the crop area through furrows, with irrigation water soaking into the crop root zone. This system is more traditional.
- The water can be mechanically sprayed onto the crop as a jet or spray, using pressure fed sprinklers or centre pivot systems. This system is more sophisticated, as it requires hydromechanical systems to pressurise and convey the water. High evaporation losses can result during this application process.
- In smaller intensive cultivation systems, and where water is scarce, water can be fed direct to the root system. This system is more intricate, well suited to intensive horticulture, and nutrients are often conveniently fed to the plants through the blending of nutrients with the applied water. Drip systems require pipe networks to feed to the crop.

Table 11 overleaf presents typical "efficiency" values associated with the above methods. Surface irrigation is more traditional, hence more common, and 50% efficiency is "typical". FAO indicative values suggest that 50-60% overall efficiency is "Good".

"Scheme efficiency" is important because it determines the gross water abstraction required from the river. Scheme efficiency is dependant not only on the irrigation methodology adopted, but also on competent scheme design and construction, and finally on the efficiency of operation and maintenance. Insofar as lake Turkana is concerned, the less efficient the irrigation scheme, the more fresh water the lake will be deprived of, although some of the water "losses" will return to the river, either through percolation, or through drainage canals. However, this "recovery" portion is generally not a high proportion, and it will contain chemicals drained from the crop areas.

As an example of typically adopted design figures, the following case studies are referenced:

The Omo-Gibe Basin Master Plan adopted 45% overall efficiency for assessing irrigation water demands in the Omo Basin (Woodroofe et al, 1996). This is "reasonable" according to the FAO indicative values in Table 12 overleaf.

NIB adopted 40% overall efficiency in the design of its Hola scheme on the Tana River in Kenya (NIB, 2004). This is "reasonable" according to the FAO indicative values in Table 12 overleaf.

- Sogreah adopted 70% in their recent studies (Sogreah, 2010). This figure seems very optimistic, and does not include any conveyance losses.
- In the Development of Kenya's National Water Master Plan 2030, the JICA Study Team of Nippon Koei (NK) proposed irrigation efficiency in the range 60 - 90% (JICA / NK, August

2012). This is the same efficiency range that was adopted in Kenya's original National Water Master Plan dated 1994 – see footnote to Table 11 below (60% for surface irrigation, and 90% for drip irrigation). In its 2012 Interim Report, the JICA Study presented a map showing "iso-annual irrigation water requirement" variation throughout Kenya, based on 60% efficiency (JICA / NK, April 2012).

Table 10: FAO "Indicative values of Conveyance Efficiency for adequately maintained canals" (Ec)

	Earthen canals (Ec)			Lined Canals (Ec)
Soil Type	Sand	Loam	Clay	
Canal length				
Long (> 2,000 m)	60%	70%	80%	95%
Medium (200-2,000 m)	70%	75%	85%	95%
Short (<200 m)	80%	85%	90%	95%

Table 11: FAO "Indicative values of field irrigation Application Efficiency" (Ea)

Irrigation Methods	Field Application Efficiency (Ea) (1) (2) (3)	Typical values of Ea
Surface irrigation (border, furrow, basin)	60%	50%
Sprinkler irrigation	75%	55-75%
Drip irrigation	90%	80-90%

Note: These figures do not include conveyance losses and apply to application losses only.
Note (1): FAO figures adopted in Kenya's National Water Master Plan (MoWD, 1994).
Note (2): The Development of the NWMP 2030: Adopted 60% (JICA / NK, April 2012).
Note (3): The Development of the NWMP 2030: Adopted 60-90% (JICA / NK, August 2012).

Table 12: FAO "Scheme Irrigation Efficiency" (E) categories

Overall scheme Efficiency (E)	FAO Indicative categories
50-60%	"Good"
40%	"Reasonable"
20-30%	"Poor"

Note: Scheme Irrigation Efficiency: E=(Ec x Ea)/100

4.16.3 Gross irrigation water abstraction estimated in the Lower Omo

Table 13 overleaf on p64 tabulates the net crop water requirement from different published sources for the Lower Omo.

Also tabulated in Table 13 is the sugar plantation crop water requirement applicable to the climatological conditions in the Lower Omo. Sugar crop water consumption data was provided by the Ethiopia Sugar Development Corporation, and this was checked using FAO's 'Cropwat' software. Climatological data was abstracted from FAO's 'Climwat' database. The FAO climate data was compared with Kenyan published data, and adapted to ensure compatibility with the Lower Omo climate and rainfall. FAO's "black soil" drainage characteristics were assumed in running 'Cropwat'.

Also included in Table 13 is data for the Hola Irrigation Scheme on Kenya's Tana River. The rainfall and climate are comparable, and both schemes are on flood plain soils adjacent to a major river.

The crop water requirements in Col.4 in the table below are consistent (yellow highlight), with variations mainly related to cropping intensity (the low value in Line 1 is due to the lower PET). The higher the cropping intensity adopted, the higher will be the irrigation required.

Gross crop water requirements are tabulated in Table 13 below for overall scheme efficiency ranging from 40 to 90%. For the purposes of computing water demands in this report, the following values have been adopted:

- *Mixed Crop 4 (cotton & maize predominant) @ 60% Efficiency*: 0.712 L/s/ha (Line 5, Col.7).
- *Sugar plantation @ 60% Efficiency*: 1.115 L/s/ha (Line 8, Col.7) (FAO 'Cropwat').

Table 13: Crop water use and gross irrigation requirements in Lower Omo

	ET mm/yr Col.1	Crop Intensity % Col.2	Crop Period Col.3	Crop Water L/s/ha Col.4	Gross 90% (1) L/s/ha Col.5	Gross 70% (2) L/s/ha Col.6	Gross 60% (3) L/s/ha Col.7	Gross 45% (4) L/s/ha Col.8
1. OBMP Mixed Crop (5)	1,551	145	Year	0.237	0.263	0.338	0.394	0.526
2. OBMP Mixed Crop (6)	2,293	145	Year	0.350	0.389	0.500	0.583	0.778
3. Sogreah Mixed Crop 2 (7)	2,293	100	Year	0.308	0.342	0.440	0.513	0.684
4. Sogreah Mixed Crop 3 (8)	2,293	120	Year	0.350	0.389	0.500	0.583	0.778
5. Sogreah Mixed Crop 4 (9)	2,293	150	Year	0.427	0.474	0.610	0.712	0.949
6. Hola Mixed Crop (10)	2,385	200	Year	0.590	0.702	0.903	1.053	1.404
7. Kuraz Sugar (11)	2,293	Total	Year	0.634	0.705	0.906	1.057	1.409
8. Kuraz Sugar (12)	2,293	Total	Year	0.669	0.743	0.956	1.115	1.487

Notes on table: *OBMP = Omo-Gibe Integrated Basin Master Plan. ET = Evapotranspiration.*

Notes on modes of irrigation and efficiency:

(1) Gross water required @90% Efficiency = Drip irrigation.
(2) Gross water required @70% Efficiency = Sogreah 2010 assumption (Sprinkler is roughly 75%).
(3) Gross water required @60% Efficiency = Surface irrigation (as assumed by NWMP 2030 – JICA/NK)
(4) Gross water required @45% Efficiency = Omo-Gibe Integrated Basin Master Plan assumption.

Notes on cropping patterns:

(5) 50% cotton, 40% maize, 25% sesame, 20% groundnut, 10% banana (Woodroofe et al, 1996).

(6) As above, but crop water needs increased in the linear proportion 2293/1551 (this study).

(7) 40% maize, 30% sorghum, 15% bean, 5% vegetable, 5% tomato, 5% banana (Sogreah, 2010).

(8) 50% Maize, 30% sorghum, 15% bean, 10% vegetable, 10% tomato, 5% banana (Sogreah, 2010).

(9) 45% maize crop 1, 45% maize crop 2, 30% sorghum, 15% bean, 5% vegetable, 5% tomato, 5% banana (Sogreah, 2010).

(10) Jan-Aug: 80% cotton, 5% onion, 10% groundnut, 5% passion fruit. Aug-Dec: 70% maize, 10% soybean, 5% groundnut, 5% green gram, 5% onion (NIB, 2004).

Notes on other data sources:

(11) Ethiopia Sugar Corporation: 3 billion cubic metres annually for 150,000 ha (Christian Science Monitor, 2011).

(12) FAO 'Cropwat' & 'Climwat' (this study): Lokitaung climate assumed and adjusted for Kaalam rainfall.

4.16.4 Plantation water demands in the Lower Omo Basin

The potential irrigation water requirement from the Omo River is computed in the two tabulations below for different assumptions of efficiency. The table is split into two tabulations, the first for the Kuraz scheme alone (161,285 hectares), and the second for the remaining area that was established as suitable for irrigation (47,370 hectares).

Table 14: Omo Irrigation – Potential annual water usage

Lower Omo: Kuraz annual irrigation @ 161,285 hectares						
Percent Field Efficiency %	Irrigation Category Method	Total Net Irrigation mm/yr	Total Gross Irrigation mm/yr	Total Gross Irrigation mm/d	Gross 161,285 hectares MCM/yr	Irrigation Demand % Omo Flow
45%	Poor	2,110	4,689	1.49	7,562	43.9%
60%	Furrow	2,110	3,517	1.12	5,672	32.9%
70%	Sprinkler	2,110	3,014	0.96	4,862	28.2%
90%	Drip	2,110	2,344	0.74	3,781	22.0%

Lower Omo: Remaining "suitable" area, mixed cropping @ 47,370 hectares						
Percent Field Efficiency %	Irrigation Category Method	Total Net Irrigation mm/yr	Total Gross Irrigation mm/yr	Total Gross Irrigation mm/d	Gross 47,370 hectares MCM/yr	Irrigation Demand % Omo Flow
45%	Poor	1,347	2,992	0.95	1,418	8.2%
60%	Furrow	1,347	2,244	0.71	1,063	6.2%
70%	Sprinkler	1,347	1,924	0.61	911	5.3%
90%	Drip	1,347	1,496	0.47	709	4.1%

Lower Omo: Combined 208,655 hectares (161,285 ha sugar + 47,370 ha mixed crop)					
Percent Field Efficiency	Irrigation Category Method	Gross Irrigation Water 161,285 ha	Gross Irrigation Water 47,370 ha	Combined Irrigation Water 208,655 ha	Irrigation Demand % Omo Flow
%		m^3/s	m^3/s	m^3/s	%
45%	Poor	240	45	285	52.2%
60%	Furrow	180	34	214	39.1%
70%	Sprinkler	154	29	183	33.5%
90%	Drip	120	22	142	26.1%

The above “irrigation demand” figures do not include canal conveyance water losses. Instead, these are assumed “returnable” to the river system, although a portion will be evaporated. The “field efficiency” in the tables above includes losses associated with the irrigation application methods. In the case of sprinklers, the water is sprayed into the air, with associated airborne evaporation losses. There will be a small “returnable” component of the losses, this being drainage from the fields back into the river. This is not quantified here, though it may be about 10% on top of the 30% loss component. It is not so critical in terms of water balance, but it could be critical in terms of its potential to carry chemical pollutants back to the river or into the underlying groundwater table.

In addition, the sugar factories would require water. A sugar mill can utilise up to 2,000 litre/tonne of cane (internet data). Assuming 24,500,000 tonnes cane produced annually, 49 MCM/yr (0.049 billion m^3) of water would be needed, and 17 MCM/yr (0.017 billion m^3) could be

"returned" after milling. These figures are not significant compared to the irrigation water demand.

Based on sprinkler irrigation technology and 70% efficiency, Table 14 above shows that 161,285 hectares in the Kuraz scheme would alone require 28.2% of the Omo River average annual inflow to Lake Turkana. With poor irrigation practices, this proportion could exceed 40% of the Omo River's average annual inflow to the lake.

The balance of 47,370 hectares with "suitable" soils would require potentially a further 10% of the annual Omo inflow to Lake Turkana (depending on the cropping patterns adopted and the efficiency of irrigation). If it is attempted to irrigate a greater area than was established "suitable", the gross water taken from the river could be far more.

Hence, whereas the Master Plan envisaged 32% of the Omo inflow to Lake Turkana utilised by the Year 2024, the above irrigation schemes alone will potentially utilise up to 52% (depending on the areas irrigated and the irrigation technology adopted). At 60% irrigation efficiency, the minimum likely scenario is that 39.1% of the Omo inflow to Lake Turkana will be utilised for the Lower Omo irrigation alone.

As there is considerable uncertainty regarding agricultural development and irrigation water needs in the Omo Basin, and as the potential reduction of inflow to Lake Turkana is considerable, the full irrigation scheme feasibility studies are urgently needed, together with the associated ESIAs, all in accordance with the recommendations of the Omo-Gibe Basin Master Plan. The significant inflow reduction into Lake Turkana reported by the earlier studies is however confirmed by the above results, and is potentially far greater than previously reported.

4.16.5 Climate change impacts on plantation water demands

The increases in temperature with ongoing climate change will raise the crop water requirements. Climate change models forecast increases in rainfall in these arid zones, but rainfall is very low anyway, and the increased rainfall volume is very small. Hence the long-term irrigation water demand will likely increase, as will evaporation losses from the lake itself.

5 LAKE TURKANA

5.1 Lake Turkana

The background data published in the Consultant's report to the AFDB (Avery, 2010) is utilised in this report, and has been restructured and updated to include more recent research references.

Lake Turkana (the lake) is Kenya's largest lake, Africa's fourth largest lake, and the world's largest desert lake. It is a closed basin within the East African Rift Valley. The lake water is slightly saline, being unsuitable for domestic use, agriculture and livestock. During drought periods, or out of necessity, people and livestock drink the lake water, but the fluoride levels are dangerously high.

The lake is commonly known as the Jade Sea on account of its remarkable colour caused by algae. The lake provides habitat for thriving fisheries resources: "…Since 1961, it has been the policy of the Kenya Government to encourage pastoral nomads to take up fishing where drought and famine otherwise rendered them destitute…(Bayley, 1982)". To this day, the lake's fisheries contribute to food security in this climatically challenged area.

The lake was formerly named "Lake Rudolf" in 1888, after the Crown Prince of Austria. The name "Rudolf" was chosen by the Austrian aristocrat and explorer Count Samuel Teleki de Szek. Teleki was the first European explorer to "discover" the lake.

Rainfall is erratic and very low, this being an extremely arid region. Evaporation rates are very high, enhanced by the very fierce SE winds that are characteristic of this lake. The lakeshore is devoid of cultivation. There is cultivation in and north of the Omo delta along the Omo River, on the top of the nearby extinct volcano (Mt Kulal, south-east of the lake), within the Horr Valley to the south, and along the Turkwel and Kerio river courses that reach the south-western lakeshore.

About 90% of the lake surface water inflow derives from the Omo River in Ethiopia (Avery, 2010). Hence the lake is almost entirely dependant on this one river basin, and any developments within this basin will thus directly affect the lake.

Traditionally, people around the majority of the lake derive their livelihood through nomadic pastoralist activities, and some fishing. In the vicinity of the Omo river delta, at the northern end of the lake, people traditionally sustain themselves through agro-pastoralist activities, and some fishing. Through the development of some tourism within Kenya, and with the presence of missionaries and Government offices within small centres around the lake, alternative modern livelihoods have developed, but these are available to very few people. Development is anticipated, for instance a wind energy generating farm between the Horr Valley and the lake; oil prospecting and potential development; a powerline linking Ethiopia to southern African countries through Kenya; road, rail and oil pipeline infrastructure linking into South Sudan and Ethiopia. These present challenges and potential conflicts as high skill levels will be sought, and these will not be readily available amongst local people at present, and take time to develop.

In recent years, population dynamics have changed. Population has increased and the Turkana area is highly dependant on food aid, both sides of the international border, a situation that exacerbates problems through encouraging in-migration to take advantage of food aid. This puts added pressure on the area's scarce resources and habitat; it adds to conflicts, undermines self-sufficiency and the sustainability of traditional skills, and encourages sedentarisation. Hence the area has many challenges already, and it is important to distinguish these from the impacts arising from developments in the Omo Basin.

The Omo River discharges into the northern end of Lake Turkana. The river has formed a delta, which has expanded and encroached further south into the lake in recent years. The delta expansion is perhaps partly a consequence of increased sediment runoff and higher floods

arising from escalation of human activities in the Omo Basin, plus lake recession exposes formerly inundated areas.

The construction of dams on the Omo River will interfere with the sediment and nutrient runoff patterns. The dams will intercept bed load and suspended sediments, although this interception might be compensated by accelerated bank erosion downstream of the dams. Colloidal sediments may well remain in suspension and pass through the dams.

Since the turn of the last century, the lake level has declined to as low as 20 metres below its 1896 level, and is currently higher, but still about 17 metres below its 1896 "contemporary peak" level – see Figure 57 on p152.

The lake waters are well mixed, due to the strong prevailing SE winds, and as a consequence, the waters are well oxygenated in the upper layers, and there is limited temperature stratification.

A 3-dimensional satellite image is reproduced in Figure 12 below, thanks to the United States Department of Agriculture's Foreign Agricultural Service (USDA-FAS). The image views the lake from south to north. The relatively flat lower Omo River valley entering the lake from the north is apparent in the image, as are the greener areas of the Ethiopian highlands, and another Rift Valley lake in Ethiopia to the north-east.

The Route Map for the Lake Turkana area is reproduced in Figure 13 overleaf (Survey of Kenya, 1978). Due to the age of the map, some names have since changed. For instance, the East Rudolf National Park, formed in 1974, is today known as Sibiloi National Park. However, the routes and place names are unaltered. The lake is accessed by road on the eastern side at Loiyangalani, Allia Bay, Koobi Fora, and Ileret. The lake is accessed on the western side through Lodwar, and a track can be followed south to Eliye Springs, and north to Todenyang.

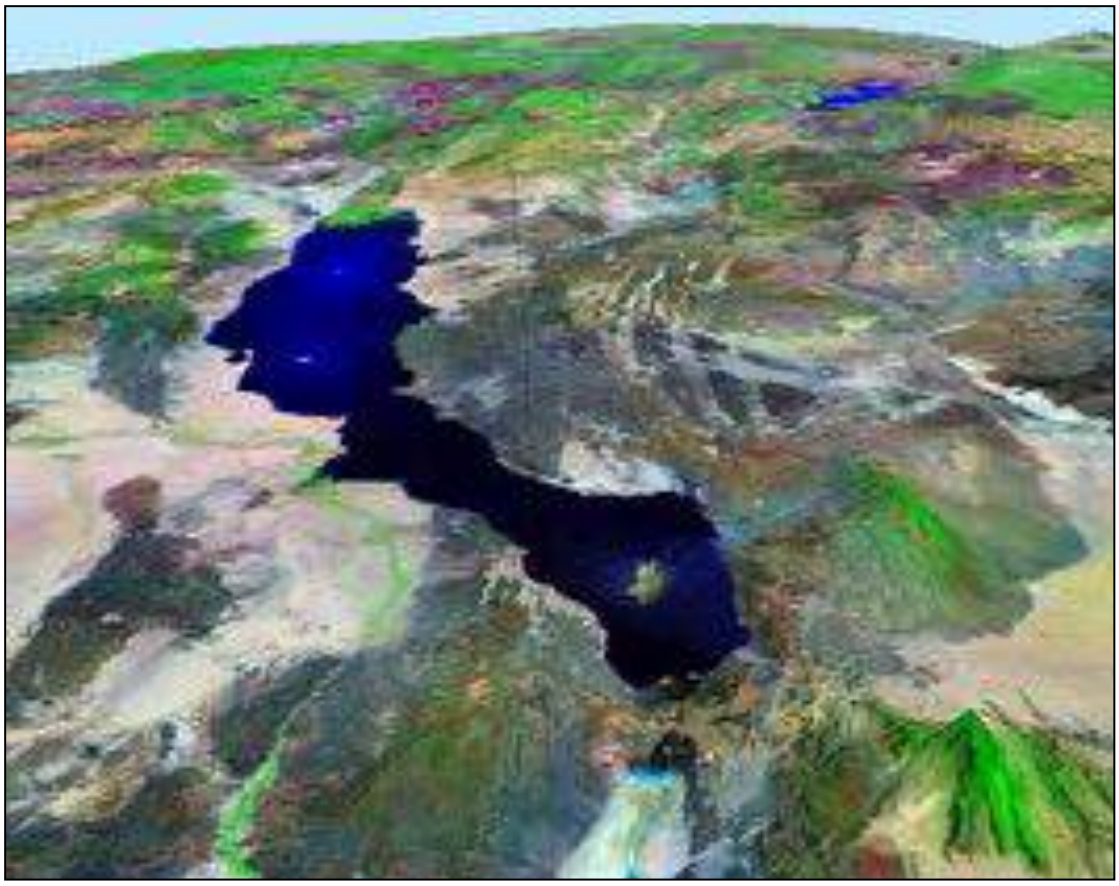


Figure 12: 3-D Satellite Image of Lake Turkana

Source of image: USDA-FAS website.

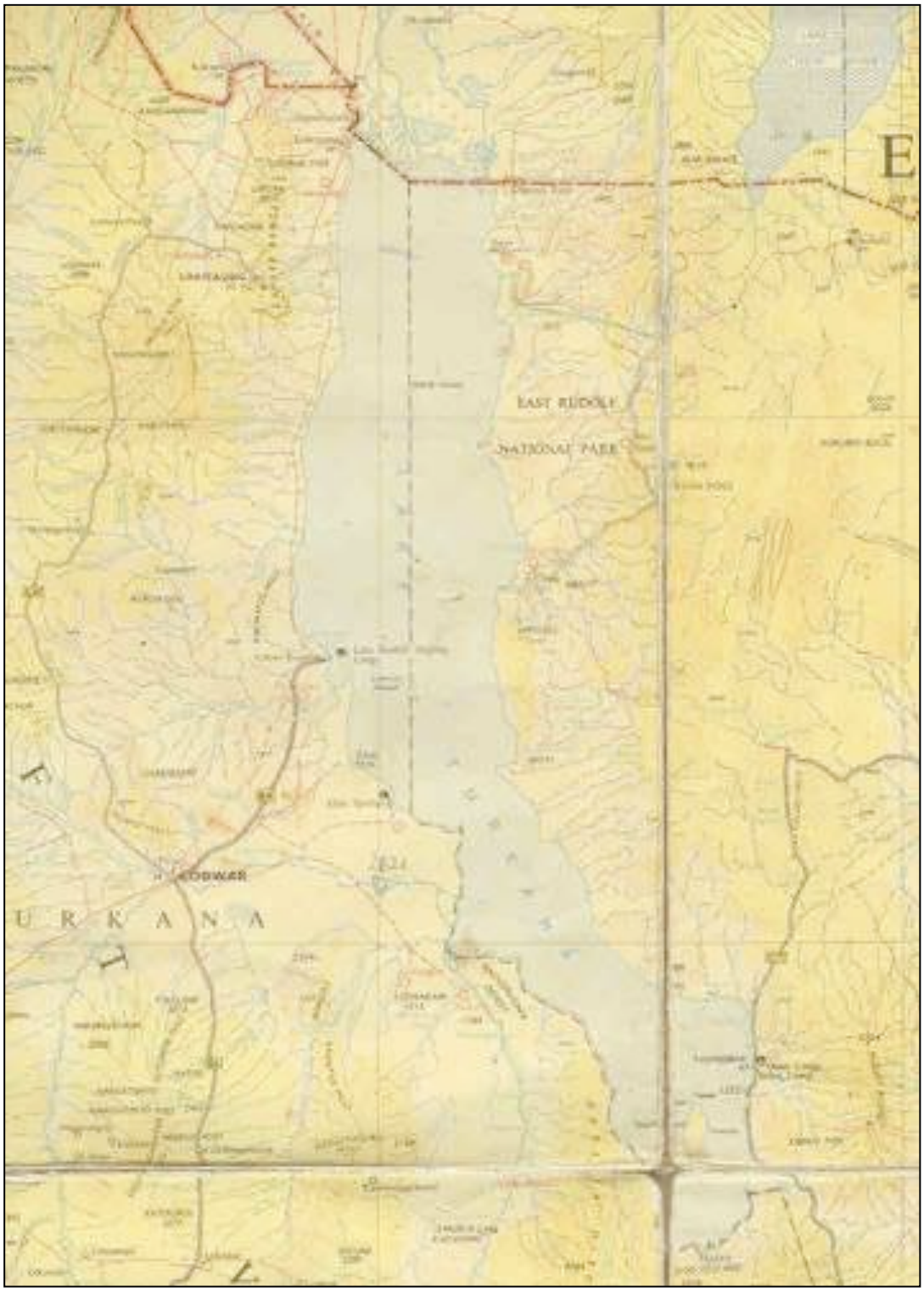


Figure 13: Lake Turkana

Source of map: Survey of Kenya 1:1,000,000 Route Map dated 1978.

5.2 Lake Turkana over millions of years and the emergence of pastoralism

The Omo delta and the lakeshore include some of the most interesting fossil beds in Africa. These can be visited at Koobi Fora in Kenya's Sibiloi National Park on the north-eastern shore of the lake.

"…Extensive palaeontological finds have been made, starting in 1972 with the discovery of *Homo habilis*. These are evidence of the existence of a relatively intelligent hominid two million years ago and reflect the change in climate from moist forest grasslands when the now petrified forests were growing to the present hot desert. The human and pre-human hominid fossils include the remains of four species, the most important being the 1999 discovery of 3.5-million year old *Kenyanthropus platyops*…" (UNEP / UNESCO / IUCN, 2005).

"…Other findings include several ancestors of modern animal species. Over 100 archaeological sites have been discovered so far…" (KWS, 1996).

Some illustrative images of the Sibiloi National Park fossil beds and a large animal fossil are included below*:*

Fossil beds at Sibiloi National Park

Fossilised skeleton at Sibiloi National Park

Petrified logs near Allia Bay

Sibiloi NP – Karsa Gate

Photo 2: Sibiloi National Park

Source of photos: Sean Avery Photo Archive.

The lake's "palaeo" history can be charted as follows (summary from Avery, 2010):

20 million years ago, the formation of the Rift Valley commenced. This was in the form of parallel faults resulting from plate movement, and was evidenced through movements in the Valley floor, and resulted in a sunken trough running through Africa - see Figure 28 on p104.

- 4.2 million years ago, the lake was in existence, and its sedimentary level history provides an interesting insight into the climate change that has occurred over this time. "…A major lacustrine (lake) phase occurred between 3.8 and 4.5 Ma with a regression around 4.0 Ma…" (Ochieng et al, 1988).
- 3.9 million years ago the Omo River flowed through the lake to the Indian Ocean, until the rifting caused further drops in the trough, leading to the lake becoming a closed basin.

Geologists recognise "three transgressive phases of the lake during the Holocene which represent high, but fluctuating water level (between 40 and 80 metres above the present lake)" *(*text reproduced above and below from Wilkinson, 1988*).* The dates given as "BP" signify the years "Before Present", and "Present" = the year 1950, being the baseline year from which the published dating was taken:

- 10,000 – 7,500 BP: The earliest and largest "transgression" occurred in the early to middle Holocene with high lake levels. The lake margins were covered by sub-desert steppe with well-developed vegetation, and a climate similar to, but more humid than prevailing today. Following this period, the lake may have fallen to contemporary levels (Butzer et al, 1971).
- 5,000 – 4,000 BP: Renewed "transgression" occurred in the middle Holocene, characterised by slightly lower lake levels fluctuating between +50 and +55 metres.
- 3,250 BP: A 3rd "transgression" occurred in the late Holocene, with high lake level +35 to +40 metres. This was believed to be the last time that the lake was connected to the Nile system (Wilkinson, 1988).

Garcin et al in 2012 reviewed the above "3rd transgression" – see Figure 14 (p72) and discussion below.

"…Lake levels during the Tertiary period were probably tectonically controlled, whereas the level fluctuations during the Holocene were climatically controlled…" (Ochieng et al, 1988).

Close faunal affinities between Lake Turkana and the Nile drainage, plus the existence of a drainage divide approximately 70 to 80 metres above 1988 lake levels, provide strong evidence of hydrographic connection (ibid). It was believed that the Lake Turkana / Nile connection was established on a number of occasions during the late Tertiary / Quaternary (Wilkinson, 1988), and that connections were almost certain to have occurred during the Holocene between 9,500 and 3,300 years BP (ibid; and Ochieng et al, 1988). The most recent link may have been 3,300 years BP, but was thought more likely to have been when the lake was higher (+80 metres), between 9,500 and 7,500 years BP (Wilkinson, 1988, citing Butzer et al 1971). A rise of 70 metres above the 1988 lake level would be required to breach the low-level divide to the west (Butzer, 1971).

The hydrographic connection of Lake Turkana with the Nile was believed to be via the Lotagipi Swamp, and the size of the lake 10,000 years ago was "Mega-Turkana" shown in Figure 16, p75, (Hopson et al, 1982). The lake surface area was 5-times what it is today, and the Omo delta was 100 kilometres to the north. A modern equivalent of the map is included in Figure 17, p76 (Garcin et al, 2012), and the Lotagipi swamp is beyond the overflow sill, and not within the lake confines.

Studies of molluscan fauna found within the lake sediments from the first of the major Holocene "transgressions" show that the lake was less alkaline and saline at that time (Wilkinson, 1988).

Garcin et al's recent research into Lake Turkana's palaeo shorelines used modern GPS equipment and modern dating methodology to re-map the lake level history since 12,000 BP, resulting in the interesting water level chart reproduced in Figure 15, p73 (Garcin et al, 2012). Garcin et al demonstrated ongoing tectonic deformation evident from distortion of the palaeo shoreline levels (ibid). Garcin's team recorded the level of the "maximum highstand shorelines" ("MHS" in Figure 17, p76). The "overflow sill" from the lake to the Nile in the Lotagipi Swamp is MHS=457 to 460 metres above sea level (masl) (SRTM data). In the northern end, the MHS=450 to 455 masl (SRTM data). On South Island, MHS=437.5 masl (SRTM data), representing a "distortion" 10-20 metres relative to the "Mega Turkana" overflow sill in Figure 16 and Figure 17. These level differences equate roughly to a tectonic deformation of 2.5 mm/yr (ibid).

The molluscan faunal evidence is to be found on some of the MHS palaeo shorelines evident throughout the lake, up to nearly 100 metres above the 2012 lake level. A good example is to be seen on South Island – see Photo 3 and Photo 4 (p74). The conspicuous eroded wave line in Photo 3 is the "Maximum Highstand Shoreline" (MHS), which was the former "overflow" level of the lake into the Nile drainage. Garcin's team undertook the dating of the fossil molluscs (such as shown in Photo 4) from which lake transgression dating was derived (Garcin et al, 2012).

Compared to earlier work, Garcin's team produced a differing interpretation of lake level decline in the last 6,000 years in Figure 14 below, with the Phase III (3rd) transgression removed (ibid) (the Butzer et al 3rd transgression is included in the graph as a dashed line).

Figure 15 overleaf shows that the lake area was "arid" the past 6,000 years, and the lake level has been speculated below 378 masl since 4,800 BP, with the lake falling potentially below today's level during this period (ibid). The 378 masl "peak" in 1896 was about 18 metres higher than the AD 2008 lake level. The "overflow sill" level is 98 metres above the AD 2008 lake level. The eroded palaeo wave line shown in Photo 3 (p74) is almost 20 metres below the present sill level due to the tectonic deformation (ibid). This study verified the height difference between the palaeo shoreline on South Island and the existing lake level, using an aneroid barometer. The image in Photo 3 offers a sobering reminder of "climate change" in the last 6,000 years.

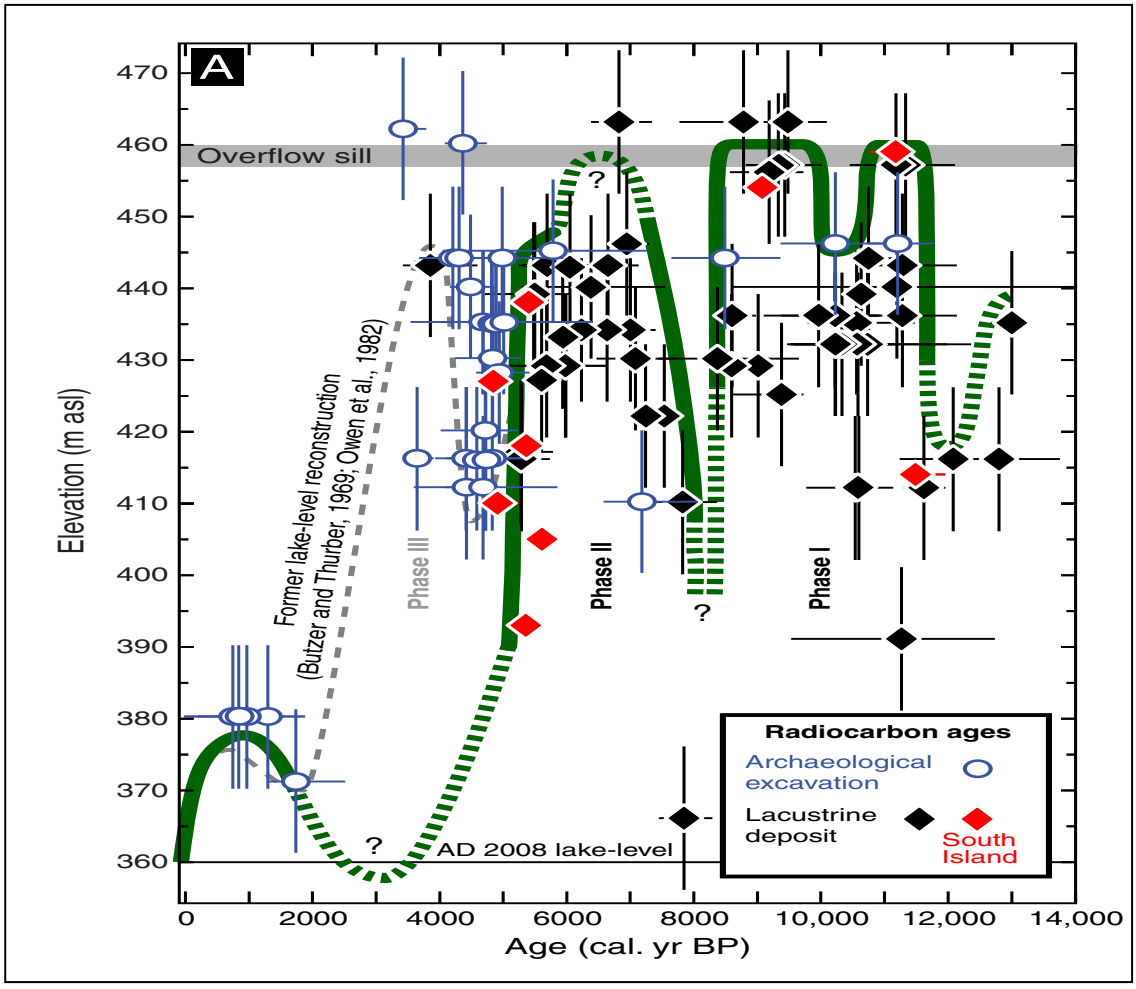


Figure 14: Lake level change comparison with the work of others

Source: Garcin Y. et al (2012). East African mid-Holocene wet-dry transition recorded in palaeo shorelines of Lake Turkana, northern Kenya Rift, Earth Planet. Sci.Lett.

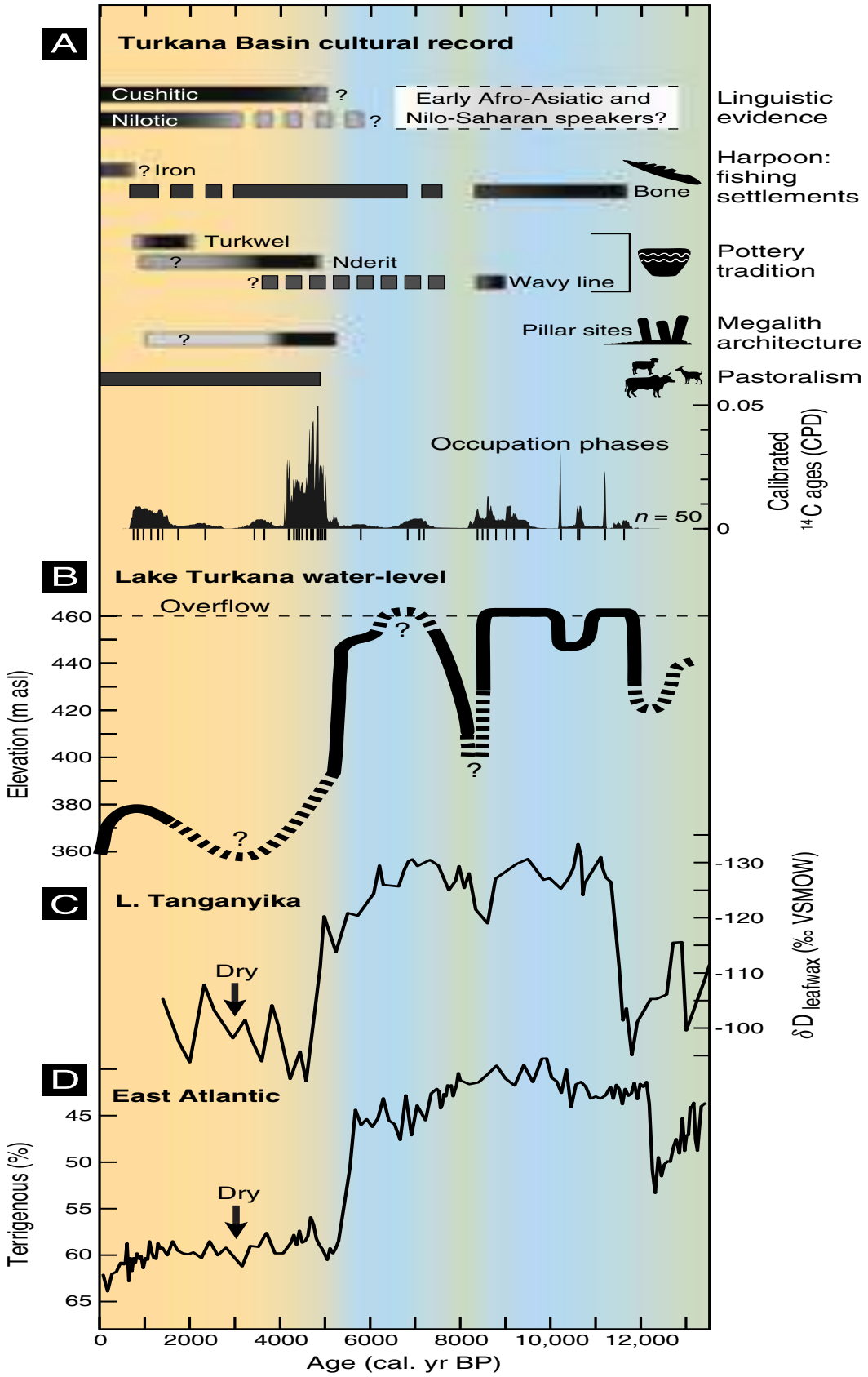


Figure 15: Lake Turkana water level since 12,000 BP *(Garcin et al)*

Source: Garcin Y. et al (2012). East African mid-Holocene wet-dry transition recorded in palaeo shorelines of Lake Turkana, northern Kenya Rift, Earth Planet. Sci.Lett.

Photo 3: Palaeo shoreline on South Island

Source of photo: Sean Avery Photo Archive (Image dated January, 2012)

Photo 4: Molluscan bed exposed on South Island's palaeo shoreline

Source of photo: Sean Avery Photo Archive.

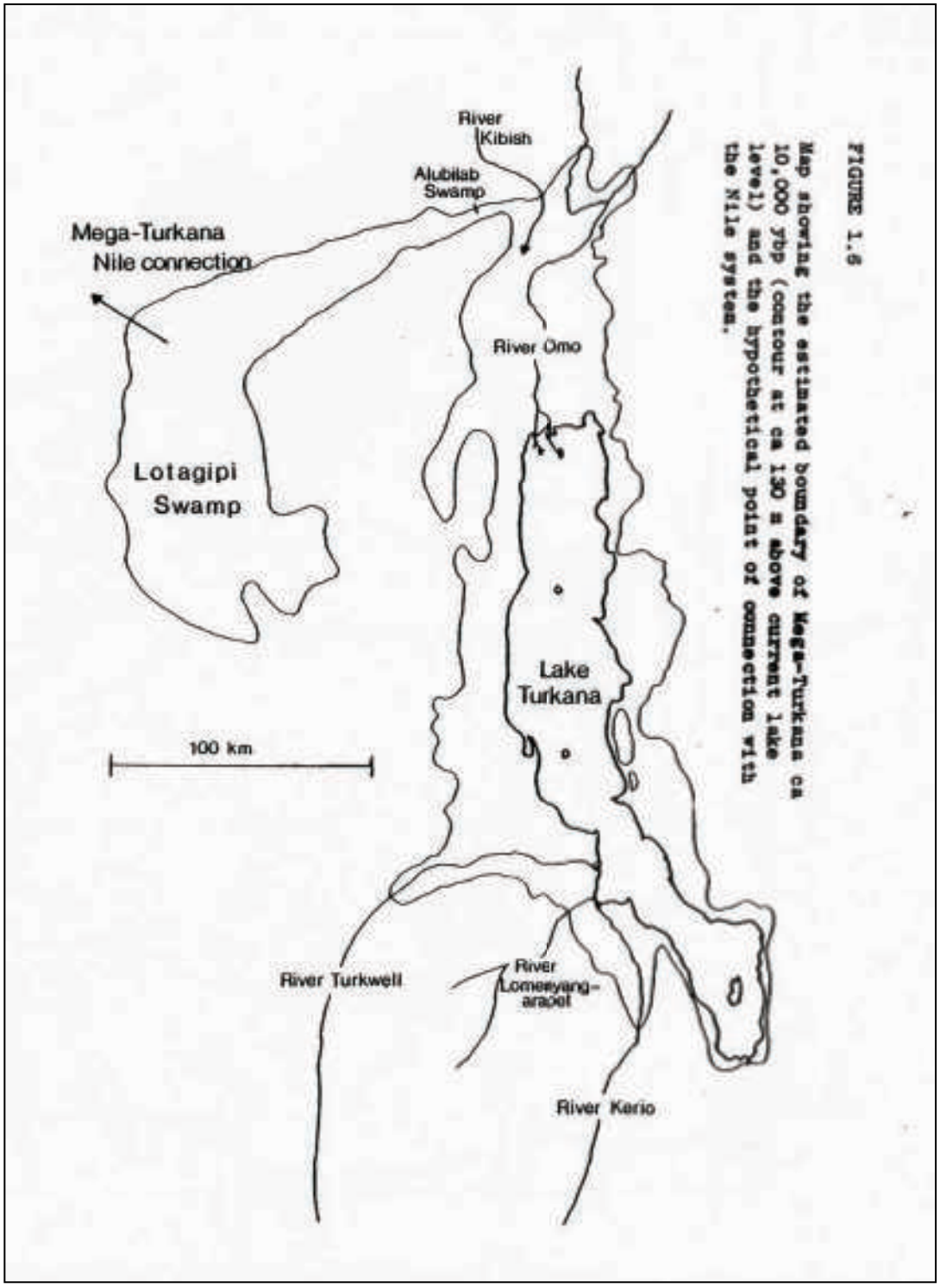


Figure 16: "Mega-Lake Turkana" compared to contemporary Lake Turkana

Source of map: Hopson et al, 1982.

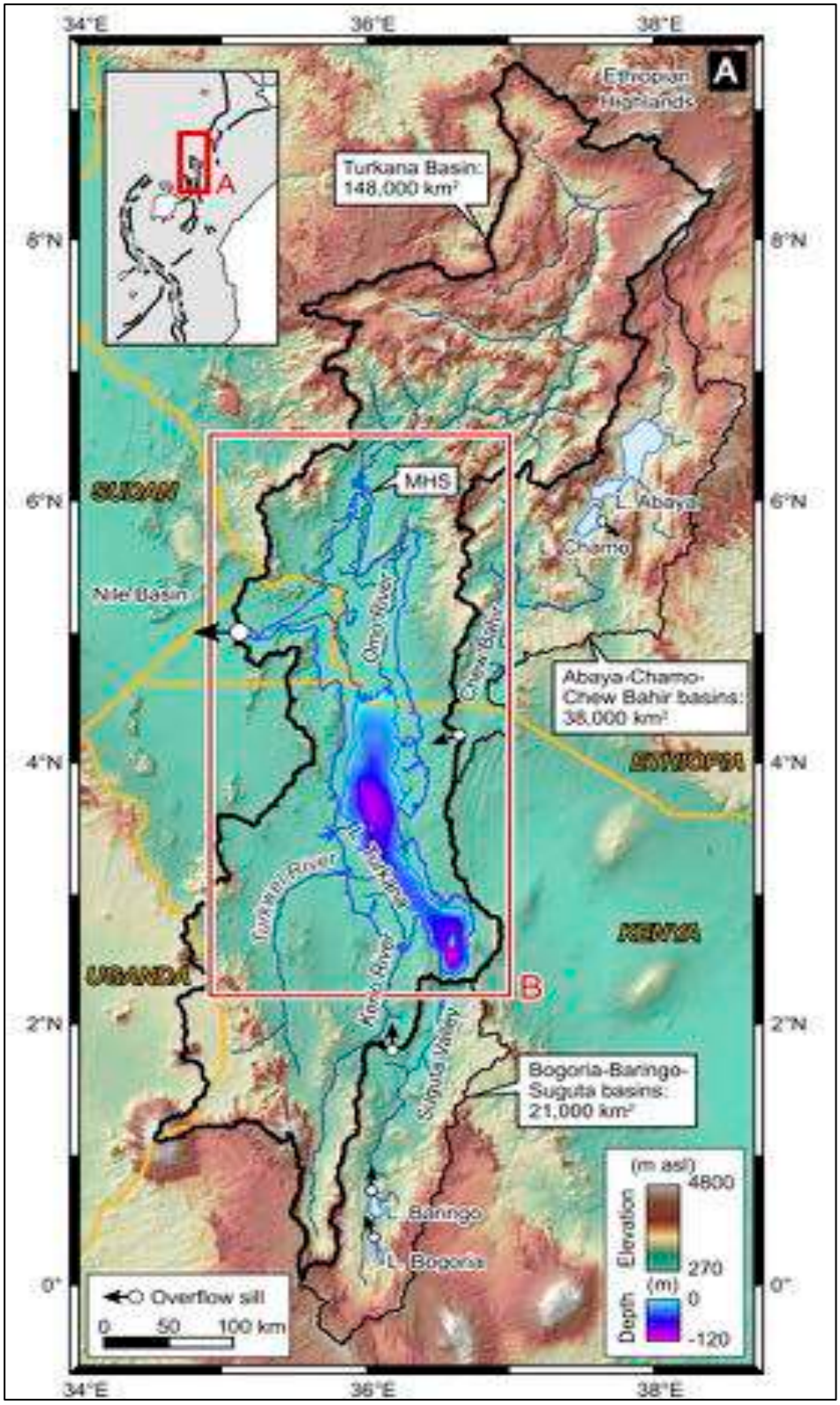


Figure 17: Lake Turkana Basin and its former adjoining basins

Source: Garcin et al (2012).
Note: MHS signifies "Maximum Highstand Shoreline".
Note that the catchment area shown above includes Sanderson's "Gulf".

5.3 The emergence of pastoralism in the last 6,000 years

Figure 15 above on p73 includes a "cultural record" of human activity (Garcin et al, 2012). "Archaeological finds indicate that at the time of the protracted lake stand (up to 6,000 years ago) this region was populated by hunter gatherers who relied mainly on fishing in their subsistence lifestyle" (Garcin et al, 2012, citing Phillipson, 1977; Robins, 1972).

Of particular interest is the consequence of the onset of aridity and falling lake level, namely the decline in hunter gathering (fishing), and the emergence of pastoralism as an effective coping response to arid climate. It is postulated that the falling lake level provided alternative opportunity, exposing fresh lands free of tsetse fly and disease (Garcin et al citing many references). Equally, this was a period of declining rainfall hence declining agricultural opportunity.

Hence pastoralism had a long and successful history coping with the aridity of the Lake Turkana area over the past 6,000 years. It is ironical that climate change and drought are so often blamed today for famine and human catastrophes in recent years. The challenges that have emerged over the past 40 years are a consequence of many factors including unsustainable population increase that was assisted by external support mechanisms (modern medicine, First World wealth and modern transportation and communication systems that enabled mobilisation of external interventions / food aid).

5.4 Lake Turkana's National Parks and protected areas

The descriptions in this section are reproduced from the Consultant's earlier report to AFDB (Avery, 2010). The lake is an area of exceptional interest and scenic beauty, duly recognised through the World Heritage status of its national parks.

Within Lake Turkana, there are three volcanic islands respectively named North, Central and South Island, the latter two of which are national parks (satellite imagery presented in Figure 72 and Figure 73, on p167).

Lake Turkana includes three National Parks and a Biosphere Reserve, whose development history is described below.

- 1973: Kenya's Sibiloi National Park was established. The Park protects 157,085 hectares of L.Turkana's north-eastern shoreline and adjacent plains and hills, together with the three million year-old fossil beds at Koobi Fora, plus a petrified forest near Allia Bay, and a variety of interesting wildlife, birdlife and reptiles characteristic of these northern arid lands (KWS). This is the only archaeological conservation area in Kenya gazetted as a National Park (ibid). Section 5.2 provides more details on the palaeontological interest of the lake.

- 1978: Mount Kulal Biosphere Reserve created as part of UNESCO's Man and Biosphere Reserve Programme. Mount Kulal towers 2,000 metres over the south-eastern lake shore. The 700,000 hectare protected area includes the southern lake waters and South Island (UNEP / UNESCO / IUCN, 2005).

  "…The area comprises a variety of landscapes and habitats, including brackish water at the southern end of the lake, a volcanic landscape with lava flows, an extensive lava desert and a volcanic island within the lake, hot springs, the occasionally flooded Chalbi salt desert, sand dunes and seasonal water courses. Mount Kulal is a volcanic mountain with a deep crater, capped by rain and mist forest..." (UNESCO's Biosphere Reserves Directory).

  "…Benefits gained from being part of the network include the integration of conservation, development and scientific research concerns to sustainably manage the shared ecosystems…" (Wikipedia).

- 1983/85: Central Island's 500 hectares National Park was established. With its three volcanic crater lakes, this Park protects a prime breeding area for Nile Crocodiles (UNEP/UNESCO/IUCN, 2005).
- 1983/85: South Island's 3,900 hectares National Park was established (ibid).
- 1997: Sibiloi, Central & South Island National Parks were inscribed on UNESCO's World Heritage List (UNESCO).

"…These remote parks are globally of great value for the conservation of water birds, the *Important Bird Area* of South Island Park especially…The Park also lies within a WWF Global 200 Eco-region…The Koobi Fora deposits are rich in pre-human, mammalian, molluscan and other fossil remains and have contributed more to the understanding of palaeoenvironments than any other site on the continent…" (ibid).

"…The Kenya Wildlife Service manages protected areas in Kenya and has agreed memoranda of understanding with the National Museums of Kenya for the conservation of fossil sites, with the Kenyan Fisheries Department for lake fisheries and the Kenya Forestry Department for catchment forests, especially for managing South Island National Park. However, local people are allowed to use areas in Sibiloi and Central Island National Parks during the dry season, November-February. With assistance from the UNESCO *World Heritage Fund,* a five year Integrated Management Plan has been developed for Lake Turkana and its parks. Its goals are conservation of the archaeological sites, Park habitats and biodiversity. Its objectives are to promote environmental awareness, education and ecotourism, scientific research and monitoring, collaboration with stakeholders and to alleviate poverty…" (ibid. citing Njuguna, 2001).

"…The area's protection is largely nominal but because of its remoteness, there is relatively little direct pressure on the environment. However, local people are beginning to become more sedentary, increasing the grazing pressure from livestock, which is now becoming a problem particularly along the shores of Lake Turkana. It also causes unauthorised trespassing into the Park and increased soil erosion in the strong winds of the area. The collection and cutting of *Salvadora persica* by local fishermen is also exposing soil to erosion. Pressure on fish populations in the lake is increasing, although attempts to introduce industrial scale fishing projects have so far failed. African Skimmers nesting on South Island have been disturbed in recent years by fishermen …" (UNEP / UNESCO / IUCN, 2005).

Hence, the Lake Turkana area is considered of great conservation value, both locally and internationally. The lake is listed as an "Important Bird Area" (IBA), providing habitat and a corridor for migration - see KENYA BIRDING article included in Volume II of this report (by Avery, K., 2012, Nature Kenya, Issue 6).

The threats to the protected areas described above are consistent with the Consultant's long experience of the area, and were confirmed by a field trip in January 2012. The threats are described in an article published by the East African Wildlife Society's SWARA magazine – see the June - July 2012 edition of SWARA included in Volume II of this report (article by Avery, Patrick, 2012).

6 DEMOGRAPHY & SOCIOLOGY

6.1 Demography

Demographic studies were not part of this study, but readily available data is included in order to put "affected" population levels into perspective with total basin populations.

6.1.1 Omo-Gibe Basin population

The 1994 population in the Omo Basin within Ethiopia was given in the Omo-Gibe Basin Master Plan together with forecasts to the Year 2009 and 2024, tabulated below. The Omo Basin's population within Ethiopia was forecast to double within 20 years (Woodroofe 1996, Vol. II, Part 1, p2.4). Roughly 6.5% of the basin population is within South Omo.

95% of the Omo Basin population live in the highland areas, and there are 40 distinct ethnic groups living within the basin (Ibid, p2.4). 96.5% of the entire basin population is "rural". In South Omo, the "rural" component is 98%.

Flintan refers to more than 45 different ethnic groups in the Southern Nation Nationalities and People Regional State (SNNPRS), with most of the pastoral groups being found within South Omo (Flintan, 2011). The SNNPRS area encompasses a larger area than the Omo Basin though, hence the larger number of ethnic groups within the SNNPRS.

A summary dated 1996 defined the characteristics of the Basin in the following sentence: "Poverty, a subsistence and largely agricultural economy, the fragility of that economy, the increasing fragility brought on by land degradation and a rapidly expanding population, isolation and lack of infrastructure further define the basin…" (Woodroofe et al, 1996).

Table 15: Omo Basin population

Year	South Omo (% Basin Pop)	Omo Basin Population
1994	591,750 (6.7%)	8,784,500
2009	904,100 (6.7%)	13,429,800
2024	1,237,550 (6.5%)	19,016,953

Source of population statistics: Omo-Gibe Basin Master Plan (Vol. XI, F1, p56).
Note: 96.5% of the entire 1994 basin population was reported to be "rural".

6.1.2 Lower Omo population

The Omo Basin Master Plan included the population statistics presented in Table 16 overleaf for "South Omo" Zone. Note that the administrative boundaries / names of Weredas are not the same today.

Sogreah assessed the Lower Omo population in 2010 to be 173,542 (see Table 3 on p51 earlier) within the following Weredas: Selamago, Nyangatom, Hamer, and Dasenech (Sogreah, 2010). This equates to 1.3% of the entire basin population, hence a very small proportion. Sogreah concluded that 82,000 people are "directly dependant" on the Omo River (ibid).

Table 16: South Omo population levels

Zone/Wereda	Town	1994	2009	2024
Bako Gazer	Jinka	175,750	268,700	367,750
Bena Kule	-	28,750	43,950	60,150
Geleb	Omo Rate	19,500	29,800	40,800
Hamer	-	35,000	53,400	73,100
Mursi Bodi	-	7,750	11,650	15,950
East of Omo		325,000	496,600	679,800
Total South Omo		591,750	904,100	1,237,550

Source: Woodroofe, Vol. XI, F1, p56, 1994. Note: 98% 1994 South Omo population "rural".

6.1.3 District population around Lake Turkana

Population has grown in Kenya from 2.5 million people in the 1930s, to 39 million people today.

Lake Turkana formerly fell within the Turkana, Samburu and Marsabit Administrative Districts of Kenya, with borders shown in Figure 26 on p92. The western shore was in Turkana District, the eastern shore within Marsabit District, and the southern shore was the northern-most tip of Samburu District.

Since 2007, the above districts have been sub-divided into several smaller districts. Details are not included here, but can be obtained from Government sources and in other reports commissioned by AFDB - see Kaijage & Nyagah, 2010. For this report, population statistics are more easily viewed in terms of the former district boundaries for which data is readily available, as presented in GoK's Vision 2030 (Figure 26 on p92).

Population statistics have been assembled in Table 17 below. For a harsh environment such as Lake Turkana, the population increases are challenging. For Turkana District, the increase has been four-fold in 40 years. Population growth rates of 3.3% per year have been used for Turkana, which means that population would double in 20 years (Watson et al, 2008). This growth rate is much the same as within the Omo Basin. It is pertinent to bear in mind that 80% of Kenya's land mass is "arid and semi-arid", and hosts 28% of the population (GoK, Vision 2030). The "arid" land portion alone occupies 56% of Kenya, and hosts 8% of the country's population (ibid). Hence the ASAL areas (arid and semi-arid lands) are very significant in terms of national planning and responsibility.

Table 17: Population statistics

Year	Turkana District	Samburu District	Marsabit District
1969	165,000 (5)	-	-
1979	-	79,908 (1)	-
1989	150,000 (5)	108,834 (1)	-
1999	386,572 (4)	154,442 (1) (6)	127,000 (3)
2006	469,713 (4)	-	-
2009	652,455 (2)	205,774 (2)	159,059 (2)

Source of table: Abstracted from Avery, 2010 (AFDB study).

Notes in table: (1) PriceWaterhouseCoopers, 2005. (2) Vision 2030, GoK, 2009. (3) Snyder, 2006. (4) Watson & van Binsbergen, 2008. (5) Rutten, 1988. (6) According to a water survey, population could higher than Census data at 202,569 (Oxfam, 2003).

6.1.4 Lake Turkana's shoreline population

Data from Kenya's 2009 population census is included in Volume II of this report (the Annexes) along with maps showing the census administrative boundaries.

Figure 18 and Figure 19 overleaf show the "population" variation along each shoreline from north to south. The red bars signify communities adjacent to the lake shore. The blue bars indicate communities that are not directly adjacent to the lake shores, but are close by (and hence might utilise the lake at times).

Figure 21 on p83 shows the variation in "population density" between the east and west lakeshore areas. The west lakeshore areas have population density 6-times higher. The areas adjacent to the eastern shores are amongst the least densely populated areas in Kenya, in the range 1-3 persons/km^2 (see Figure 20, on p83). This is a function of the greater aridity of this area (as evidenced by the Chalbi desert to the east of the lake).

Figure 20 on p 83 shows the respective "cumulative population" distribution along the east and west shores. These are for illustrative purposes, based on the following assumed band widths:

- The western "belt" analysed is about 50 kilometres wide. The population within this "belt" is 154,000, of which about 56,000 are along or close to the shore.
- The eastern "belt" analysed is about 100 kilometres wide and holds a population 55,000, of which an estimated 35,000 are on or close to the lakeshore.

Thus, about 200,000 people live within reach of the lake, of which about 90,000 are along or close to the lakeshore. These are estimates only as no fieldwork has been done to establish the distance of lake dependant communities from the lake. To put these figures into perspective, Oxfam estimated the fishing community along the NW shore to number 8,000-10,000 (Oxfam, 2009). The NW shore enjoys the highest fisheries diversity index for the lake.

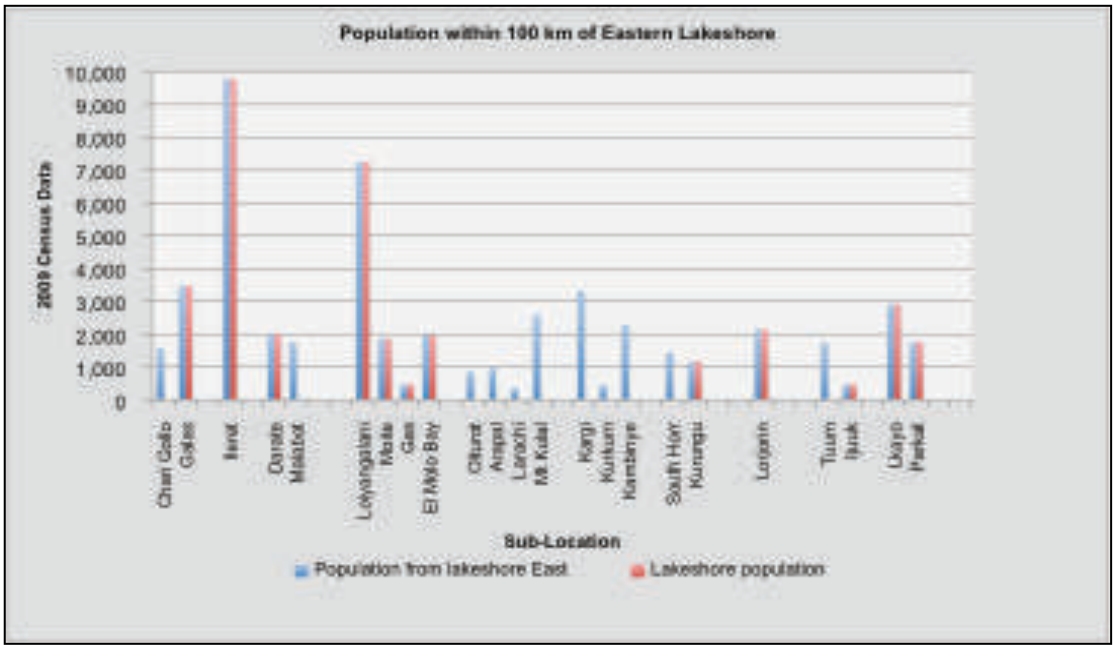


Figure 18: Population - Eastern lakeshore

Source of data: 2009 Kenya Population Census.

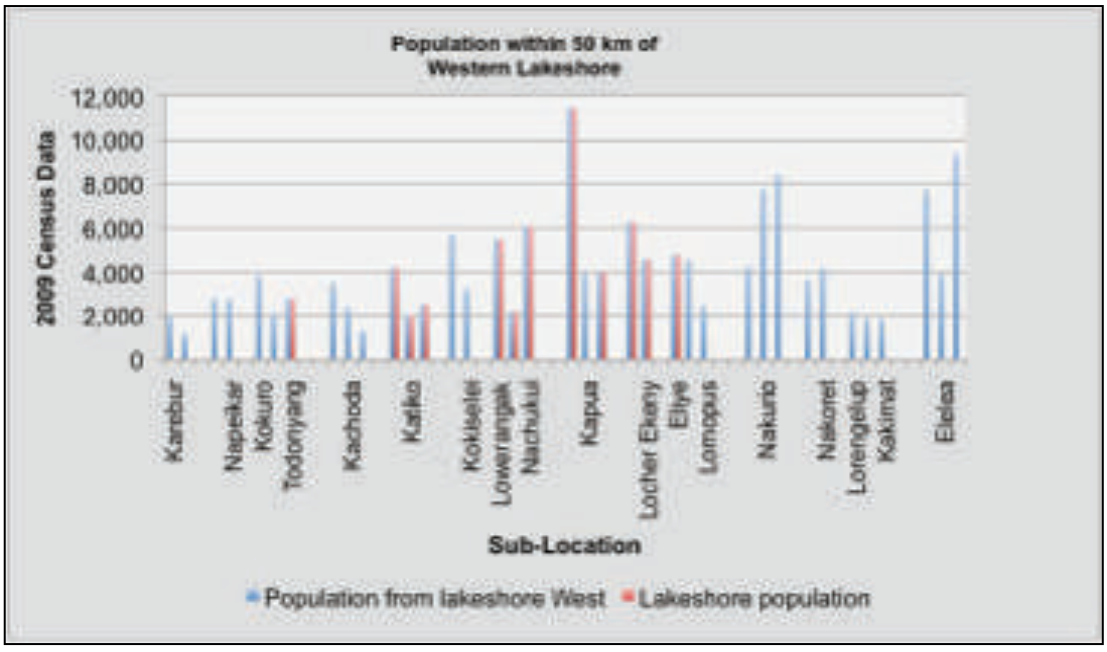


Figure 19: Population - Western lakeshore

Source of data: 2009 Kenya Population Census.

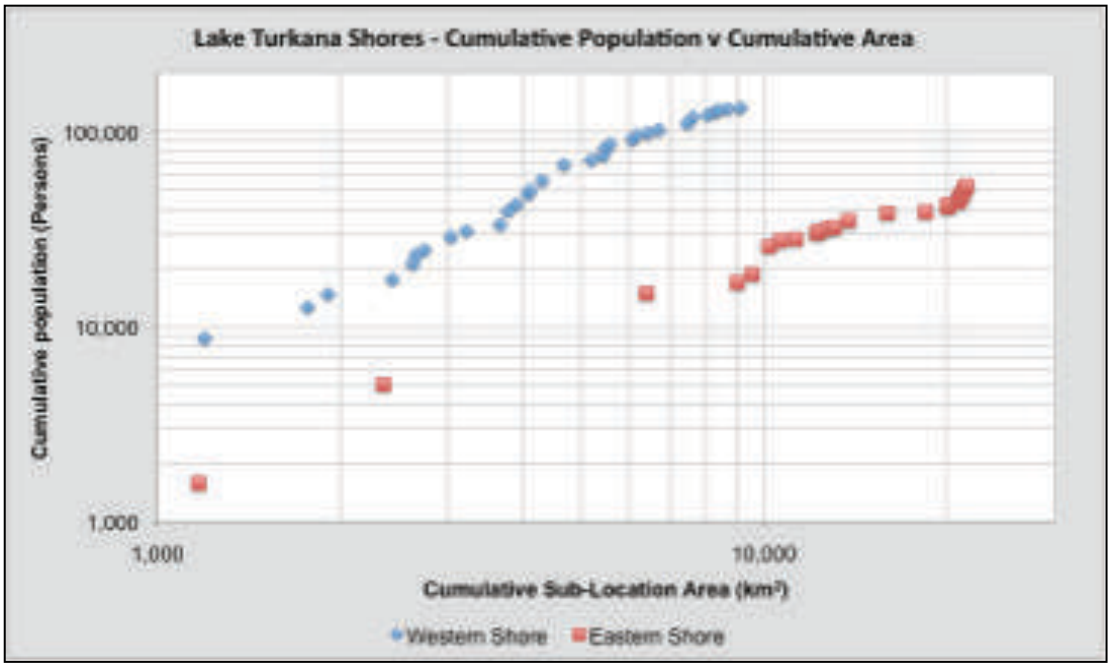


Figure 20: Cumulative population compared with cumulative area

Source of data: 2009 Kenya Population Census.

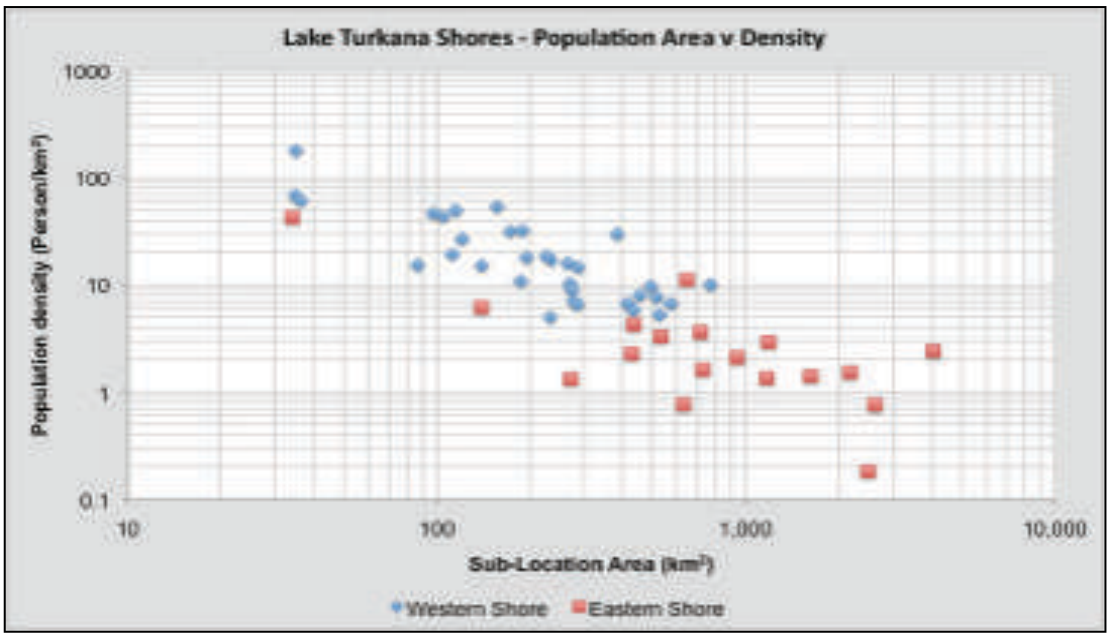


Figure 21: Population density compared with census area

Source of data: 2009 Kenya Population Census.

6.2 African Development Bank: "Socio-Economic Analysis and Public Consultation of Lake Turkana Communities in Northern Kenya" (Kaijage & Nyagah, 2009; & 2010)

The above independent socio-economic study was commissioned by AFDB in parallel with the AFDB hydrological study. The AFDB intention was to contribute to a full ESIA on the effects of Gibe III on Lake Turkana. The objective was to fill the gap left by the various Ethiopian studies, which had not included Lake Turkana and its communities within their ESIA studies. Two reports were prepared, dated 2009 and 2010 respectively.

The socio-economic analysis and public consultation of Lake Turkana communities was undertaken in two phases. Phase 1 undertook fieldwork in villages on the western side of the lake, and the second phase extended consultations to villages on the eastern side (Kaijage and Nyagah, 2010).

The socio-economic study was conducted at a time when the hydrological consequences of Gibe III had not been quantified. Hence the study team was only able to gather perceptions, and was unable to evaluate these perceptions against actual data. This was a pity as these communities depend on third parties for information, and such information may be incorrect, biased or incorrectly interpreted.

The report correctly stated: "Hydrological report should be a predetermining factor to the authenticity of the fears of the community" (ibid, p178), and noted that without this data, their report "cannot be entirely conclusive" (ibid, Chapter VIII).

The following extracts follow the thread of the socio-economic study conclusions (ibid):

- It is an area challenged by drought, with "erratic short rains"
- The tribes adjacent to the lake are "primarily nomadic pastoralist"
- "…The northern part of Kenya is well known for episodic insecurity and violence…"
- "…All communities studied face gender inequality…" (especially women)
- "…The communities sampled are food insecure and highly dependant on relief food…"
- "…Living standards are low with majority of people living below the poverty line…"
- "…Poverty and vulnerability is widespread…"
- "…Fishing is a significant source of livelihood…"
- "…The dominant production systems…are nomadic pastoralism…"
- "…Poor market infrastructure limits the (livestock) sector…"
- "…Land ownership is vested in the county council…"
- "…Land is also legally owned under customary law…"
- "…Majority of member of households interviewed are not employed…"
- "…Fishing was a source of income for all communities interviewed except North Horr…"
- "…Due to aridity the northern part of Kenya does not have comparative advantage on crop production…"
- "…Communities interviewed at Kalokol North, Loiyangalani and El Molo Bay do not farm…"
- "…Subsistence crop production is practiced along Kerio and Turkwel riverine zones…"
- "…limited subsistence crop lakeshore farming is practiced at Ileret…"
- "…Social services are scarce...and provision of such services is challenged by nomadic pastoral lifestyles…"

- "…The pastoralist lifestyle has little demand for sanitation facilities…"
- "…The current state of infrastructure for the entire study area is poor…" A consequence is that this is "…retarding development of other sectors…"
- The average distance to a health facility in Northern Kenya is 52 kilometres, compared to the "national norm" of 5 kilometres (ibid).
- "…there is under exploitation of renewable energy…"
- "…there is lack of electricity supply…" (except in Lodwar, and more recently Loiyangalani)..
- "…Majority of members interviewed lacked basic education…"
- The percentage of householders with primary education was found to be as low as 13.9% at Ileret, with the highest being 53.1% at Kalolol (ibid). This is an interesting reflection of the high variation in literacy levels.
- "…The community along lake Turkana have a negative attitude to Gibe III…This is due to inadequate factual information, misinformation and misconception about the project…" This has brought about "…much uncertainty and fear among communities…"
- On the other hand: "…majority of stakeholders from the communities where consultations took place were not aware of the Gibe III project…"
- "…the few who knew about Gibe III…have knowledge from activists including Friends of Lake Turkana, from the media, from Members of Parliament etc…"
- "…The communities reported high dependance on Lake Turkana for fish, domestic water, income from fish selling, flood farming, transportation, tourism, marine and wildlife conservation, a source of nutrition (Maasai roots), security as it acts as a shield between rival communities, and also for recreation…"
- "…The validity of the above fears are strongly hinged upon uncertainty and speculated reduction of water of Lake Turkana as a result of the construction, subsequent filling, management and operational regime of Gibe III dam and the Omo River, most of these fears stay validated as long as there is no detailed analysis and studies to prove otherwise…"
- "…In as much as several mitigation measures have been suggested during public consultation processes, the population around the Lake will make mitigation measures on the impacts of Gibe III costly and demanding. This is because there are almost half a million people on the western and about two hundred thousand on the eastern side. This vast population in a rather hostile desert and arid environment where relief food is a common thing and sustainability is yet to be achieved, will benefit most by first returning the living standards to acceptable levels, then proceeding with mitigating the impacts of Gibe III project…"
- "…Good practises show that treaties on Trans-boundaries have been effected in several countries with most water bodies now being protected in an effort to conserve the environment for posterity of the nations. There must be a treaty in place to protect the Lake Turkana and River Omo from future degradation…"
- "…Lake Turkana and its surrounding communities are equated to a cradle of mankind. Lake Turkana is an environmental asset that provides life-supporting systems from which Lake Turkana communities derive a number of services. This calls for action that will prevent depreciation in economic value of this lake so that it continues to provide its aesthetic and life sustaining services such as aquatic life, terrestrial life, boating and fishing. This beautiful lake resource in the middle of the desert, its unique species of fauna and flora attracts tourists from different corners of the world. The Lake's communities preserve diverse unique indigenous cultures, which attract tourists. A case at hand is the El Molo tribe, a dwindling tribe that has always survived centuries by fishing in Lake Turkana. Lake Turkana has existence value for conservationists and many other people who may not be necessarily using the lake directly..."
- "…Externalities mentioned can be associated with a lack of clearly defined property rights. Lake Turkana is trans-boundary water. Ethiopia may claims ownership and property right on Omo River and chooses to maximize its use by building Gibe III hydropower project;

furthermore, Omo River is located within Ethiopia. However, water from Omo River gives existence to Lake Turkana. The Turkana communities also claim that nobody should tamper with Omo River water, which sustains their lake. Hence Lake Turkana communities can be seen to have property rights to the Omo water that sustain their lake. The Problem inherent this argument is that of conflicting rights to claims that requires policy makers to give due attention to different interest groups who are making conflicting claims in order to have their interests given…"

The report presents a range of recommendations.

The Kenya Government's "Vision 2030" has recognised "the inequalities between the north and the rest of Kenya" and attributes these to "conscious public policy choices taken in Kenya's past" (GoK, Vision 2030). The area's marginalisation is well known. In mitigation, the Kenya Government has formed a separate Ministry of State for Northern Kenya and arid lands within the Office of the President.

Recent announcements of oil finds have added a new dimension to the considerations listed above. There is excitement, anxiety levels in the area are raised, and there is escalating speculation, with fears of land grabbing. Expectations are in danger of being exaggerated and proving unrealistic. These expectations need to be carefully managed through proper information dissemination at the local level, otherwise there will be disappointment, and conflicts will develop. These challenges are being addressed through local initiatives, notably the efforts of Friends of Lake Turkana (FoLT, 2012a), but Government support is needed.

6.3 Lower Omo socio-economic indicators

Various educational indicators from the Omo-Gibe Basin Master Plan are tabulated below in Table 18. In general, indicators in South Omo fall below the basin average.

Table 18: Omo-Gibe Basin educational indicators

Pupil per Classroom		
School	South Omo	Basin Average
Primary	22	49
Junior	80	31
Senior	42	62

Pupil per Teacher		
School	South Omo	Basin Average
Primary	20	32
Junior	68	20
Senior	64	24

School Enrolment Ratios		
School	South Omo	Basin Average
Primary	11.5%	23.9%
Junior	5.4%	9.5%
Senior	2.6%	5.6%

Source: Woodroofe, Vol. II, Part 2, TA8 (ii).
Note: Population projected to double in 20 years (Woodroofe et al).

The Omo-Gibe Basin Master Plan stated that in 1995, health care in Ethiopia was "depressed" compared to elsewhere in Africa, and even worse in the Omo-Gibe Basin – see Table 19 overleaf.

There was one doctor per 68,000 people. The most commonly reported diseases were helminthiasis, upper respiratory tract infections, dysentery and diarrhoea, eye diseases, tuberculosis and malaria (Woodroofe, Vol. II, Part 2, TA9(i), p3). "In general, most of these are water borne and are related to poor personal hygiene, inadequate and unsafe water supply, and lack of basic sanitary facilities…" (ibid).

Table 19: Omo-Gibe Basin health facility indicators

Health Facility Indicators				
Facility	Govt Standard	Omo Basin In 1995	Ethiopia (1)	Africa (1)
Health Post	2,000 < 5 km	Nil		
Health Station	10,000 < 15km	32,173		
Health Centre	100,000 < 50 km	268,108		
Hospital	1,000,000	2,145,000		
Population/Doctor		68,000	29,000	9,000
Population/Nurse		20,000	12,000	2,000
Population/Bed		11,000	3,500	900

Source: Woodroofe, Vol. II, Part 2, TA8 (ii).

Note (1) in Table: Data for Ethiopia and Africa from "Better Health Care" by the World Bank.

6.4 Regional ethnic diversity and distribution

Figure 22 on p88 and Figure 23 on p89 present traditionally generalised ethnic groupings in East Africa and the Horn of Africa. The peoples of Northern Kenya are Nilotic (in the west) and Cushitic (to the east). The Nilotic peoples extend from South Sudan and Uganda, whilst the Cushitic communities extend from southern Ethiopia and Somalia. Lake Turkana formed a natural north/south physical barrier separating the migrating Nilotic linguistic people (the Turkana and Samburu occupying the areas west and south of the lake) from the Eastern Cushitic linguistic peoples (Dasenech, El Molo, and Gabbra occupying the area east of the lake, shown on the map as "Galla" and "Somali to the far east").

Figure 24 on p90 shows the distribution of culturally diverse pastoral tribes in the Lower Omo, comprising Turkana and Dasenech nearest the lake, with Nyangatom, Hamer, Chai, Kara, Mursi, Bodi tribes along the Omo River north from the lake.

Figure 25 on p91 illustrates the distribution of culturally diverse communities around the lake. Although traditionally the Turkana occupied the western side of the lake, the community has crossed the thinnest portion of the lake to occupy the eastern shore between El Molo Bay and Moite, and beyond north to Sibiloi National Park.

The Turkana and Samburu are Plains Nilotes. The Turkana tribe is Kenya's third largest pastoral group, and engages traditionally in pastoralism, but also in cultivation along the Kerio and Turkwel Rivers, and fishing on Lake Turkana. The Samburu are Maa-speaking pastoralists. The livestock principally include cattle, sheep, goats, camels and donkeys.

The Cushitic peoples include the Dasenech and El Molo. The El Molo is the lake's only traditional "hunter gatherer" tribe which traditionally fished and hunted crocodile and hippo. The Dasenech have also been referred to in the literature as Shangila, Merille and Galeba. The term "shangila" means "slave" and hence is somewhat derogatory (Pers.Comm., David Turton). The Dasenech live in the Omo delta, extending south into the Ileret area of Kenya, and into the northern parts of Sibiloi National Park. The Dasenech are agro-pastoralists, and hence also cultivate. The El Molo is a remnant community living on El Molo Bay north of Loiyangalani. Although "Cushitic", the El Molo tribe has over the years integrated with the Samburu. The Gabbra are traditional Galla-speaking "Cushitic" camel pastoralists who range over the northern areas of Kenya between the lake, the Ethiopian border, and Marsabit in the east. The Rendille are Sam-speaking "Cushitic" camel nomads who range the Kaisut desert south-east of the lake, south of the Gabbra range, extending south towards Isiolo.

Cushitic communities on the eastern shores to this day still consider the lake as a physical barrier that protects them from rustlers (Kaijage and Nyagah, 2010).

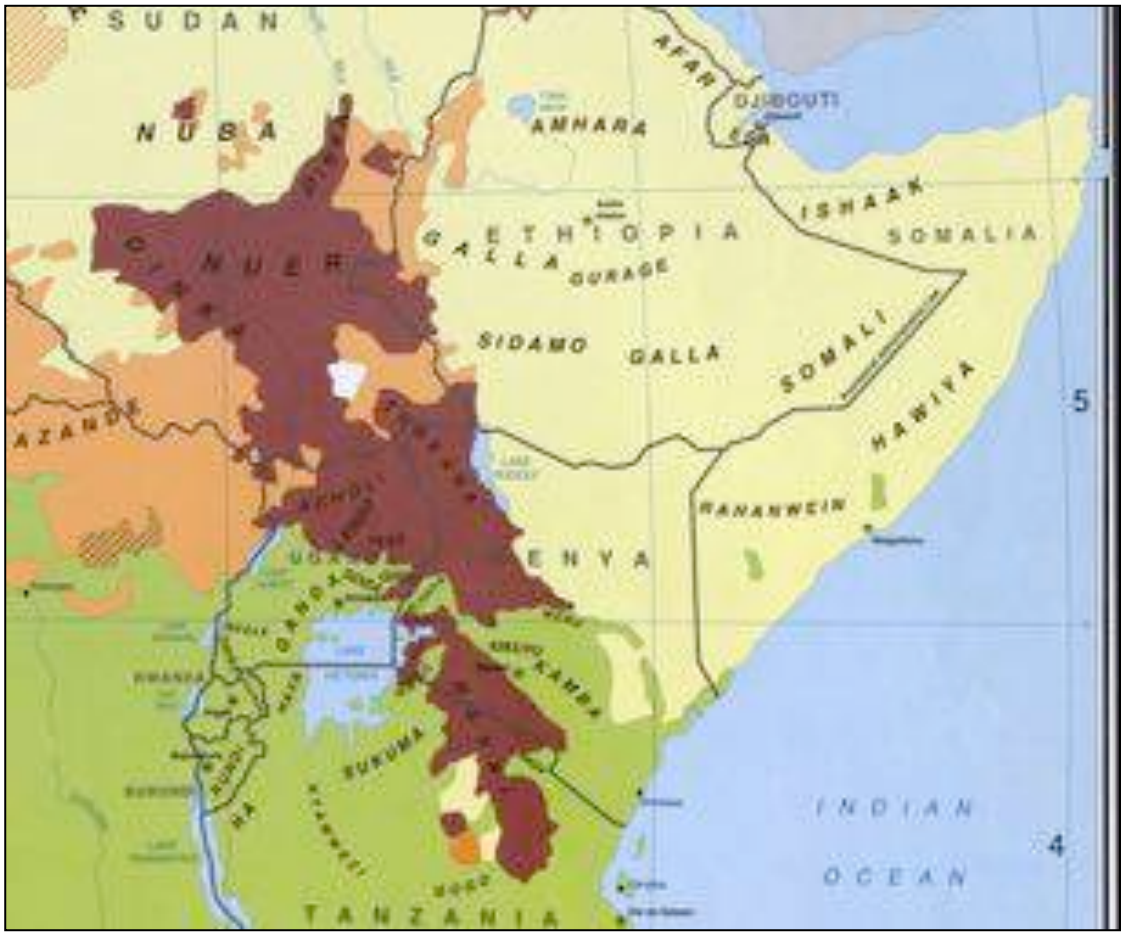


Figure 22: Ethnic groups in the Horn of Africa

Source of map: Central Intelligence Agency, USA, 1974.

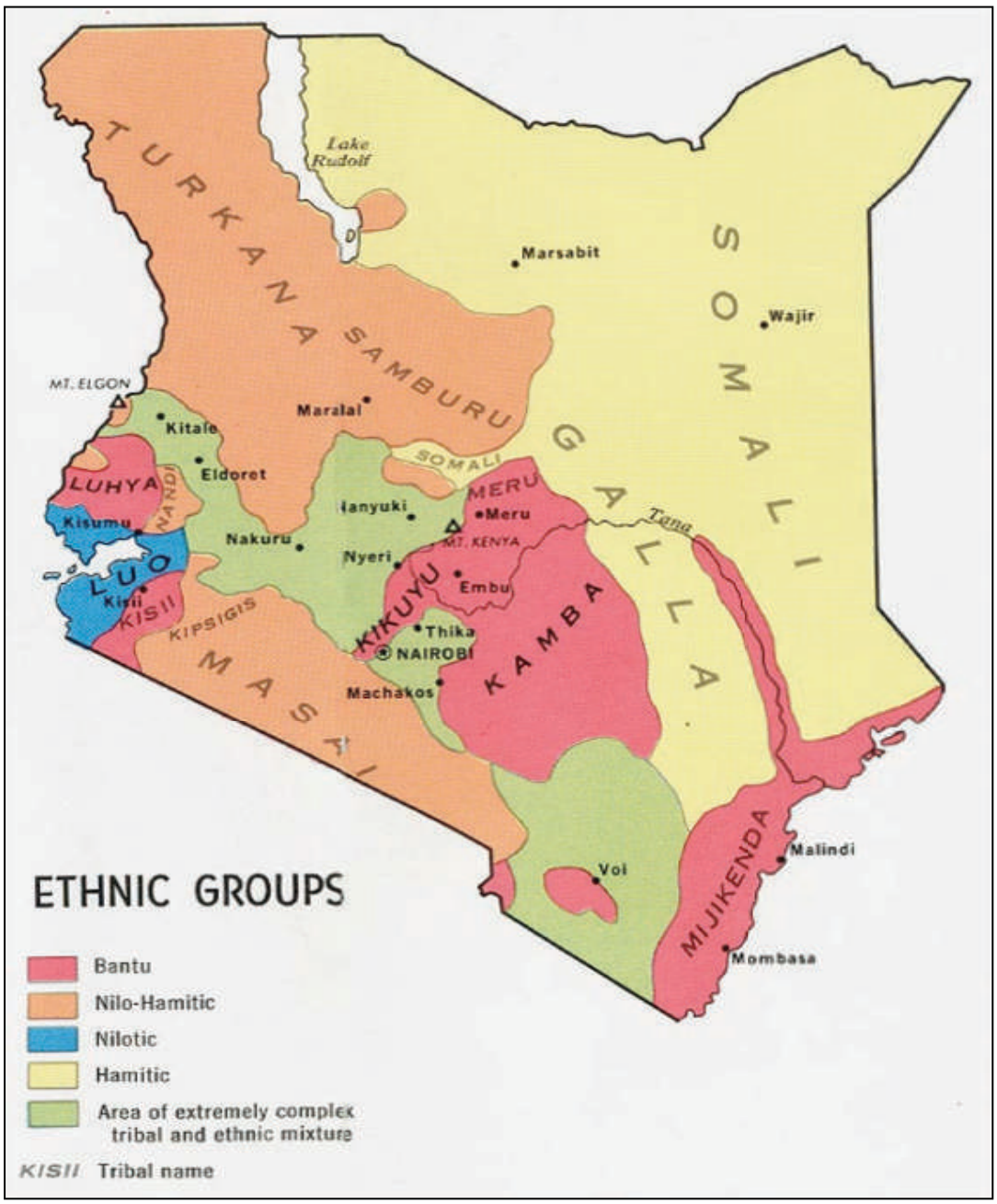


Figure 23: Ethnic groups within Kenya

Source of map: Central Intelligence Agency, USA.

Figure 24: Peoples of the Lower Omo Valley

Source of map: www.mursi.org kindly provided by Dr. David Turton.

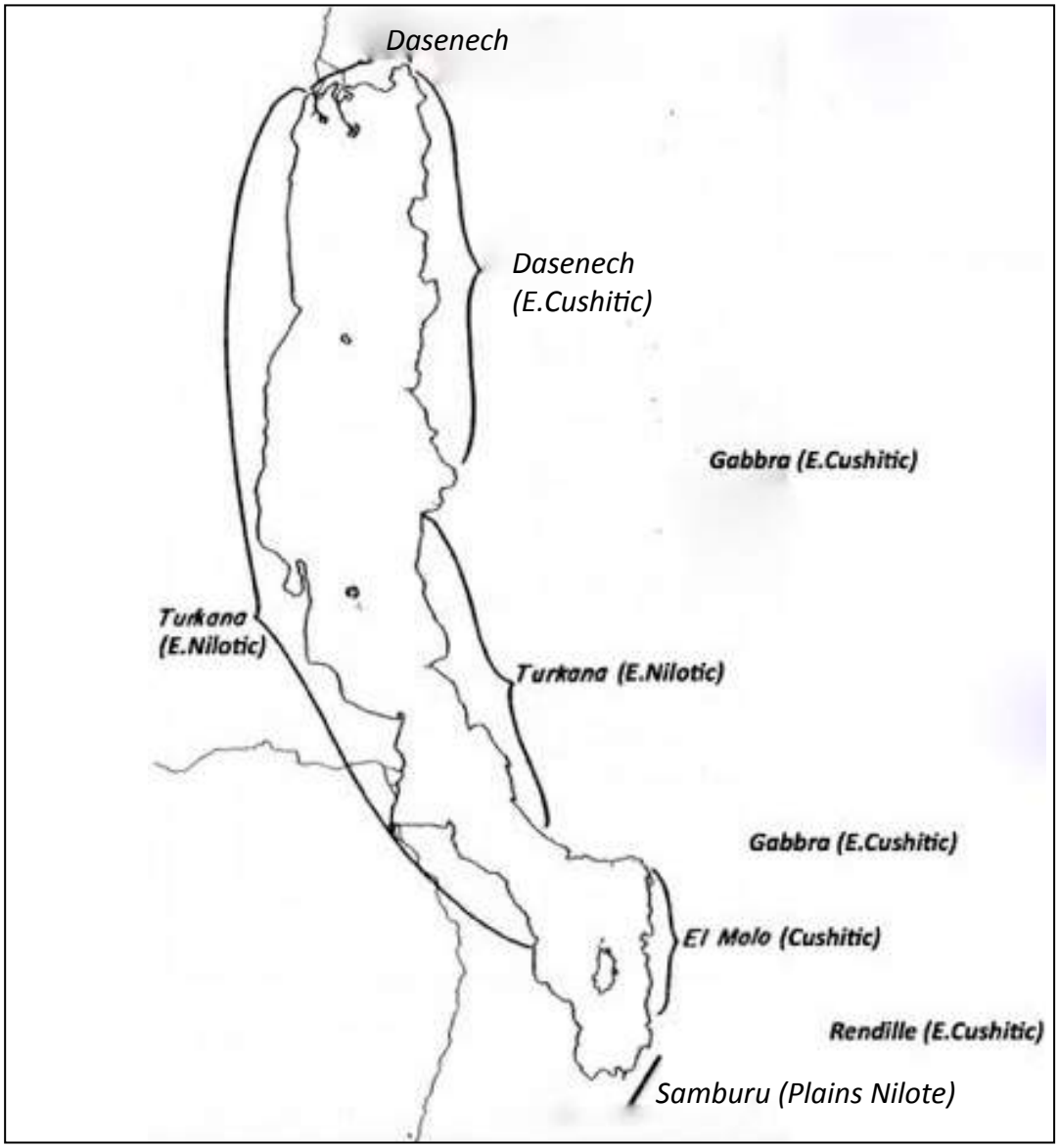


Figure 25: Tribal distribution around Lake Turkana's shores

Source of lake base map with shoreline tribal distribution: *Hopson et al, 1982 (modified).*
Source of linguistic groups (Nilotic and Eastern Cushitic): Feddes & Salvadori, 1979.
Originally summarised in Avery, 2010.

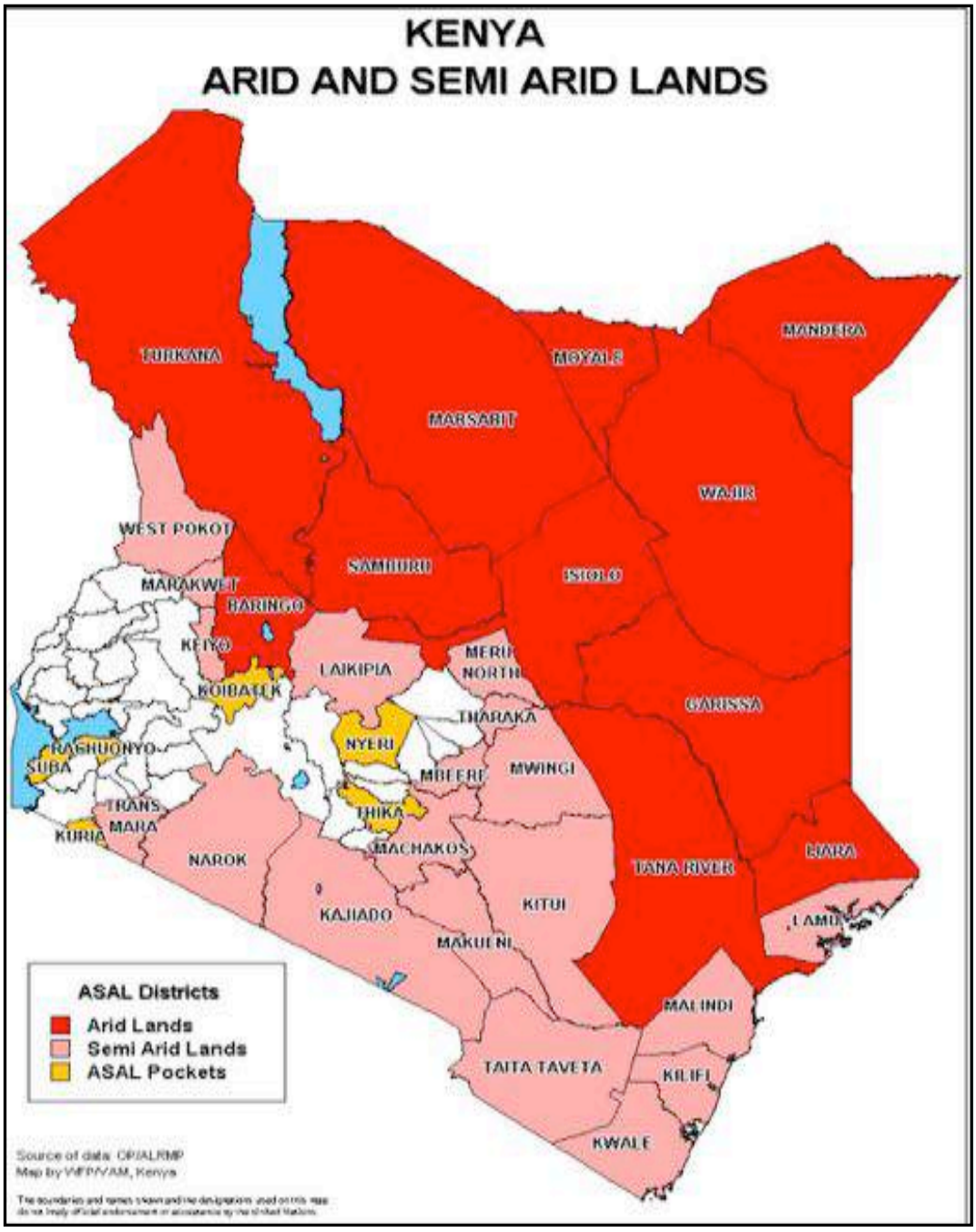


Figure 26: Kenya's ASAL areas (arid and semi-arid lands) demarcated

Source of map: Government of Kenya, Arid and Semi-Arid Lands Programme. The map is based on pre-2007 District boundaries as given in GoK's Vision 2030 (2009).

7 LAKE TURKANA FIELD EXPEDITIONS

7.1 Field expeditions to Lake Turkana

The Consultant has undertaken many field expeditions into the Lake Turkana area over the past 30 years. As part of this study, a field expedition was planned in November / December 2011. Weather conditions proved exceptionally wet at that time, with road access being impassable due to swollen seasonal watercourses (luggas). The fieldwork was therefore delayed until January 2012. Two specific field trips were then undertaken as described below, in January 2012, and in April 2012.

7.2 January 2012: Expedition to Lake Turkana's islands, Omo Delta & Turkwel Delta

A field team comprising the Consultant and two Field Assistants flew from Nairobi to Lodwar. Lodwar is the largest town near lake Turkana, with many Government facilities based there. Lodwar has a tarmac airfield operated by the Kenya Airports Authority, with daily scheduled flights, and Lodwar also provides the only Government hospital near the lake.

A Field Assistant's personal report on medical facilities is included in Volume II of this report (Annexes).

The Lodwar District Hospital was visited to meet key officials and to better understand the health challenges of the area. This is a Government facility. A poster on the wall flagged "Malnutrition reduction" as top of the Turkana Central / Loima Districts "Health Priorities". The Public Health Officer identified the lack of appropriate sanitation to be his personal key target for health improvement, as people prefer the traditional practise of open defecation, even within towns like Lodwar.

The team then proceeded by road to Kalokol, where the Kenya Marine & Fisheries Research Institute (KMFRI) was visited. This was a courtesy call during which the challenges facing the lake fisheries were informally discussed. The Consultant retains ongoing contact with KMFRI as their staff kindly assisted with data acquisition in the past.

The Kalokol Health Centre was visited. This private facility was established and formerly operated by the Africa Inland Church (AIC). The Health Centre was once sufficiently equipped to perform surgery, but today the Centre provides basic services only, and with very limited resources. The Centre does have some donor support, but this is specific to HIV support, whereas the Centre has many routine medical cases to handle such as malaria, which also require support medical funding. The Health Centre used to regularly mobilise an outreach field clinic to villages to the north, but has been unable to do so recently as there is no functional vehicle available.

The team then spent several days cruising around the entire lake with a Turkana boat crew. A small camp was established on the beaches of North, Central and South Island respectively. The islands were chosen as a base in view of concerns about overnight security. The border areas are very tense. In spite of Kenyan security presence on the border at Todenyang, border skirmishes between Turkana and Dasenech tribesmen are frequent. One such skirmish took place during the field trip. The shores are vulnerable areas. Turkana fishermen avoid spending nights on the shore, preferring instead to return overnight to villages away from the shore. In one case where the fishermen were working near the NE shore at Selicho (beyond the Turkana tribal area), the fishermen were sleeping in their fishing boats, which remained moored far offshore, as they were fearful of attacks by Dasenech tribesmen (the NE shore is traditionally inhabited by "Kenyan" Dasenech).

Two articles by the Field Assistants were published, the first in the East African Wildlife Society's SWARA magazine (Avery, Patrick, 2012), and the second in Nature Kenya's KENYA BIRDING (Avery, Kieran, 2012). Copies are included in Volume II of this report (Annexes).

7.2.1 March 2012: Safari to Loiyangalani on the Eastern Shore

The Consultant undertook a three-vehicle safari to the south-eastern lakeshore and the small centre of Loiyangalani, driving from Nairobi via Nyahururu, Rumuruti, Maralal, Baragoi and South Horr. This is the main access route to the lake from the south. Beyond Rumuruti north, the road is gravel surfaced. Maralal is the last town and main supply point until Loiyangalani is reached. In wet conditions, these roads can be impassable, and very challenging weather was encountered on the return journey with many trucks encountered stuck in mud between Maralal and Rumuruti. The Baragoi area is a high-risk area, with bandit attacks frequent. One such attack occurred at Merti (between Baragoi and Maralal) the day before the return journey, and there were Kenya Police vehicles in evidence looking for the culprit. On enquiring with the Police, our party was advised that such attacks "do not happen every day".

The purpose of this visit was to sample water from perennial springs within the vicinity of Loiyangalani, to visit the Desert Museum near Loiyangalani, and to make a courtesy call to the Health Centre run by the Consolata Sisters in Loiyangalani. This Health Centre has an outreach programme to various villages, but this depends on the availability of a vehicle provided by the Parish priest. A brief meeting was also held with missionaries of the Africa Inland Church, and the OCPD (commanding officer) of the Kenya Police establishment.

Loiyangalani is literally an "oasis in the desert", with characteristic clusters of doum palms shading several warm perennial springs. The spring water is mineralised but potable, and it is piped to water points serving a growing settled population. There is an airstrip, some basic shops, tyre repair facilities, tourist lodges and camps, schools, churches, clinics, and some Government offices, and notably posts of the Kenya Police and the Kenya Wildlife Service.

8 LAKE TURKANA ENVIRONS – BIOPHYSICAL ENVIRONMENT

8.1 Biophysical environment – Introduction to previous reports

The information on the lake's biophysical environment was previously presented in the reports to the AFDB (Avery, 2009 and 2010), and has been updated in this report. Similar information is presented in other reports that can be referenced separately (Ngece, Maina, Mbogo, Kaijage & Nyagah, all 2010).

8.2 Agro-climate and temperature

Lake Turkana is "arid", falling within the 80% of Kenya made up of ASAL districts (arid and semi-arid districts demarcated in Figure 26 on p92). 70% of the ASAL areas are "arid" zones affecting 56% of Kenya (GoK Vision 2030).

8% of Kenya's population inhabits the "arid" areas, and 20% inhabits the "semi-arid" areas. Hence 28% of the population is found within the ASAL districts (ibid).

Lake Turkana lies within Agro-climatic Zone VII-1, a "very-arid" zone, the most severe combination of moisture and temperature classifications in Kenya, with the characteristics summarised in Table 20 and Table 21 below.

Note that temperatures of more than 50^{o}C have been reported from the Suguta Valley, just south of Lake Turkana (Dunkley et al, British Geological Survey, 1993).

Fuller details on climate are included in Chapter 11 (from p121 onwards).

Table 20: Agro-climatic zone – Lake Turkana

Zone	Classification
Moisture Zone:	"Very Arid" zone
Average annual rainfall:	150 to 350 mm
Average annual potential evaporation:	2,100 to 2,500 mm
Vegetation:	Desert scrub
Potential for plant growth:	Very low potential
Risk of failure of an adapted maize crop:	95 to 100% risk

Source: Sombroek et al, Kenya Soil Survey.

Table 21: Temperature zone – Lake Turkana

Zone	Classification
Temperature Zone:	"Fairly hot" to "Very hot"
Mean annual temperature:	24 to 30 ^{o}C
Mean maximum temperature:	30 to 36 ^{o}C
Mean minimum temperature:	18 to 24 ^{o}C
Absolute minimum temperature:	10 to 16 ^{o}C

Source: Sombroek et al, Kenya Soil Survey.

8.3 Flora

Lake Turkana is a very arid zone with shores whose vegetation cover varies with the topography and underling soils / geology. There are barren lava covered shores, stony deserts, grasslands, and mixed bush, and grassland, and woodland. Sandy / bouldery luggas drain to the lake, and these are fringed with arid land trees.

Remote sensing of biomass between 1981 and 2003 classified the Turkana area as "sparse grasslands" (Bai & Dent, 2006, work commissioned by FAO). Based on remote sensing of biomass and rainfall, it had been concluded that 18% of the country with 35% of the population were "hot-spots" of land degradation (ibid, cited by UNEP). In these areas there was a decrease in both net productivity of biomass and rain-use efficiency. Reductions in "biomass" equate to reduction in grazing. Along with one other area of the country, the very arid grasslands of Turkana were identified as the key "hot-spot" of land degradation (ibid). Ngece described the Lake Turkana environment as "substantially disturbed by human activities" (Ngece, 2009). More recent studies talk of 30% of Kenya's forests and 10% of Kenya's grasslands being subject to degradation (Muchena, 2008).

Hence, the Lake Turkana area is perhaps the most vulnerable area of the country.

Following the recommendations of the AFDB hydrological study (Avery, 2009), an assessment of Landsat imagery was undertaken to determine the changes in flora with time (Ngece, 2010).

Ngece analysed Landsat imagery dated 1973, 1986, 1995, 2001 and 2008. An overall summary with conclusions was presented in AFDB's Final Hydrological Report (Annex 1, Avery, 2010), reproduced in Volume II - Annexes to this report. The imagery was used to differentiate areas covered with lake water, swamps, woodland, bush and grasslands. The study showed how the Omo delta vegetated areas increased with falling lake level between 1973-2008, as would be expected. The study demonstrates a reduction in woodlands in all areas where there are settlements, which was also anticipated (Avery, 2010). The desolate southern end of the lake, where there are no settlements, showed very little change, which was also anticipated (ibid). There was even supposedly an "increase" in woodland in this southern area (ibid).

The appearance within the Turkwel / Kerio irrigated areas of the invasive alien tree *Prosopis juliflora* was noted some time between 2001 and 2008 (ibid). This plant species is aggressive and thrives in arid areas. It was introduced to the Lodwar areas by well-meaning NGOs to "green the deserts", but without proper thought to the consequences. The plant invades and overwhelms grasslands, and is not popular with communities that depend on pastoralism (ibid). The field visit in January 2012 revealed the Turkwel delta becoming choked with *P. juliflora* that was displacing natural reed beds.

Prosopis julifora is native to Mexico, and is now widespread throughout northern Kenya. It is not unlike an Acacia in appearance, with small mimosa-type leaves and large thorns. The tree grows to six metres height, is aggressive and shuts out other species through interlinking of canopies (Wikipedia). It can withstand high temperature, drought, and saline soils. It was first introduced in the 1970s to the Afar Region of Ethiopia, with good intention, and has been in Kenya since the 1980s (Avery, 2010). Eradication is very difficult. Instead, attempts are being made in Ethiopia to commercialise / utilise the tree. The wood itself can be used, the wood can also be converted to charcoal, seeds can be crushed to make cattle fodder...there are many potential uses.

Commercialising *Prosopis juliflora* is however reported in Ethiopia as leading to conflicts between settlers and pastoralists. Ethiopian pastoralists refer to it as the "Devil Tree", and insist it should be eradicated (ibid). Government is perhaps realistically viewing the tree as a resource to be utilised, and even a "blessing in disguise" (ibid). However, insufficient is known. For instance, goat herders in Baringo in Kenya have claimed that their goats lose their teeth through eating *Prosopis julifora* seeds!

8.4 Fauna

The semi-desert areas of Kenya traditionally contained abundant wildlife. The north-eastern shores of Lake Turkana include the Sibiloi National Park (gazetted 1974), with its protected shoreline, grasslands and scattered bush. The Park should host a variety of wild game species. The KWS Sibiloi National Park Tourist Map lists Grevy's and Burchell's Zebra, Grant's Gazelle, Beisa Oryx, Cheetah, Topi, Greater Kudu, Gerenuk, Hippo, Lion, Leopard, Striped Hyaena, Silver-Backed Jackal, Crocodile, Hippopotamus, and more than 350 species of birds. The Tourist Map's game list is incomplete, as the list should include Reticulated Giraffe, plus other species have been seen, for instance Wildcat and Baboon (the Consultant's visit in July 2010).

Due to competition with increasing numbers of pastoralist's livestock, and bush-meat poaching, the wildlife population has in general diminished outside national parks, reserves and conservation areas. This is evident throughout Kenya, and there is often livestock competition within the parks as well. Grazing is permitted within Sibiloi National Park, although it is discouraged.

Wildlife is to be found mainly on the north-eastern side of the lake, where the human population densities are lower, but wildlife will also be encountered throughout the desert regions east and south-east, where community-based wildlife conservancies are being encouraged through Kenya's Northern Rangelands Trust. However, whilst the creation of these conservancies provides an alternative revenue stream to the communities, it reduces the areas accessible for domestic livestock, and this will create challenges unless the tourism revenues are sufficient and distributed equitably.

A field visit was undertaken in January 2012, during which the Central and South Island National Parks were visited (reported earlier in Chapter 7, p93). An informative article describing some of the findings was published in the East African Wildlife Society magazine SWARA (Patrick Avery, 2012, see http://www.mursi.org/documents, also included in Volume II - Annexes to this report). A second informative article was shared with the Kenyan ornithology fraternity and was published by Nature Kenya in KENYA BIRDING (Kieran Avery, also included in Volume II – Annexes to this report). The key observations on fauna were:

1. No wildlife was seen on the western plains near Lodwar, Kalokol and Todenyang. The eastern shores were only briefly visited.
2. Birdlife was plentiful and diverse, with many passage migrants seen.
3. The island national parks have no permanent ranger presence, hence are vulnerable to poaching activities.
4. Commercial fishing on the lake is widespread. There is even a fishing community living legitimately on the beaches of North Island.
5. There is widespread encroachment by commercial fishing interests within "protected" areas. Fishing camps were seen on both island national parks, and fishing boats are known to head into the protected waters of the Sibiloi National Park under cover of darkness.
6. Fishing nets were found right across the mouth of the main Omo River channel where the river disgorges into lake.
7. Crocodiles are very scarce today, even on Central Island National Park, which is renowned as having the largest population of Nile Crocodiles on earth (far from the case today). Only four crocodiles were seen on Crocodile Lake on Central Island National Park. On an 8-day safari on lake (which included the Omo and Turkwel deltas), less than 30 crocodiles were seen, and not a single hippo was seen. It should be noted that Sibiloi National Park was not explored.
8. Crocodiles and soft-shelled turtles are often caught and die on fishing hooks and within nets. Evidence of these casualties was found in fishing camps.
9. Pelicans are occasionally shot by fishermen for food. The feather quills are used to make containers to carry salt.

10. Fishermen are poor and opportunistic and will plunder the eggs from crocodile nests, for food.

In March 2012, the Consultant was invited to contribute to the workshop hosted by National Museums of Kenya (NMK) / Kenya Wildlife Service (KWS) / UNESCO / IUCN which was investigating threats to the lake and its important World Heritage sites (details included in Volume II of this report). The UNESCO / IUCN Mission Report concluded later that the sites are "endangered" (WHC, 2012). Their Mission Report expressed concern at encroachment into protected areas, and noted that Grevy's Zebra and Reticulated Giraffe are now extinct in Sibiloi National Park (see UNESCO excerpts in the Annexes; also WHC, 2012).

The lake itself contains a diverse variety of fish, 60 species having been recorded (KWS), including some endemic species. The lake is also home to the Nile crocodile and the Hippopotamus, and these animals are protected within the Sibiloi and Island National Parks. More information on the National Parks and the Mount Kulal Biosphere Reserve was presented earlier in Section 5.4 (p77).

The arid lands host a remarkable diversity of interesting birdlife, and the Omo delta wetlands and oxbow lakes in particular provide contrasting habitat for a range of birds, and are located on important bird migratory routes (FoLT, 2010). Sibiloi National Park has 350 recorded bird species (KWS).

The photographic images below are examples of the diverse character of the southern, eastern and north-eastern lake shore.

South end of the lake | *El Molo Bay shore near Loiyangalani* | *North-eastern shore near Allia Bay*

Photo 5: Shores of Lake Turkana

Source of images: Sean Avery Photo Archive.

8.4.1 Domestic livestock units in Lake Turkana and the Lower Omo

The arid and semi-arid lands account for 50% of Kenya's livestock production (Snyder, 2006). The people of Turkana are mostly semi-nomadic pastoralists traditionally sustained by livestock and wild foods harvested from natural habitat. With frequent drought, livelihood dependance on pastoralism is vulnerable, and humanitarian food aid has been a feature of the area since the 1970s. The delivery of drought food relief has "become an institutionalised part of drought coping mechanisms" (Snyder, 2006). This is not sustainable, and has exacerbated tensions through resultant in-migration attracted by the opportunity to take advantage of food aid.

Ebei et al tabulated data on drought occurrence and associated small livestock mortality rates – see Table 22 below. The Ebei et al tabulated drought dates differ with other data sources. For instance Watson & van Binsbergen cite severe droughts in Turkana District dated 1976, 1991/92, 2004/05, with reported mortality rates as high as 70%, notably in 1976 (similar to the Ebei & Oba findings). The Arid Lands Resource Management Project refers to "Nine droughts recorded in Kenya in the last 40 years" (Abass, ALRMP), to which can be added the drought of 2009, grouped within decades as follows:

- 1971, 1975, 1977
- 1980, 1983/1984
- 1991/1992, 1995/96, 1999/2000
- 2004/2005, 2009

Notwithstanding discrepancies in dates, drought occurrences are frequent in the ASAL areas of Kenya. The variability in rainfall is a topic presented later in this report in Figure 42. The

situation is different in the Lower Omo. Although rainfall is similar, the perennial Omo River provides constant fresh water to those that can access the river.

Table 22: Drought events in Turkana District, *after Ebei et al (2007)*

Local name for drought	Year	Mortality rate (1) %
Lotiira	1952	61
Namotor	1960	55
Kimududu / Kibekbek	1970	54
Kiyoto atang'aa / Lopiar	1980	65
Lokwakoyo / Alkalkal	1990	53
Logara / Epompo	2000	63

Note (1): Mean mortality rate of small stock. Source: Ebei, Oba & Atuja (2007). Table originally presented in Avery, 2010 (AFDB study).

Table 23 overleaf compares livestock numbers in Turkana District with an ILRI (International Livestock Research Institute) estimate of land carrying capacity of the rangelands. In the 20-year period 1982 - 2003, the Turkana District's livestock population practically doubled. The ILRI study concluded that the sum of all livestock numbers exceeded the "carrying capacity" of the rangelands "by the end of the 1990s", and that Turkana District "today" (in 2008) "must be heavily over-stocked" (Watson & van Binsbergen, 2008).

The challenges in regard to competition for available forage are clear, and increasing human population is reducing the opportunities for mobility, as is land allocation to alternative uses. Thirteen million people in the Horn of Africa were reported affected by the 2010 / 2011 drought, including 7.7 million in Kenya and Ethiopia (Tilstone, 2011). In some parts of Kenya, 80 to 90% of livestock was reported to have perished, although recent reports urge caution and suggest it may have been less than 1/10th this proportion in the Horn of Africa (ibid). The same report correctly points out the absence of accurate population data in the drylands, and warns of being "misled by exaggerated estimates" (ibid).

The above comments on over-stocking are consistent with the remote sensing observation that Turkana's sparse grasslands are "hot-spots" for "land degradation" (Bai et al, 2008). The equivalent human population in 2008 was estimated at 469,713, with 86% of households estimated to own livestock (Watson & Binsbergen, 2008, p8).

A set of data on livestock population for Marsabit District is included in Table 24 overleaf, and compared with Turkana LSU data in Figure 27 on p101. Stock numbers rise and fall, but overall, Marsabit stock numbers have declined. In contrast, Turkana LSU levels increased from the early 1990s. The Marsabit statistics show a large reduction in both cattle and camel numbers since the late 1980s. Livestock numbers are controlled by forage availability, which is rain dependant, but security plays a part. The quality of the statistics is however uncertain.

Table 25 on p101 includes comparable livestock data for the three districts bordering Lake Turkana, and also includes some data for the Lower Omo. The year 2003 was chosen for convenience of available data only. Turkana and Marsabit Districts are similar in size, and the numbers of cattle and camels are of a similar order of magnitude, whereas the shoat population in Marsabit is a quarter the equivalent population in Turkana District. In contrast, the Lower Omo area contains the largest number of cattle thanks to the perennial Omo River, and this is achieved within a fraction of the area.

Samburu District to the south of the lake is also relevant to any study of the project area, as it reaches the southern lakeshore. This district is one-third the size of Turkana District. Samburu as a whole differs in several respects. It is topographically different, with mountainous areas of Basement Complex rocks. Mean annual rainfall is higher and the annual predicted biomass production is double the figures expected in areas bordering the lake (Kalff et al, 1983). Hence there are proportionally higher cattle numbers evident to any visitor. This is confirmed by estimates obtained from a recent census (Kinnaird et al, 2010). The tabulated 2003 figures below are estimates as the census did not include the whole district, and presented data for 2001 and 2010. The census is interesting because the cattle numbers in 2010 had halved since

2001, believed to have been due to the very severe drought. Whilst cattle numbers halved, over the same period the hardier shoats and camels remained numerically much the same (ibid).

Table 23: Livestock population in Turkana District

	Shoats	Cattle	Camels	Donkeys	LSUs Donkeys Excluded
1978 [4]	2,667,700	522,900	112,400		464,547
1981 [4]	1,117,800	147,000	108,000		231,520
1982 [4]	1,142,300	158,100	99,800	77,700	228,653
1982 [1]	(1,065,920)	(103,290)	(82,780)		(188,271)
1984	1,546,000	162,900	94,100	57,800	251,467
1987 [4]	1,856,100	221,100	108,800	62,200	306,240
1988 [4]	2,166,900	288,500	81,000	44,100	321,627
1990 [5]	960,000	413,000	117,000	52,000	318,667
1993 [2]	1,267,880	153,550	63,153		198,862
2003 [2]	2,926,800	193,600	140,760		400,413
2005 [6]	3,075,400	197,900	172,400	35,160	443,393
Holding cap [3]	2,439,003	146,898	79,801	-	291,367

Source of table: Avery, 2010 (AFDB study), updated substantially. Data sources listed below.

Sources of statistics in the table:

(1) Rutten: The original Rutten data Table 5.4 was presented in Tropical Livestock Units (TLU). TLUs are converted above to livestock numbers assuming the conversion 1 TLU = 1 head of cattle = 10 sheep = 11 goats = 0.7 camels (after Watson & van Binsbergen 2008, p15-16). Note this definition differs from the Ministry of Water Development Design Manual LSU (Live Stock Unit) definition for water consumption (1 LSU = 1 Camel = 3 Local Cattle = 2 Grade Cattle = 3 Donkeys = 15 Shoats).

(2) MoL&DF, Turkana District, Annual Reports, 2003-2005: Note that the last livestock census was undertaken in 1988 and that the MoL&DF figures are otherwise "adjustments" based on "perceptions of District Livestock Officers" (Watson & van Binsbergen, 2008).

(3) ILRI, Watson & van Binsbergen, 2008, p15: These are "collective" figures, taking into account different Livestock Units competing for / sharing the same forage.

(4) Ministry of Agriculture & Livestock Development Management (MALDM, 1994). Note that data 2000-2005 was not based on counts but on the "perception" of the DLOs (District Livestock Officers) (Watson & van Binsbergen, 2008).

(5) Turkana Drought Contingency Planning Unit (MALDM, 1994, p175).

(6) UNICEF / Rural Focus (UNICEF, 2006).

Table 24: Livestock population in Marsabit District

	Shoats	Cattle	Camels	Donkeys
1963 (Brown)[7]	549,000	225,000	207,000	
1964 (Spinks)[7]	618,000	280,000	320,000	6,000
1970 (Watson)[7]	509,000	196,000	146,000	
1972 (Watson)[7]	375,000	142,000	134,000	
1977 (MoLD)[8]	859,000	395,000	134,000	17,000
1979 (MoLD)[8]	840,000	291,000	145,000	
1983 (MoLD)[8]	1,025,000	420,000	220,000	20,000
1984 (MoLD)[8]	627,000	252,000	200,000	18,000
1985 (MoLD)[8]	662,000	260,000	206,000	21,000
1986 (MoLD)[8]	796,000	299,000	204,000	22,000
1987 (MoLD)[8]	836,000	314,000	227,000	23,000

	Shoats	Cattle	Camels	Donkeys
2002 [9]	673,700	128,000	69,000	17,100
2003 [10]	744,120	145,250	75,000	
2004 [10]	788,000	150,350	78,000	
2005 [10]	760,000	150,250	75,000	
2006 [10]	625,000	94,250	60,000	
2007 [10]	673,000	96,400	80,000	

Data sources:

(7) Cited in Range Management Handbook for Kenya, Marsabit (MoLD, 1991).

(8) Range Management Handbook for Kenya, Marsabit (MoLD, 1991).

(9) DLPO, MoLD, Marsabit (Oxfam Quebec (2003) & ECHO).

(10) DLPO, MoLD, Marsabit (Maina, 2010).

Table 25: Livestock population in Marsabit District compared with other districts and the Lower Omo

	Area km^2	Shoats	Cattle	Camels
2003 Marsabit District [3]	66,000	744,120	145,250	75,000
2003 Turkana District [4]	68,032	2,926,800	193,600	140,760
2003 Samburu District [5]	20,988	(236,000)	(155,000)	(12,450)
Lower Omo [6]	1,582 [7]	448,955	447,882	344

Source of original table: Avery, 2010 (AFDB study), updated with Lower Omo data.

Data sources:

(3) Maina, 2007 (AFDB study).

(4) Table 23 *above.*

(5) Estimated from Ewaso Ngiro 2010 census and 2001 data (Kinnaird et al, 2010).

(6) Sogreah, 2010, citing 'Downstream ESIA' of Agriconsulting & Mid-Day, 2009.

(7) Sogreah 2010, Table [10].

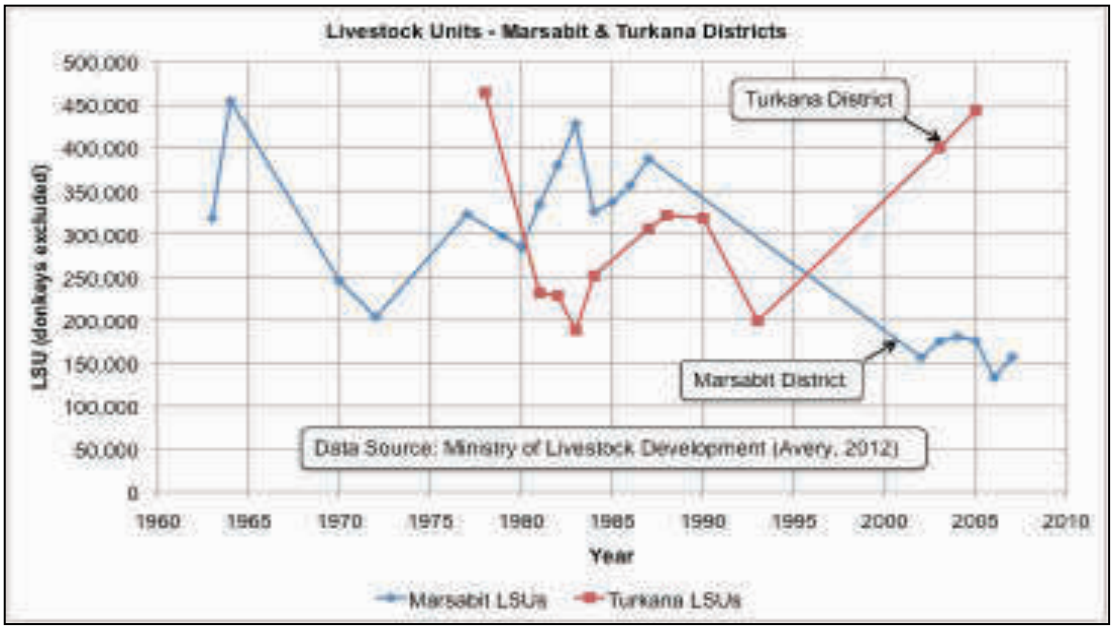


Figure 27: Livestock unit trends in Turkana and Marsabit Districts

8.4.2 Geology and physiography

Lake Turkana was formed within the Kenya Rift, an integral part of the East African Rift System extending over 3,000 kilometres from the Red Sea and Gulf of Aden, through Ethiopia, Kenya and Tanzania, to Southern Mozambique – see Figure 28 on p104 (Dunkley et al, British Geological Survey, 1993).

"…The Rift Valley is divisible into three main physiographic zones, which are broadly coincident with the main tectonic elements of the Rift. These are the inner trough, the western margin, and the eastern margin…" (ibid).

Lake Turkana lies within the "inner trough", which is visible on a satellite image as a string of lakes / closed basins, the first in Kenya being Lake Turkana, followed by Lake Baringo to the south, then Lake Bogoria, Lake Nakuru, Lake Elmenteita, Lake Naivasha, Lake Magadi, before crossing into Tanzania to Lake Natron, continuing south to southern Mozambique, through a further succession of lakes / closed basins. A similar string of lakes exists to the north-east through Ethiopia's Rift Valley.

The Rift Valley is regarded by geologists as "one of the best examples of an incipient or early stage in the formation of a constructive plate margin" (ibid).

Geologically, the Omo-Gibe Basin consists of the following proportions (Woodroofe, Vol. II, Part 1, Page 2.5):

- 11%: Pre-Cambrian Basement (outcropping in the lower basin).
- 80%: Tertiary volcano-sedimentary rocks overlain by felsic lavas and pyroclastics (throughout, but primarily associated with the highlands).
- 9%: Quaternary alluvial and lacustrine deposits and recent volcanic cover.

Earlier references cite different geological proportions, namely 68% volcanic deposits and 25% alluvial deposits (Yuretich et al, 1976; and British Geological Survey, 1993).

Lake Turkana's chemistry is dominated by the Omo River inflows that are largely responsible for replenishing the lake. The lake water chemistry is in turn linked to the basin geology.

8.4.3 Topography and soils

The Omo Basin in Ethiopia is divided on the basis of topography, 49% being "Highland" (above the 1,500 metre contour line), and 51% being "Lowland" (below the 1,500 metre contour line) (Woodroofe, Vol. II, Part 1, p2.8).

A map of soils surrounding Lake Turkana is included in Figure 29 on p105 (Kenya Soil Survey, Sombroek et al). Descriptive notes of the soil types are included in Volume II of this report - Annexes.

The terrain around Lake Turkana is the sculpted product of climate, rift faulting and vulcanism. The eastern, western and northern lake shorelines are accessible by road, but the southern shoreline is very much less accessible, although rough tracks exist. Very accurate shore descriptions are provided in previous detailed references (Hopson et al, 1982).

In brief, the northern end of the lake is flat with surrounding hills, and is dominated by the inflowing Omo River delta and its plains. The delta zone is the most densely populated area of the lake environs on account of the perennial fresh water inflow, and the opportunities for more settled agro-pastoralism and fishing. The northern end of the lake is also the most important from the point of view of fisheries, being the most productive sector of the lake. The flat areas north of the lake, with their meandering channels and oxbow lakes, were the bed of the former larger palaeo lake that existed less than 10,000 years BP (Butzer et al, 1971) – see Figure 16 on p75.

The lake shoreline is generally barren with stunted vegetation, offering no opportunities for cultivation (apart from the Omo delta region). There is very little aquatic vegetation on account of the high lake water salinity. Due to the strong winds, much of the shoreline is a "high-energy" shoreline with vigorous wave action. People subsist through nomadic pastoralism, agro-pastoralism and fishing. The north-eastern shoreline includes the Sibiloi National Park with its fascinating fossil beds, its petrified forest near Allia Bay, and with grazing and browse for wildlife

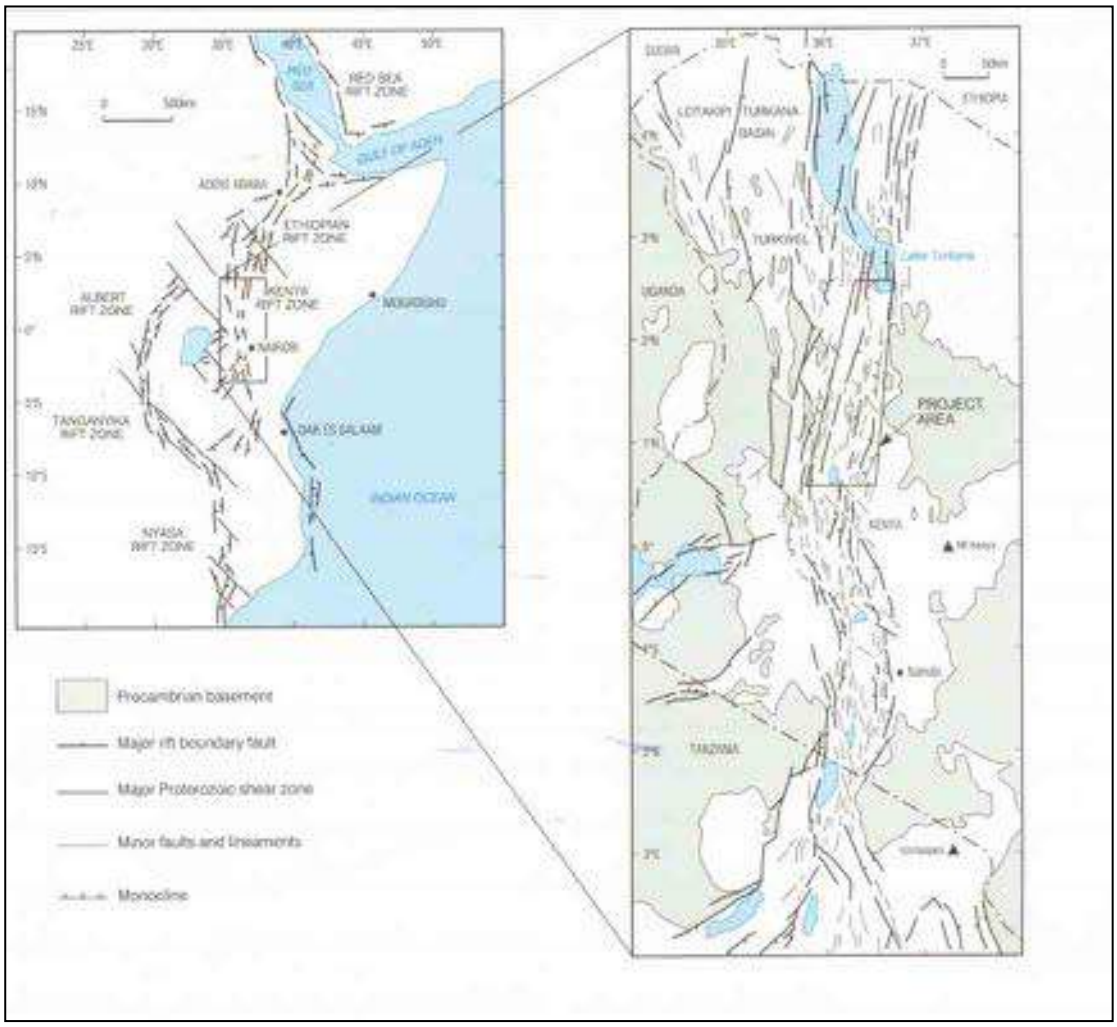
(and also livestock). To the south-east of the national park lies the Chalbi Desert with its flats, dunes and stony desert hills.

The south-eastern lake shoreline to the south is predominantly strewn with lava boulders, with lava scarps overlooking the lake, and with lava headlands also jutting into the lake. Looming 2,000 metres in elevation over this area is the massive Mount Kulal, the top of which is forested, in stark contrast to the desolate surrounding landscape.

The southern end of the lake is very difficult terrain, created through the volcanic activity of the "Barrier Volcanic Complex", which formed a dam blocking this end of the lake from the Suguta Valley beyond to the south. Hence the lake was once a very much larger lake, and once extended south of the "Barrier".

The south-western rugged shore is mountainous, rising dramatically and steeply from the lake, a feature caused by the older Basement geology exposed here – see Figure 29 on p105.

Further north, the immediate western lakeshore is flat compared to the rugged terrain of the lake's southern end, but with a mountainous backdrop to the north approaching Todenyang. However, there are interesting dunes at Eliye Springs south of Lodwar. Eliye's sandy beach and doum palms are not unlike the Kenya coast, providing another interesting contrast in this rugged terrain. Eliye is proposed as a future "resort city" associated with the proposed Lamu to South Sudan transport corridor, which is planned to pass the western side of the lake (FoLT, 2012a). The western shoreline also includes the discharge points / deltas for the Kerio and Turkwel rivers, although flows are intermittent. The western shores are much more densely populated than the eastern shores (see Figure 21 on p83).



Notes:
The Rift Valley extends from the Red Sea and Gulf of Aden rifts at the Afar triple junction, through Ethiopia, Kenya, Tanzania, to southern Mozambique (British Geological Survey, 1993).

Figure 28: Rift Valley, and Lake Turkana within the Rift Valley

Source of maps: Dunkley et al, British Geological Survey, 1993
(abstracted from BGS Figure 2.1).

Note: Descriptive notes on soil types and topography are included in Volume II of this report - Annexes.

Figure 29: Soil Map of the Lake Turkana area within Kenya

Source of soil map: Soil Map of Kenya, Kenya Soil Survey, Sombroek et al.

9 LAKE TURKANA - DRAINAGE BASIN

9.1 Lake Turkana's drainage basin

Contemporary Lake Turkana is a closed basin, and the lake water level is sustained by the inflow from rivers and rainfall on the lake surface, which balance the natural "losses" (predominantly due to the very high lake surface evaporation characteristic of arid areas).

The literature presents a wide range of catchment areas depending on interpretation, ranging between 148,000 km^2 (Butzer et al, 1971), 130,860 km^2 (Hopson et al, 1982), 203,080 km^2 (Velpuri & Senay, 2011; ILEC, 2011, etc), and 148,000 km^2 (Garcin et al, 2012; UNEP, 2012).

The main difference between Hopson's 130,860 km^2 and the 148,000 km^2 of Butzer / Garcin and others is the exclusion of "Sanderson's Gulf", a "large tectonic depression lying to the north of the Labut Range and west of the Omo Delta" (Hopson et al, 1982). Butzer described the "Gulf" as "…an extension of Lake Rudolph and now serves as an overflow basin for water from the Omo River..." (Butzer, 1971).

Sanderson's Gulf became disconnected from the main lake sometime between 1908 and 1920 (Hopson et al, 1982). Sanderson's Gulf is the terminus of the Kibish River and other ephemeral watercourses, and perhaps overland flooding from the Omo River as well. This depression is very well illustrated by the ponding evident NW of the lake in the aerial imagery in Figure 49 (later in this report on p142). Flood water ponded in the depression, forming a separate lake. This ponded water would contribute to the underlying water table through percolation, which will be linked to the lake water table. However, unless Sanderson's Gulf filled and spilled to the main lake, it would not be contributing to the surface water inflow to Lake Turkana.

The very much larger area of 203,080 km^2 (Velpuri et al and ILEC) stemmed from inclusion of the Ethiopian Rift Valley lake basins within the Turkana Basin, which is not a correct reflection of the contemporary basin that actually contributes surface water flow to the lake. The error was pointed out and has since been corrected.

In former wetter times (>7,500 BP), the Ethiopian Rift Valley's Lake Abaya and Lake Chamo drained into Lake Turkana from the north-east via Lake Chew Bahir (once named Lake Stefanie). At the same time, Lake Bogoria overflowed north into Lake Baringo, which in turn overflowed into the Suguta Valley, which filled and overflowed into the Kerio River and thence north into Lake Turkana – see Figure 17 above on p76. At that time, the Suguta Lake level was over 200 metres higher than Lake Turkana's level today.

Today, the Ethiopian Rift Valley lakes do not contribute to contemporary Lake Turkana surface water inflows, nor does the Kibish River. Neither do Lakes Bogoria, Baringo and the Suguta Depression, all of which today are closed basins, as is Lake Turkana itself. Hence the contemporary Turkana surface water basin area is very much less than the former basin area.

A Turkana surface water drainage basin drainage map is included on p108 in Figure 30 (after Vetel et al, 2004). A modern GIS based map is included on p109 in Figure 31 (UNEP, 2012). The UNEP GIS map includes the Sanderson's Gulf catchment, which is not strictly contributing to lake surface water inflows, for the reasons given above.

The following main drainage areas were delineated in earlier studies:

- Omo River.
- Kerio and Turkwel Rivers.
- Other ephemeral rivers.
- The lake surface itself.

Although the Omo catchment is only 56.6% of the total in Table 26 overleaf, the Omo River contributes over 90% of the lake inflow (Ferguson & Harbott, 1982; Avery, 2010). This river rises in the Ethiopian highlands where rainfall increases with altitude, and annual rainfall is overall very much higher – see Figure 32 on p110.

The Kerio and Turkwel Rivers contribute less than 10% of the total water discharge into the lake, although they comprise 30% of the Turkana surface water drainage area (see Table 26 below). Note that the Turkwel River has since been dammed by Kenya for hydropower generation at Turkwel gorge, hence the flows are arrested at this point, thereby affecting the potential contribution pattern to the lake.

The ephemeral rivers contribute floods intermittently, and these floods are short-lived. The contribution of water and minerals by the ephemeral rivers is said to be minimal (Hopson et al, 1982).

Hence the Omo River is the principal source of water and water-borne sediments, nutrients and minerals entering the lake. The chemistry of the lake is thus mainly governed by the Omo River water quality, as stated earlier. Any changes in the quality and quantity of the Omo River waters will thus directly affect the lake ecology.

Table 26: Catchment areas after Ferguson & Harbott *(Hopson et al, 1982)*

Drainage Area	Catchment Area km^2	% Total Drainage
Omo Basin	74,000 (1)	56.6 %
Ephemeral rivers	9,900	7.6 %
Kerio & Turkwel Rivers	39,400	30.1 %
Lake Turkana surface	7,560	5.7 %
Total	130,860	100 %

Source: Ferguson & Harbott, 1982 (Hopson et al., Vol.1, Table 1.3)

Note (1): Given as 78,006 km^2 in Gibe III Downstream EIA (Agriconsulting & Mid-Day, 2009) as the Kibish catchment was included within the Omo catchment.

Table 27: "The Lake Rudolph Basin" – "Approximate Dimensions"

Drainage Area (2)	Catchment Area km^2
Omo River	73,000
Sanderson's Gulf	11,000
Rudolph Littoral	15,000
Lake Rudolph	7,500
Turkwel – Suam River	24,500
Lomenyangaparat River (3)	3,500
Kerio River	13,500
Total (1)	148,000 (1)
Suguta Depression (2)	13,000 (2)
Baringo Basin (2)	5,500 (2)

Notes on table:

(1) Butzer et al 1971 (see Hopson et al., 1982, Table 1.3).

(2) Butzer and Hopson did not include the Ethiopian Rift Valley lakes within the "Rudolph" Basin. Butzer did however tabulate the Suguta and Baringo catchment areas, but the areas were not included in the "Rudolph" Basin total area (as shown in the table above).

(3) R.Lomenyangaparat is a seasonal river reaching the western lakeshore (its drainage area is intermediate between the Turkwel and Kerio Rivers - see Figure 16 *on p75**).***

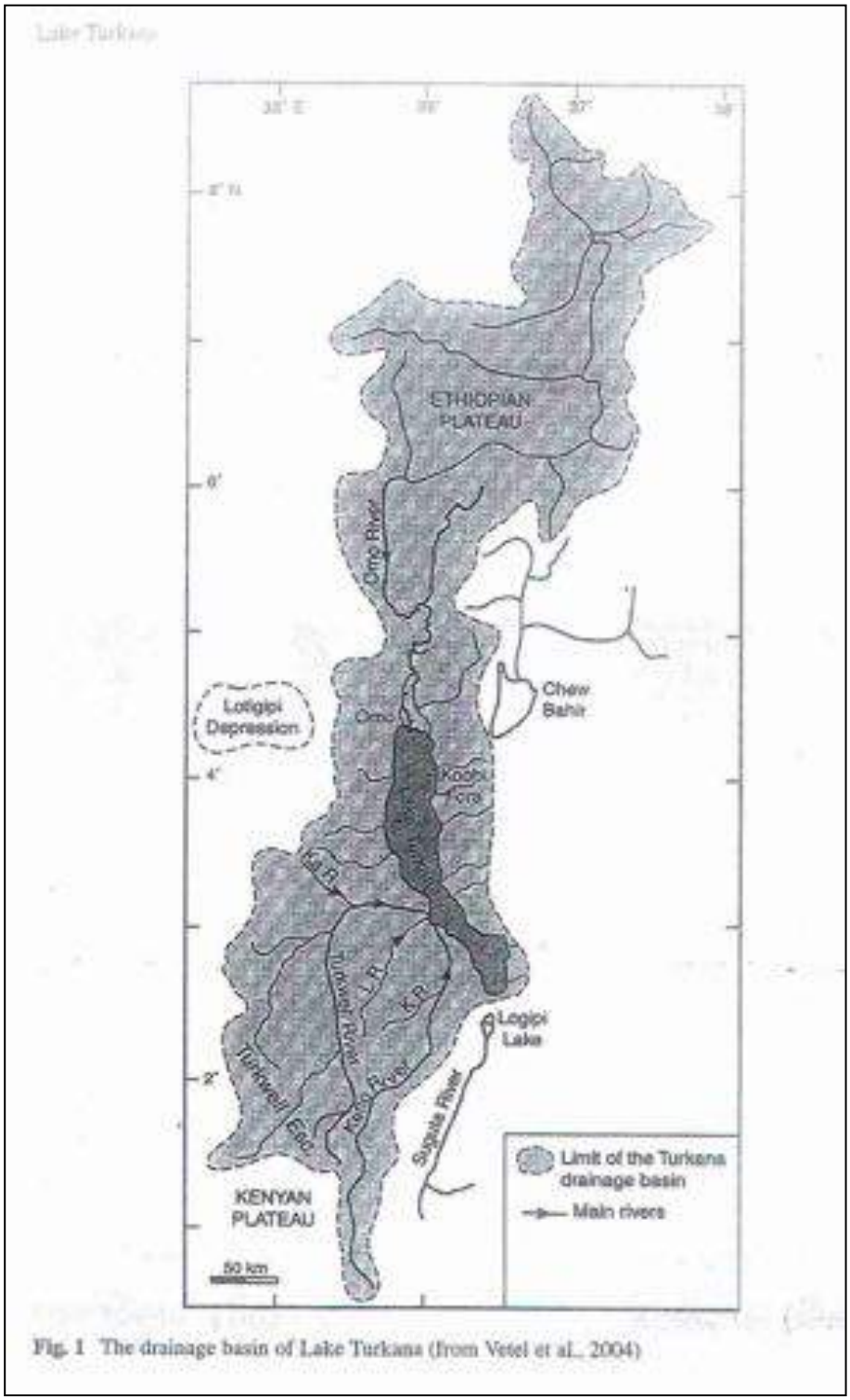


Fig. 1 The drainage basin of Lake Turkana (from Vetel et al., 2004)

Figure 30: Lake Turkana's catchment area

Source: Vetel et al, 2004.

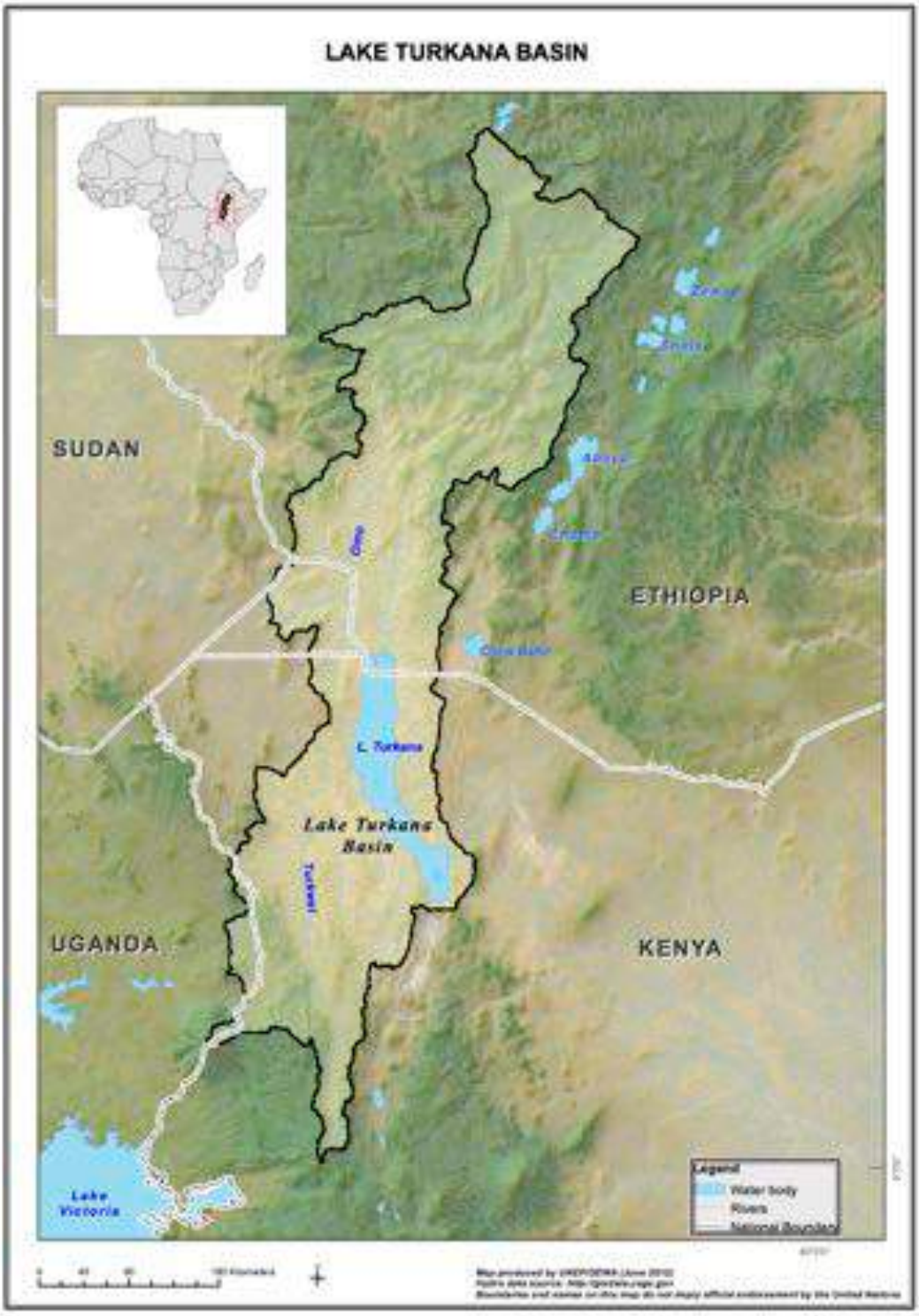


Figure 31: Lake Turkana Basin (148,000 km^2)

Source: UNEP / DEWA, June 2012 (Pers.Comm., UNEP, Nairobi, 2012).

Note that the "Sanderson's Gulf" catchment is included as contributing to lake inflow (refer to discussion above – see Section 9.1 on p106).

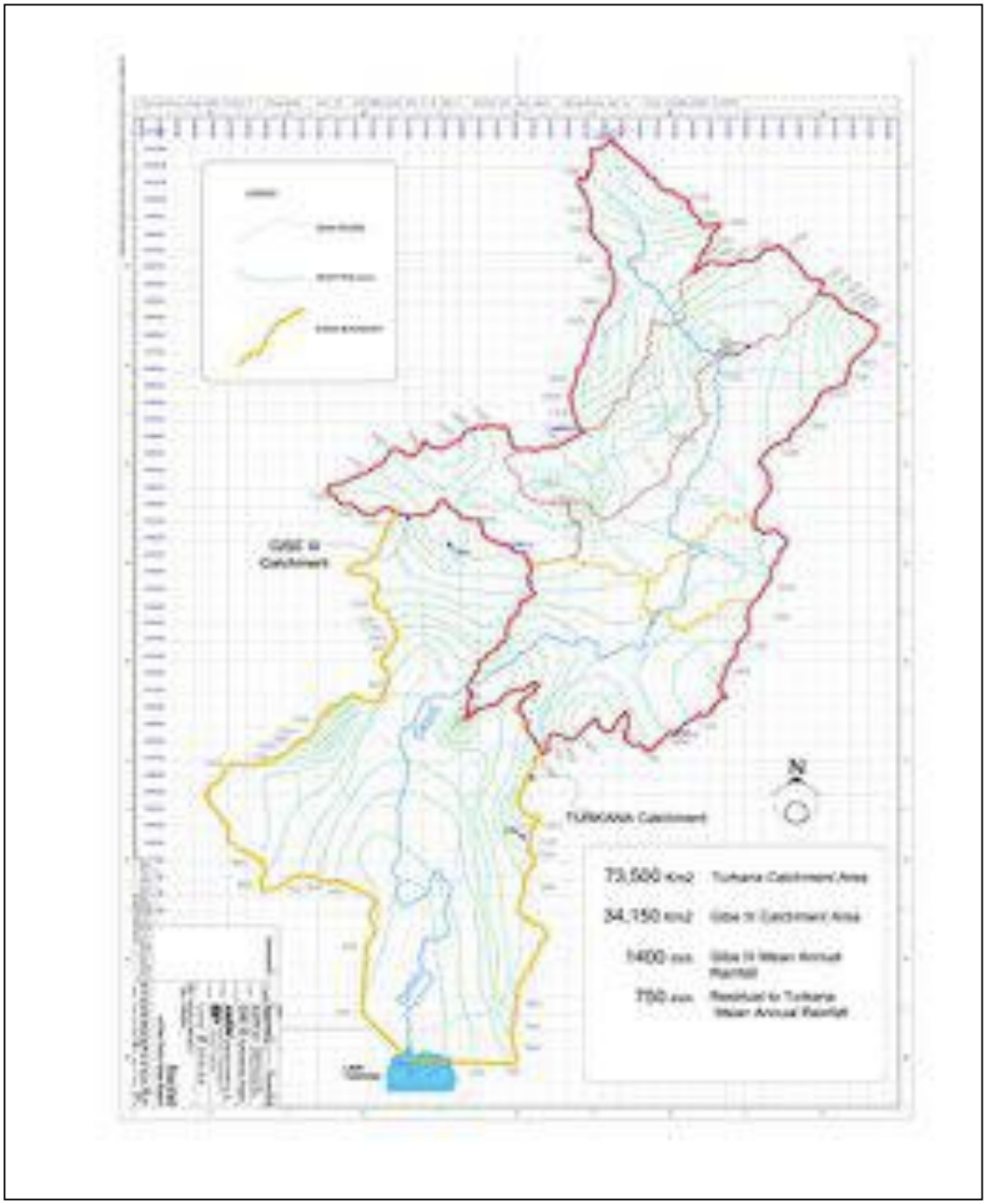


Figure 32: The Omo River's catchment area, with rainfall isohyets, and with Gibe III catchment delineated (in red).

Source of Figure: Extracted from "Presentation on Gibe III Reservoir First Impounding Addis Ababa, 3rd June 2009", by Studio Pietrangeli for the Ethiopian Electric Power Corporation (EEPCo).

9.2 Kerio River basin and delta

The Kerio River reaches the lake a short distance south of the Turkwel river delta, both deltas being on the south-west side of the lake. The Kerio delta is similar to the Turkwel delta, but of the "constructive-elongate" type delta (Wilkinson, 1988, citing Elliot in Reading, 1978).

The Kerio River Basin in Kenya covers a total of 17,800 km^2 extending over 350 kilometres distance, with an average basin width of only 50 kilometres (Sogreah, 1982). The upper basin rises in high altitude forest to the north-east of Timboroa (altitude 2,750 metres). The middle basin is the Kerio Valley, which is fed by perennial rivers from forests on the top of the western wall of the Rift Valley. The lower basin is semi-arid, and river flows are irregular. Flows have been measured at River Gauging Station 2C8 at Lokori, at which point the drainage area is 6,470 km^2. Based on measurements between 1970 and 1973, the mean inter-annual flow at Lokori was estimated to be 10.5 m^3/s (Sogreah, 1982). Much of this flow can be expected to dissipate between Lokori and Lake Turkana, although some flash floods can reach the lake.

Hence the Kerio River contribution to the water balance of Lake Turkana is likely to be less than 5 m^3/s on average per annum. The Kenya Government has been reported to be considering transferring water from Lake Victoria (FAO, 2007), but such plans are far distant.

The Kerio river channel to the lake is clearly marked in green in Figure 29 on p105 (the green colour signifies soils developed on recent floodplains). Similarly, the fainter green lines in the 3-D satellite image in Figure 12 on p68 are the Turkwel and Kerio Rivers. The Kerio is south of the Turkwel.

9.3 Turkwel River basin and delta

The Turkwel River also reaches the lake south of Lodwar. The Turkwel has a "fluvial-dominated, high constructive lobate" type delta (Wilkinson, 1988, citing Elliot in Reading, 1978).

The Turkwel River Basin covers an area 23,900 km^2 (Sogreah, 1982). Hence the combined Kerio and Turkwel catchment area is 17,800 + 23,900 = 41,700 km^2, which is slightly larger than estimated in Table 26 above (p107) by Ferguson & Harbott in 1982 (Hopson et al, 1982).

The Turkwel Basin is by far the largest river basin in northern Kenya, originating at an altitude 4,320 metres on Mount Elgon on the Kenya Uganda border to the west.

The Turkwel River runs a course of length 340 kilometres, and there are three distinct catchment zones (Sogreah, 1982), as follows:

- The Suam River, catchment area 5,900 km^2, which drains from the Uganda border in the west, to Turkwel Gorge where the river is dammed.
- The Wei Wei and Morun Rivers which drain the Cherangani Hills, with a combined catchment area of about 1,500 km^2 at Marich Pass, prior to joining the Turkwel River at Kaputir (ibid).
- The semi-arid plain of the Turkwel River forms the third part of the basin extending from Kaputir (downstream of Turkwel Gorge) to Lake Turkana (ibid). The only flow is in the form of releases from the dam, supplemented by localised flash floods arising from storms. The major part of any water reaching Lodwar infiltrates or evaporates before the lake is reached. A river gauging station existed at Lodwar, but very few measurements were obtained. During a field trip in January 2012, a strong flow was seen at Lodwar, with a fraction of the flow seen reaching the delta at the lake.

The "yield" of the Turkwel River at Lodwar was estimated, prior to the construction of the Turkwel Dam, to be 810 Mm^3 (25.7 m^3/s) annually (Sogreah, 1982). At that time, Sogreah estimated the mean annual inflow at Turkwel Gorge to be 600 Mm^3 (19.0 m^3/s).

The Turkwel river channel is clearly marked leading to the lake on Figure 29 on p105, and in the 3-D satellite image in Figure 12 on p68 (the rivers are conspicuous because of the distinct green colouration along their water courses, and the Turkwel is the northernmost of the two).

9.4 Combined Turkwel / Kerio runoff into Lake Turkana

The combined average annual combined Turkwel and Kerio runoff into the lake was estimated to be less than 30 m^3/s (Sogreah, 1982). This is about 5% of the contribution by the Omo River (Avery, 2010).

9.5 "Other rivers" contribution to runoff into Lake Turkana

There is no flow data for "other" seasonal river inflows into Lake Turkana.

Annual runoff in the Lake Baringo catchment was reported to be about 4% of annual rainfall (Sogreah, 1982). The Consultant has experience of rainfall / runoff studies of other arid zone catchments, and in such zones, the percent runoff is unlikely to exceed 5%.

5% runoff was thus adopted as the basis for estimating "other catchments" runoff from rainfall in the water balance model developed for Lake Turkana (Avery, 2010).

9.6 Climate change in Kenya's Rift Valley basin

A recent Interim Report on "The Development of the National Water Master Plan 2030" has presented water balance data for each of Kenya's basins, and predicted the effects of climate change (JICA / NK, April 2012).

The JICA study team derived average precipitation 509 mm/yr in the Rift Valley basin (present), rising to 583 mm/yr in Year 2030, and 653 mm/yr in Year 2055 (ibid).

For Kenya's Rift Valley basin, the annual river flow was determined to be 4% of annual rainfall currently, and this was forecast to increase to 5% by Year 2055 (with climate change). These figures tally with the percentage runoff assumptions made above by Avery in 2010.

9.7 Irrigation in the Turkwel and Kerio Basins, and in Turkana District

A separate study commissioned by the AFDB assessed the irrigation potential within the Lake Turkana drainage basin in Kenya (Maina, 2010). The summary findings from the AFDB report are tabulated below. The tabulated Kenyan irrigation schemes are a fraction of the scale of irrigation schemes envisaged in the Lower Omo, and have negligible impact on the lake.

Table 28: Irrigation in the Turkwel / Kerio basins

	Area hectares	Water requirement m^3/s
Present irrigation	2,187	2
Potential irrigation	10,000	10

Note: Table taken from Avery, 2010 (AFDB hydrological study).
Original source of data: Maina, 2010 (AFDB Draft report).

Kenya's Range Management Handbook for Turkana District estimates that "less than 3% of the District has agricultural potential" (MALDM, 1994, Ch5, p159). A figure of 20,000 hectares is mentioned (ibid, p160). The Handbook describes the Turkana as "semi-agriculturalists", as grain, whether purchased or grown comprises 30% of their diet, with sorghum being planted "in low-lying flood plains where rainwater collects easily" (ibid, p176). Because the rains are unpredictable, "cultivation is risky", hence the Turkana "do not rely heavily on cultivation" (ibid).

The total irrigated area in the whole of Kenya in the year 2011 was 165,830 hectares (JICA, 2012). The updated National Water Master Plan currently under preparation lists potential dams for irrigation within Rift Valley Province, but none are close to Lake Turkana (ibid).

The only potential new irrigation scheme in close vicinity to the lake is the recently announced Todenyang scheme reported earlier in this report in Section 4.11 on p53.

9.8 Leakage from Lake Turkana into the Suguta Valley

The possibility of "minor sub-surface flow" from Lake Turkana into the lower elevation Suguta Valley to the south has earlier been investigated (Dunkley et al, British Geological Survey, 1993).

The Suguta Valley is located at an altitude 60 metres below Lake Turkana's water level, and there are no significant emergent springs, thus suggesting an impermeable barrier between Lake Turkana and the Suguta Valley (ibid).

British Geological Survey (BGS) referred to the work of Yuretich & Cerling who had concluded that the chemical balance of the lake rules out the possibility of any major sub-surface flow from the lake to the west or south. But BGS also cautioned that minor outflow could be masked by "various uncertainties attending the chemical balance".

10 CLIMATE AND RAINFALL - THE OMO BASIN

10.1 Climate zones of Ethiopia

The climate data in this chapter was previously presented in the Consultant's report to AFDB (Avery, 2010). This has been reviewed and updated where possible.

Ethiopia's varied topography has created three climatic zones, which are known as follows (Cheung et al, US Library of Congress, 2008):

- "Dega" or "cool zone", which covers the central sections of the western and eastern parts of the north-western plateau, elevation mostly above 2,400 metres altitude, with daily temperatures ranging from "near freezing" to 16^{o}C.
- "Weina Dega" or "temperate zone", which consists of parts of Ethiopia's central plateau, ranging in altitude between 1,500 metres and 2,400 metres.
- "Kolla" or "hot zone" which generally comprises areas below 1,500 metres altitude, the Danakil Depression and tropical valleys of the Blue Nile (and also the Lower Omo Valley).

Within each climate zone, seasonal variations and atmospheric pressure systems contribute to the creation of three seasons, as follows (ibid):

- The "Keremt" Season, the main rainy season, usually lasting June to September, covering all of Ethiopia except the southern and south-eastern parts (Seleshi & Zanke, 2004; Cheung et al, 2008).
- The "Belg" Season, the light rains season, usually from March to May. This is the main source of rain in the south and south-eastern parts of Ethiopia (ibid).
- The "Bega" Season, the dry season, October to February, during which the whole country is dry, with the exception of occasional rainfall in the central sections (ibid).

10.2 Tropical climate and the ITCZ

The seasonal variation in climate stems from the oscillation of the Inter Tropical Convergence Zone (ITCZ). The ITCZ is "a low pressure area of convergence between tropical easterlies and equatorial westerlies along which equatorial wave disturbances take place" (Gamachu, 1977). Put simply, the ITCZ is the region that circles the Earth, near the equator, where the trade winds of the northern and southern hemispheres come together (NOAA). The intense sun and warm water of the equator heat the air in the ITCZ, raising its humidity and making it buoyant. Aided by the convergence of the trade winds, the buoyant air rises. As the air rises, it expands and cools, releasing the accumulated moisture in an almost perpetual series of thunderstorms (ibid).

Greatest rainfall typically occurs when the midday sun is overhead (ibid). On the equator this occurs twice a year in March and September, and consequently there are two wet and two dry seasons. Further away from the equator, the two rainy seasons merge into one, and the climate becomes more monsoonal, with one wet season and one dry season. In the northern hemisphere, the wet season occurs from May to July, in the southern hemisphere from November to February (ibid).

Seasonal shifts in the location of the ITCZ drastically affect rainfall in many equatorial nations, resulting in the wet and dry seasons of the tropics rather than the cold and warm seasons of higher latitudes. Longer-term changes in the ITCZ can result in severe droughts or flooding in nearby areas. The following sections describe the monthly changes that occur:

- In March, the ITCZ is located south of Ethiopia, moving northwards. In south-western Ethiopia, the surface air currents are the Atlantic maritime equatorial westerly air flows from the south-west (Gamachu, 1977).
- In April, the ITCZ is located in southern Ethiopia.
- In May, the ITCZ starts moving rapidly northwards.

The easterly and south-easterly moist air currents ascend over the highlands in spring, and they bring the "small rains"- the "Belg". The Atlantic westerly air flows may also be a source of moisture at this time.

- In June and July, the ITCZ is located in northern Ethiopia and north of Ethiopia. In August, the ITCZ starts moving rapidly south from its position in northern Ethiopia.
- In September and October, the ITCZ is located in central and south-central Ethiopia.

Between June and September when the ITCZ is located north of Ethiopia, the Omo Basin is under the influence of equatorial westerly air flows from the Atlantic Ocean and south-easterly winds from the Indian Ocean. The equatorial Atlantic westerlies bring rain - the "Keremt", whereas the Indian Ocean south-easterlies are dry, having deposited their rain over the Kenya highlands (Woodroofe & Associates).

- In November, the ITCZ has shifted southwards towards the Equator.
- Through December, January and February, the ITCZ remains to the south. The air currents are determined by anti cyclones over Egypt and Saudi Arabia, and by the low-pressure area over south-west Ethiopia and Lake Victoria. Rain at this time of "winter" might be due to convection storms coupled with orographic rainfall (Gamachu, 1977).

10.3 Climate variation and change within the Omo Basin, Ethiopia

The climate of the Omo Basin varies from a tropical sub-humid climate in the uppermost northern catchment in the highlands of Ethiopia, to a hot arid climate in the southern-most parts of the Basin (which includes the semi-desert of Lake Turkana in Kenya). The intermediate catchment, which comprises the bulk of the Omo Basin, falls within the tropical sub-humid zone (Woodroofe & Associates, 1996).

Annual rainfall varies from 1,900 mm/yr in the north / middle areas of the Omo Basin, to less than 300 mm/yr in the south (Woodroofe & Associates, 1996). A rainfall contour map was included earlier in Figure 32 on p110. The annual rainfall generally diminishes from the middle basin as the river drops from the highlands to the lowlands and Lake Turkana in the south.

The annual rainfall fluctuation over time for three selected stations is shown in Figure 33 on p119 together with 5-year moving averages. There is no apparent change in mean annual rainfall average evident from the graphs over the record period.

The variation in the monthly rainfall pattern through the basin is shown in Figure 34 on p120. In the north, the rainfall seasonality is uni-modal, becoming increasingly bi-modal towards the equator, as reported by others (Salini; Studio Pietrangeli; Agriconsulting; Avery, 2010).

Interesting studies have been done on long-term rainfall trends in Ethiopia. Data from 1960 to 2008 was analysed, for instance, with the findings below reported (Cheung et al, 2008):

- "…Overall…there are no significant changes or trends in annual rainfall at the national or watershed level in Ethiopia..."
- "…Many of the contradictions in previous findings on trends and climatic extremes in Ethiopia may be explained by the arbitrary division of the study area as well as the quality of the data..."
- "…It is unclear whether climate change is driving any systematic trends in Ethiopia's rainfall…"

- "…In the Omo Basin as a whole, the "Keremt" rainfall was the majority at 48.1% of the annual total, with the "Belg" rainfall accounting for 31.4% of the annual rainfall…"
- "…In the Omo Basin, a small decline in "Keremt" rainfall was reported over the period analysed, with this decline being offset by a small increase in the "Belg" rainfall…" (ibid).

Consultants Sogreah cited a global climate change study by Cline W.R. 2007, with similar findings, namely "decrease in average rainfall from April to September (the wettest period) and an increase from October to March (driest period)".

The main significant change expected in the Omo Basin is the increasing runoff proportion resulting from catchment change, as reported previously (Woodroofe et al, 1996; Salini & Studio Pietrangeli, 2009; Avery, 2010). This increasing trend dates from about 1987, the consequence of catchment degradation, which increases flood magnitudes and diminishes low flows.

The impacts of climate change have been evaluated for various scenarios of population growth, temperature change, and precipitation change up to the year 2070 (Salini & Studio Pietrangeli, 500 HYD RSP 001A, Jan 2009). The Salini & SP report noted that rainfall data only up to 2002 was used, and should be updated. Two climate models were applied, and the runoff was shown to vary in the range -10% to +6%. As there is an increasing runoff trend due to catchment change, no long-term detrimental change was anticipated in the conclusion.

As a general trend, global warming increases evaporation, which in turn reduces runoff (provided rainfall does not increase). There is no evidence of precipitation change in the basin (Cheung et al, 2008), and the decline in runoff with increasing temperature is likely to be offset by the ongoing increase in runoff percentage associated with catchment development. The increase in evaporation rate with warming will increase the evaporative losses from storage reservoirs and Lake Turkana itself.

Temperature data is included in Section 11.3 on p123. There is a diurnal temperature cycle, hot during the day, and cooling at night. The maximum and minimum monthly temperature averages measured in the Lower Omo and near Lake Turkana are fairly uniform through the year – see Figure 35 on p120. Long-term temperature rise with climate change has been demonstrated elsewhere in this report based on the increasing mean air temperature at Lodwar, as well as increasing lake water temperature – see Figure 39 on p125, and Section 11.3 on p123.

10.4 Rainfall and evaporation in the Lower Omo, Ethiopia

The Omo Basin Master Plan's main report presented data for 22 meteorological stations ranging in altitude 1,300 to 2,550 metres above sea level (Woodroofe et al, 1996, Vol. VI, A1). The main report did not list any climate stations within the Lower Omo, although this was the major potential area proposed for irrigated agriculture. The nearest climate station included was at Jinka, at an altitude 1,480 metres, almost 1,000 metres higher altitude than the lake, with potential evapotranspiration only 1,196 mm/yr. The Master Plan's main report did include a map of annual potential annual evapotranspiration (PET), with the Lower Omo falling within the contour PET = 1,600 mm/yr. This is very low when compared to Kenyan data in Turkana, for which PET > 2,400 mm/yr up to the Ethiopian border – see Figure 45 on p133.

However, in another volume in which the Master Plan presented the "Lower Omo Irrigation Pre-Feasibility Study", a table of rainfall and PET was included citing data for a climate station not listed in the main report. Details provided were: "Kelem, alt. 440 masl, UTM P37 1610.5295". "Kelem" is also called "Kaalam" in another volume of the Master Plan, for which monthly rainfall data is presented (Woodroofe et al, 1996, Vol. VI, A1). Hence "Kelem" is the "Kaalam Mission" referred to by Butzer (Butzer et al, 1971).

Sogreah presented data from Omorate itself (from the "defunct Presbyterian Mission"), and this data is tabulated in Table 29 and Table 30 below on p118, along with the data from the Master Plan. This "defunct Presbyterian Mission" is likely to be the "Kaalam Mission" referred to by

Butzer, (for which Butzer published data from 1966 - 67 totalling a similar 330.5 mm/yr - Butzer et al, 1971). The original Sogreah data source would be useful to see, especially the Sogreah PET values.

Sogreah noted that rainfall in Omorate is 1/5th of the rainfall at Gibe III dam, and potential evapotranspiration is 35% higher than at the dam (Sogreah, 2010). As there is insufficient rain in the lower basin to sustain rainfed agriculture, it is easy to see why indigenous people developed the skills of successful flood recession agriculture (ibid and others).

The tables overleaf show that the Sogreah Omorate rainfall is nearly identical to the Master Plan's Kelem (Kaalam) rainfall data, totalling 335 and 308 mm/yr respectively – see Table 29 on p118.

In contrast to the above direct rainfall data comparability, Sogreah's 2,293 mm/yr evapotranspiration at Omorate is much greater than the PET = 1,551 mm/yr reported by the Master Plan for "Kelem" (see Table 30 below on p118). The Sogreah 2,293 mm/yr figure is directly comparable with Kenyan data for northern parts of Lake Turkana (for which PET is at least 2,400 mm/yr - see Figure 45 on p133). Table 30 also includes an evapotranspiration figure of 1,702 mm/yr for the Gibe III "dam site". The Master Plan's Lower Omo evapotranspiration of 1,551 mm/yr is less than the corresponding figure at the higher elevation cooler dam site, which is not possible.

Wind affects evapotranspiration rates. The Master Plan does not provide any wind data for the Lower Omo plains, the nearest climate station being at Jinka, almost 200 kilometres north of the lake, and located at the higher altitude 1,480 metres above sea level. At Jinka, the annual average wind speed was 1.21 m/s. On average, wind speed did not fall below 0.9 m/s, varying within the range 0.9 to 1.4 m/s with a peak 2.0 m/s in March (Woodroofe et al, Table B2, Vol. VI, A1, 1996).

Strong SE winds are the norm on Lake Turkana, being much stronger in the southern sector of the lake (Hopson et al, 1982). Butzer stated: "...there can be little question that southerly winds, from SSW to ESE quadrant, are the rule at all seasons both over Lake Rudolf and the Omo delta plain…" (Butzer et al, 1971). Butzer provided wind measurements for the period June - August 1968. A mean wind run of 163 kilometres in 24 hours (1.9 m/s) was recorded (Butzer's data was also cited by Hopson as evidence of diminishing wind strength towards the delta – Hopson et al, 1982). Butzer's reported average wind speed of 1.9 m/s is less than elsewhere on the lake, but is almost double that at Jinka, and comparable to Lodwar's 2.3 m/s average wind speed (see Section 11.2 on p121). The wind speeds on the Omo delta plains are thus significant and will contribute to high evapotranspiration rates.

Available average minimum and maximum monthly air temperature variations applicable to the Lower Omo are plotted in Figure 35 on p119. The Lower Omo's Kaalam Mission data is comparable to the FAO Climwat data for Lokitaung not far away in northern Kenya, as would be expected. Also plotted is data for Lodwar, which is warmer but comparable, being further south than Lokituang and closer to the equator.

It is concluded in this report that the Master Plan's "Kelem" PET of 1,551 mm/yr is too low. According to the Sogreah Eto data, the Master Plan's "Kelem" PET is less than the applicable figure for the Gibe III dam site, yet the dam site is located at a higher and cooler altitude. This would be inconceivable. If correct, it would mean that the Master Plan's Lower Omo Irrigation Pre-Feasibility Study under-estimated the crop water requirements in the Lower Omo. The irrigation water demands based on evapotranspiration needs are potentially 67% of the value that should have been calculated. To an extent, the Master Plan inadvertently compensated by adopting a very low 40% overall irrigation efficiency (see Section 4.16 on p61 later in this report).

Table 29: Lower Omo rainfall: Mean monthly (mm/mth) and annual averages (mm/yr)

	J	F	M	A	M	J	J	A	S	O	N	D	Yr
Omorate [1]	15	18	36	89	50	18	39	4	5	20	17	24	335
Kelem [2]	11	22	42	69	40	19	18	8	15	17	29	19	308
Kaalam [3]	9	1	73	8	108	-	1	66	34	-	31	-	331
Fejij [4]	6	36	54	85	41	38	13	8	30	26	38	36	411
Gibe III [5]	29	43	87	117	155	204	241	236	163	84	34	26	1,420

Sources:

(1) "Defunct Presbyterian Mission at Omorate" (Sogreah, 2010).

(2) "Kelem" @ 440 masl (Omo-Gibe Basin Master Plan, Vol. V, Lower Omo Irrigation Pre-Feasibility Study, 1996). Also called "Kaalam" in Omo-Gibe Basin Master Plan (Woodroofe et al, Table A2, Vol. VI, A1).

(3) "Kaalam Mission", data recorded by JR Swart, June 1966-67 (Table 1-5, Butzer, 1971).

(4) Fejij is located @ 600 masl: Lat.4°40'N, Long.36°25'E, about 20 kilometres north of the Omo delta, data 1985-89 only (Woodroofe et al, 1996, Table A2, Vol. VI, A1).

(5) Gibe III catchment (Climate Change Report, Salini & Pietrangeli, 2009).

Table 30: Lower Omo evapotranspiration: Mean monthly (mm/mth) and annual averages (mm/yr)

	J	F	M	A	M	J	J	A	S	O	N	D	Yr
Omorate [6]	202	203	194	138	248	197	217	230	172	126	151	217	2,293
Kelem [7]	136	142	157	149	109	123	113	95	129	138	127	134	1,551
Gibe III [8]	136	135	157	160	159	139	132	134	135	148	137	130	1,702

Sources:

(6) "Defunct Presbyterian Mission at Omorate" (Sogreah, 2010).

(7) Omo-Gibe Basin Master Plan (Vol. V, Lower Omo Irrigation Pre-Feasibility Study, 1996).

(8) Gibe III catchment (Climate Change Report, Salini & Pietrangeli, 2009).

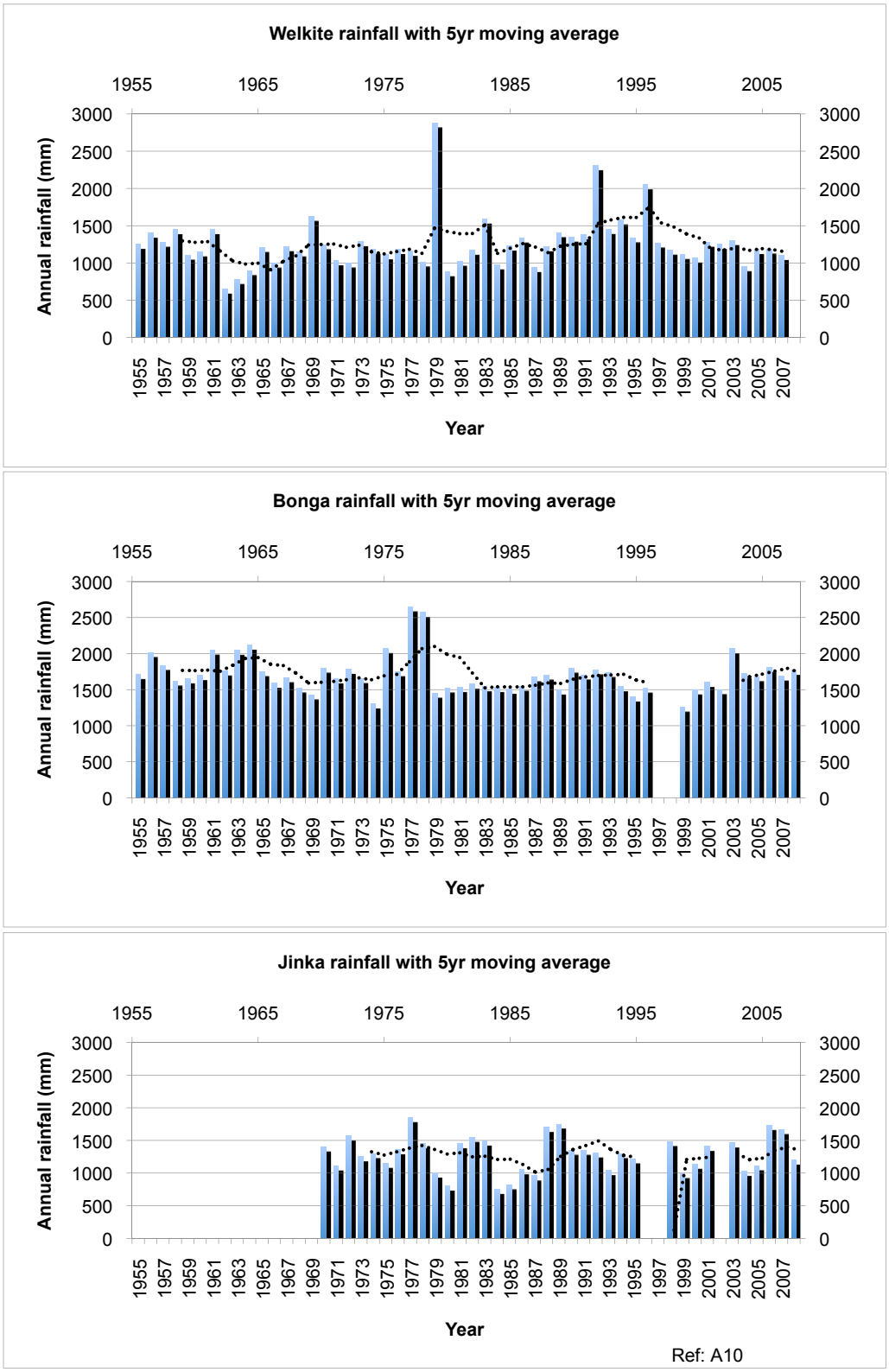
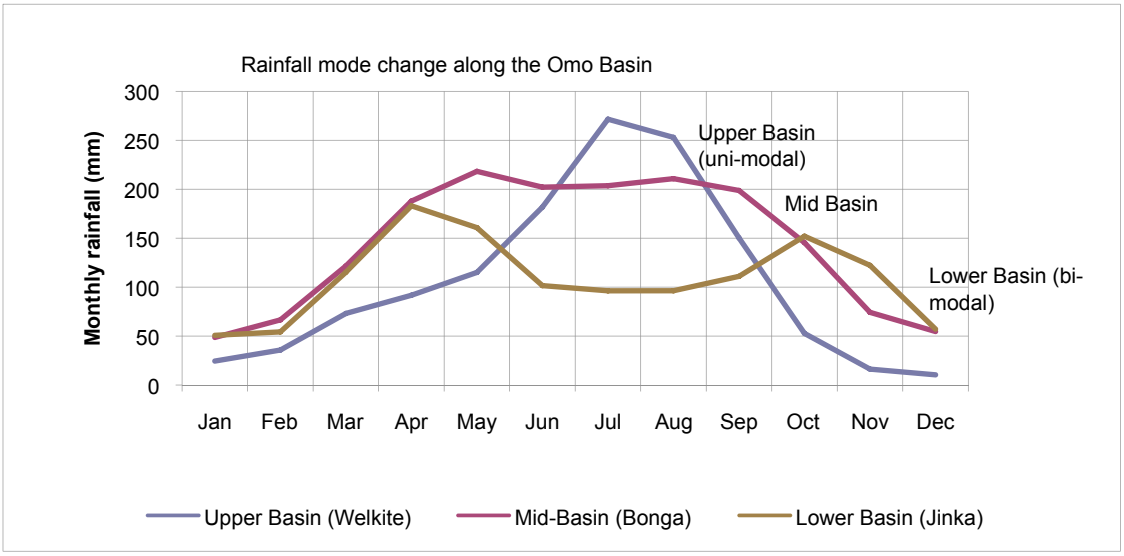


Figure 33: Annual rainfall variation in the Omo Basin at three selected rainfall stations (1955 - 2008 data)

Source of graphs: Avery, 2010 (AFDB study).
Source of monthly rainfall data: National Meteorological Agency (NMA), Addis Ababa.



Rainfall station co-ordinates as follows:

Welkite:	*Altitude 1,550 metres*	*Latitude 8° 16' N, Longitude 37° 49' E (1954 – 2008)*
Bonga:	*Altitude 1,650 metres*	*Latitude 7° 13' N Longitude 36° 14' E (1953 – 2008)*
Jinka:	*Altitude 1,480 metres*	*Latitude 5° 47' N Longitude 36° 34' E (1970 – 2008)*

Figure 34: Variation in average monthly rainfall pattern between upper, middle & lower Omo Basin (1955 – 2008 data)

Source of rainfall data: NMA, Addis Ababa, and Omo-Gibe Basin Integrated Development Master Plan, Vol. VI, A1, 1996. Source of Graph: Avery, 2010 (AFDB study).

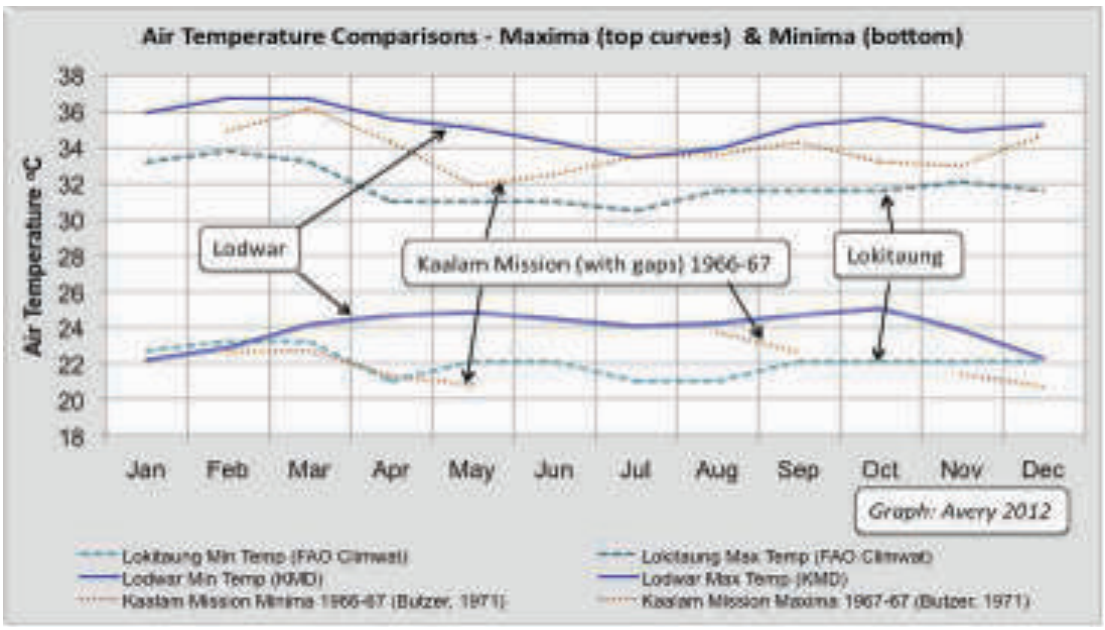


Figure 35: Average monthly variation in minimum & maximum daily air temperature at Lodwar, Lokitaung & the Lower Omo

Kaalam Mission Data collected 1966 - 67 (with uncertain data left as gaps). Kaalam is located 20 kilometres due north of the lake, on the west bank of the Omo River (Butzer, 1971).

11 CLIMATE & CLIMATE CHANGE - LAKE TURKANA

11.1 Meteorology

The climate of Lake Turkana is documented, although the arid zones of Kenya have very few full meteorological stations, as they are more concentrated in the densely populated highlands, as well demonstrated in Figure 36 (on p122).

The Kenya Meteorological Department (KMD) unfortunately no longer issues regular publications and yearbooks, although climatological data can be purchased. The last published summary of climatological statistics dated 1984 included full meteorological statistics for Lodwar 35 kilometres west of the lake, and for Lokori 55 kilometres SW of the lake (summarised in Table 31 overleaf). The closest station to the east of the lake in this KMD publication is Moyale, a long distance away. Data can also be obtained from other sources, such as FAO's 'Climwat' database.

Rainfall data tends to be more plentiful, being collected at many other locations and collected by parties other than the Kenya Meteorological Department. An example is the Kenya Police Department, whose remote posts will often measure rainfall daily, and will file rainfall record returns to the Kenya Meteorological Department in Nairobi. Available data is presented later in this report (see Table 32 on p127). Also listed is a station in Omorate in Lower Omo in Ethiopia referred to as a "defunct Presbyterian Mission" (Sogreah, 2010), plus Fejij, a station in Lower Omo listed in the Master Plan with a short record. Rainfall in the area of Lake Turkana is very low, increasing slightly towards the north end of the lake.

The "agro-climate" of Lake Turkana was described earlier as "very arid" and "fairly hot to very hot", with "desert scrub" and "very low potential for plant growth" – see Table 20 and Section 8.2 (on p95). The Turkana area has very high evapotranspiration rates – see Figure 45 on p133.

11.2 Wind

Wind data is recorded at the Lodwar Meteorological Station, as noted in Table 31 on p122.

Lake Turkana is characterised by strong prevailing SE winds. The lake winds are stronger than recorded at meteorological stations away from the lake (such as Lodwar), and the winds are strongest in the southern sector of the lake.

The mean daily wind run in Lodwar is 126.2 mile (202 km/24 hrs = 2.35 m/s).

The 1972-75 Turkana Project recorded the mean daily wind run at Loiyangalani as 760.8 km/24 hrs (8.7 m/s) compared to 294.8 km/24 hrs (3.4 m/s) for the same period at Longech. Longech is located on the lake near Kalokol, on the western shore, not far from Lodwar. The same study cited data from Butzer for the Omo delta plains north of the lake, which recorded a wind run averaging 163 km/24 hrs (1.9 m/s) (measured July – August 1968). These measurements correctly reflect the diminishing wind strength from the southern sector of the lake to the northern sector and the Lower Omo valley plains.

The winds have a pronounced daily cycle. The "general tendency" is "for strong morning winds to be followed by a relatively calm afternoon period" (Hopson et al, 1982). Generally, the wind blows strongly from 0900 - 1200 hrs, and is calm from 1600 - 2000 hrs (ibid). For this reason, experienced boat crews will not choose to venture onto the lake in the mornings.

Table 31: Climatological statistics for two stations near Lake Turkana

	Unit	Lodwar Data since 1919		Lokori 1976 - 77 1979 - 80
Temperature - Maximum	°C	1946 - 80	34.8	36.2
Temperature - Minimum	°C	1946 - 80	23.8	20.9
Temperature - Range	°C	1946 - 80	11.0	15.3
Relative humidity 0600 GMT	%		56	51
Relative humidity 1200 GMT	%		35	44
Rainfall – Mean	mm	1919 - 80	193	399
Rainfall – Highest	mm	1919 - 80	498	485
Rainfall – Lowest	mm	1919 - 80	19	103
Max 24 hr Rainfall	mm	1919 - 80	101.6	63.7
No of days of rain > 1 mm	No	1919 - 80	19	37
Daily sunshine – Mean	hr	1958 - 80	9.8	-
Daily sunshine – Max. Mean	hr	1958 - 60	10.2	-
Daily sunshine – Min. Mean	hr	1958 - 60	9.1	-
Daily radiation – Mean	Langley	1966 - 80	535	647
Monthly Evaporation - Mean	mm	1961 - 80	3,488	3,945
Daily wind run – Mean	mile	1967 - 80	126.2 (1)	108.2

Source: Climatological Statistics for Kenya (KMD, 1984).
Note: More recent data can be obtained from KMD – see later in this report.
Note (1): 126.2 mile/day = 203.1 km/day = 2.35 m/s

Figure 36: Kenya's meteorological stations

Source: Climatological Statistics for Kenya (Kenya Meteorological Dept., 1984).

11.3 Temperature increase in Lake Turkana

Global warming is well established, and regional East African lakes are warming as well, and as would be expected, the temperature change in the lake waters follows the trend of the rising air temperature (Water Resource Associates, 2010).

Sogreah cited a study by Ethiopia's National Meteorological Agency (NMA) for the period 1961 - 2006 (NMA, 2007). This NMA study determined a temperature increase 0.37^{o}C per decade in Ethiopia. Sogreah included graphs from that study showing anticipated change throughout Ethiopia. In the Lower Omo, the "anticipated change" was respectively: Year 2030: +0.9^{o}C; Year 2050: +1.7^{o}C; Year 2080: +2.7^{o}C (Sogreah, 2010).

Sogreah also cited global work by Cline W.R. (Cline, 2007), which forecast slightly higher increases than the above NMA report (ibid).

In order to evaluate the climate temperature change trend on Lake Turkana, the monthly mean maximum and monthly mean minimum temperature data was obtained for the Lodwar Meteorological Station. This is the nearest full meteorological station to the lake. Data was provided for the period 1967 - 2012. Earlier data is available as the station has been in operation since 1946, but the earlier data has not been digitised by the Kenya Meteorological Department, and hence was not provided. It would be useful to obtain this in a future study.

The results are plotted in Figure 37, Figure 38, and Figure 39 overleaf. The maximum and minimum air temperature has risen about 2 to 3^{o}C in 45 years (0.44 to 0.67^{o}C per decade).

Also plotted is satellite derived average lake temperature data kindly provided by the School of Geosciences of the University of Edinburgh (Pers. Comm., Dr Stuart MacCallum, 2012). For comparison, historic data is included from the earlier studies (Hopson et al, 1982; NIVA, 1988). The data trends are consistent. Temperature fluctuates little through the year in Lake Turkana, although there is a discernible cycle that matches the annual weather cycles. The general long-term trend is increasing temperature, although less noticeable with the daily minima data. The historic NIVA water temperature data of the late 1980s was higher than normal, approaching air temperature, and this would be consistent with the lake being at one of its historic lowest ever levels following a period of diminished inflow of cooler waters from the Omo catchment.

The water temperature data is based on measurements close to the surface of the lake. The water will obviously become cooler at depth, and this has been established by earlier measurements (Hopson et al, 1982), although this lake is quite well mixed. The measurements in the figures are also assumed average for the lake, as there is a temperature gradient along the length of the lake, cooler in the deeper southern sector, and warmer in the shallower northern sector. This temperature gradient is apparent from data presented in earlier studies (Hopson et al, 1982), as well as this study - see Table 39 and Figure 69 (p165 & 166 later in this report).

Studies by Water Resource Associates on Lake Victoria forecast an increase in temperature of only 1.3^{o}C in the 73-year period 1985 - 2058, with temperature change levelling out in later years – see Figure 40, p125 (Water Resource Associates, 2010). This rise in temperature is unlikely to be especially significant.

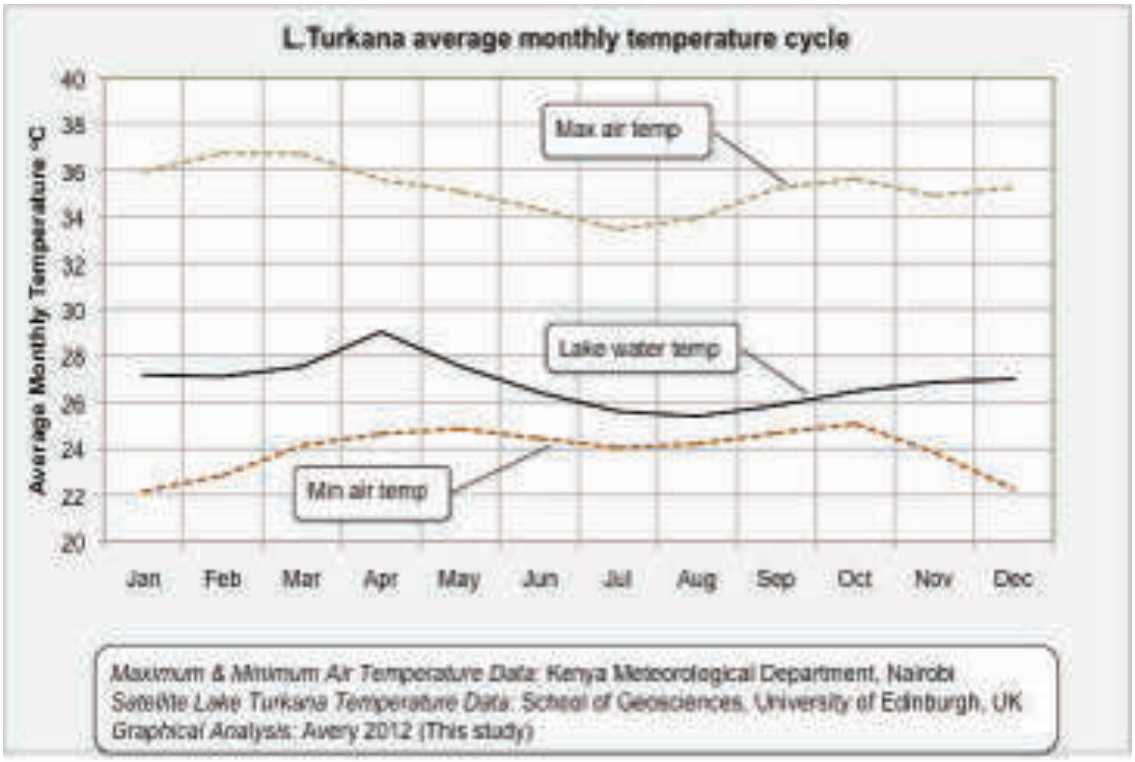


Figure 37: Lake Turkana's "Average Monthly" temperature cycle

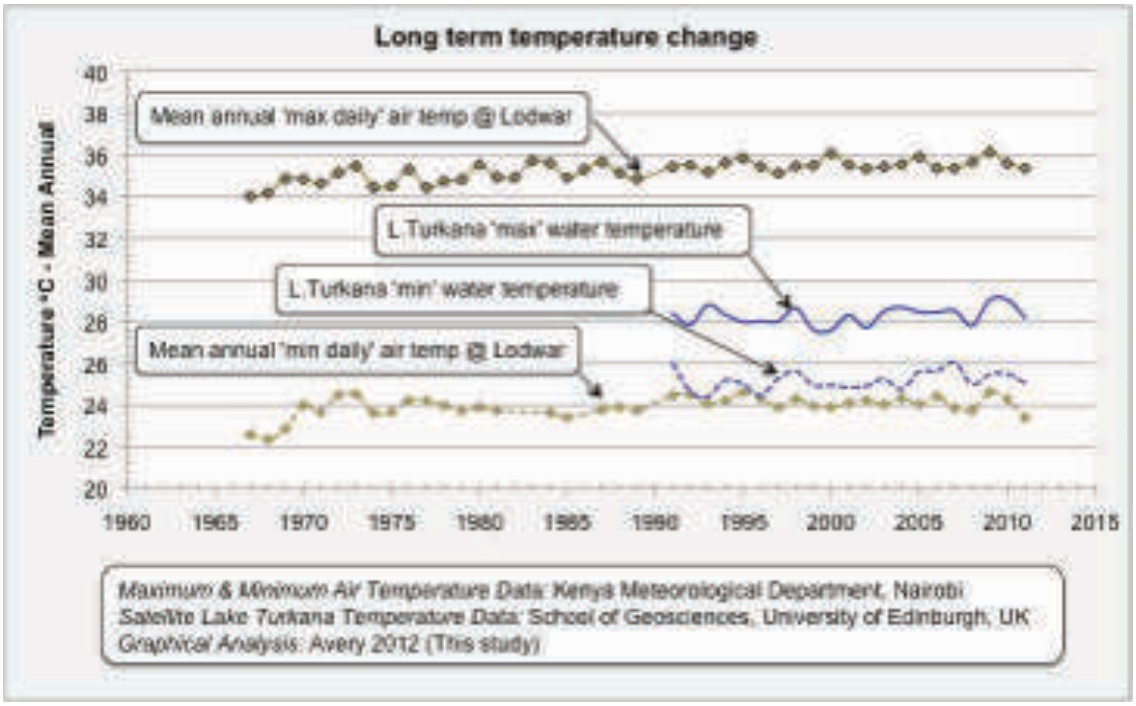


Figure 38: Lake Turkana's annual mean "Min." & "Max." temperature trends, 1967 - 2012

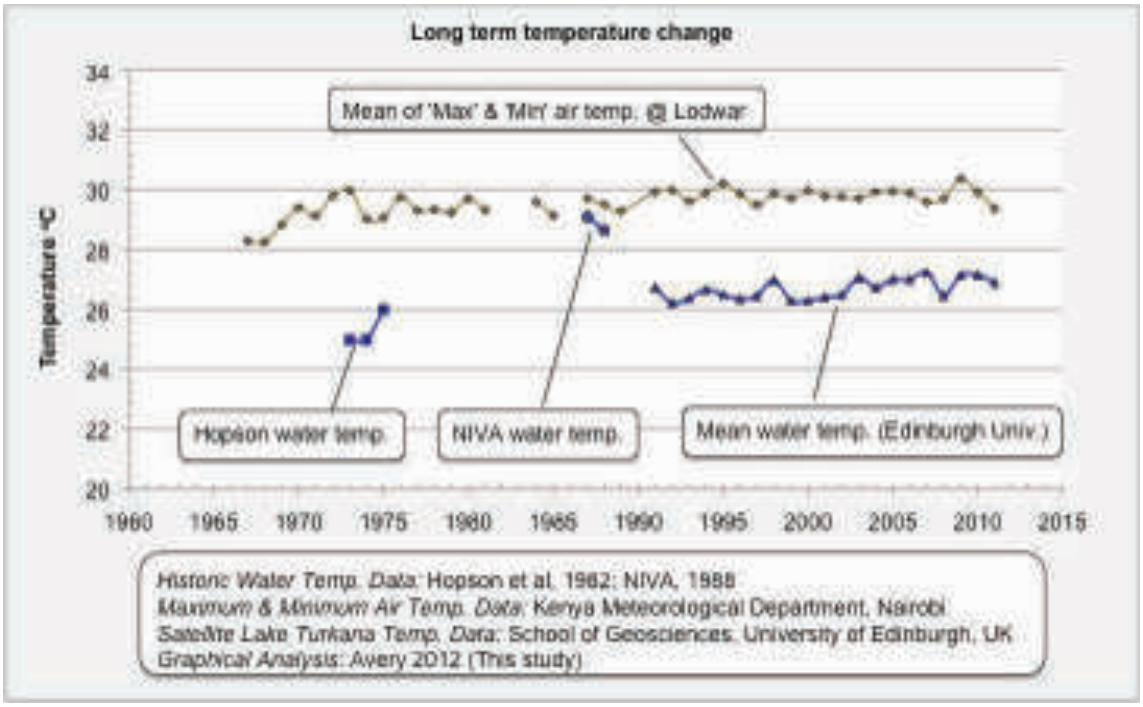


Figure 39: Lake Turkana's "Mean" surface water temperature data, 1967 - 2012

Note: "Mean" is the average of the "Maximum" and "Minimum".

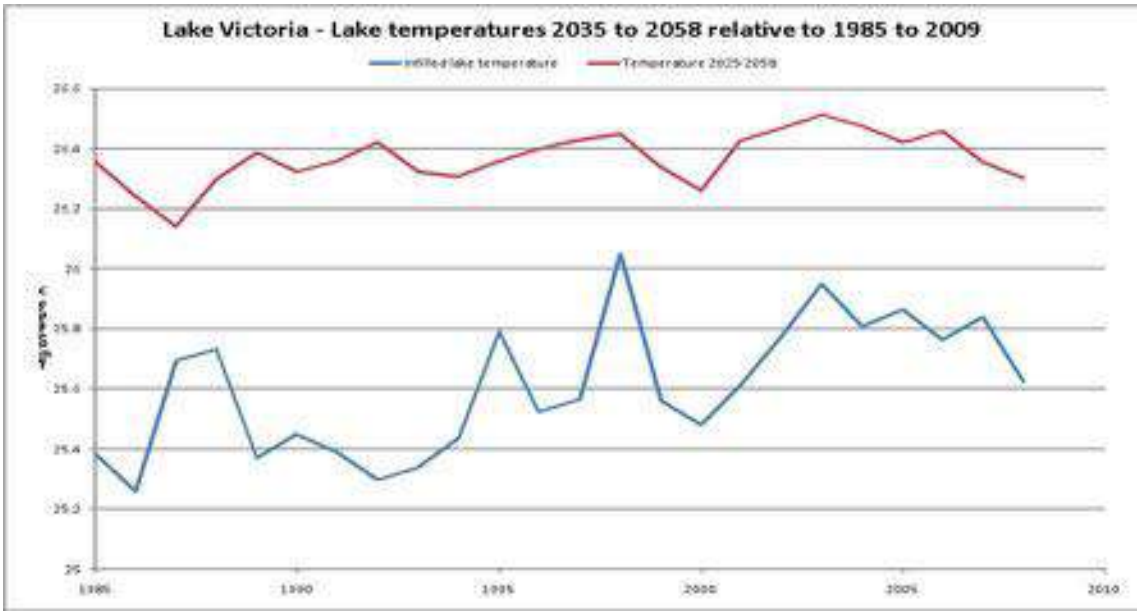


Figure 40: Lake Victoria temperature change, 1985 - 2009 & 2035 - 2058

Source of Graph: Water Resource Associates, 2010.
Lower Blue Line in Graph: Period 1985 - 2009. Temperature Range = 25.3 to 26.0 °C.
Upper Red Line in Graph: Period 2035 - 2058. Temperature Range = 26.2 to 26.4 °C.

11.4 Rainfall variation on Lake Turkana's shores, and climate change

Rainfall data was presented for the previous study for AFDB (Avery, 2010). Data was obtained from the Kenya Meteorological Department (KMD) for stations adjacent to the shores of Lake Turkana (summarized in Table 32 overleaf - after Avery, 2010). The data from the same stations was extended to 2011 for this study, although very little new data was available. Data for Lower Omo is obtained from consultants' reports and the Omo-Gibe Basin Master Plan.

Rainfall stations other than Lodwar have a high proportion of days with "missing data"; hence these records were less useful than the Lodwar data (ibid). Avery's analysis showed an apparent increase in rainfall towards the northern sector of the lake (ibid), but a single exceptionally high rainfall reading unduly influenced the evident annual average. However, stations in the Lower Omo valley show annual rainfall comparable with Todenyang. There are no rainfall stations at the southern end of the lake, but the southern end is even more arid and rainfall can be expected to be no higher than at Lodwar, and possibly lower (ibid), increasing beyond into the mountains at South Horr.

The monthly average rainfall variation was tabulated in Table 33 on p127 below, and is presented graphically in Figure 41, on p128 (after Avery, 2010). Rainfall on Lake Turkana is very much lower than within the middle and upper Omo Basin, which receives up to 2,000 mm/yr in the wetter western parts of the middle and upper basin. The bi-modal rainfall pattern observed in the Lower Omo Basin was similarly reflected in the Turkana rainfall stations. The "greener" characteristics of the "moister" Omo Basin are visually evident in the 3-D satellite image in Figure 12 (p68), in contrast to the barren landscape surrounding the lake (ibid).

The rainfall database was extended for this study, both forwards and backwards in time. The Kenya Meteorological Department's digital database for Lodwar did not extend further back than 1940. Data is available in hardcopy form, but this is not readily accessible. However, an annual data series extending back to 1921 was obtained from a Consultant's report (Norconsult, 1983), and this was included in Figure 42 (p128) where the long-term annual rainfall series for Lodwar is plotted. The long term average and moving average are both plotted. This data provides a valuable insight into climate change over the period of rainfall record. The 1920 - 1930s decade was the driest on record. The lowest ever recorded annual total was 18.5 mm recorded in 1933 (ibid). The early part of that century was a period of sharp lake recession (falling lake level). The 1950s were also extremely dry, and this was the period when contemporary lake levels "bottomed out".

Since 1921, the overall annual rainfall trend has been to increase. Climate change models produce variable results. For instance, Sogreah included the "anticipated change in rainfall" for Ethiopia (citing Ethiopia's National Meteorological Agency [NMA], 2007). The NMA graphs presented by Sogreah extended into northern Kenya, and the "anticipated change" in rainfall in northern areas of Kenya was 2030: 3.1-6.1%, 2050: 5.8-11.0%, 2080: 9.5-18.9% (ibid, Figure [20]). Since the rainfall is so low anyway, the increases do not amount to much in volumetric terms.

Sogreah cited another study on climate change (by Cline W.R., 2007) forecasting to 2099, which anticipated "decreased average rainfall from April to September (the wettest period) and an increase from October to March (driest period)". This was similar to the findings of a study cited by Avery, 2010, namely Cheung et al, 2008, which was discussed earlier in Section 10.3.

Figure 43 shows the variability of Lodwar and Todenyang rainfall (p129).

The Arid Lands Resource Management Project refers to "Nine droughts recorded in Kenya in the last 40 years", to which can be added the droughts of the 1920 - 1930s, 1940 - 1950s, and 2009, as follows (grouped within decades):

- 1971, 1975, 1977.
- 1980, 1983 / 1984.
- 1991 / 1992, 1995 / 1996, 1999 / 2000.
- 2004 / 2005.

The data and comments in this section relate only to the Turkana climate, and do not reflect the changes in lake level which are controlled by the Omo River flow, which in turn is controlled by the more humid and differing climate / rainfall regime prevailing further north in the Ethiopian highlands.

Research has shown that for very large lakes, the rainfall on the lake surface may be significantly higher than measured over the shoreline, for instance 20 - 30% higher in the case of Lake Victoria (Sene, 1998).

Table 32: Rainfall data for Lake Turkana – Data proportion available

Station No	*Latitude*	*Longitude*	*Station Location*	*Years Record*	*Start Year*	*% With Data*
Omorate			Omorate [5]	?	?	?
Fejij	N 04° 40' 00"	E 36° 25' 00"	Fejij [6]	5	1985	?
8535001	N 04° 32' 00"	E 35° 55' 00"	Todenyang	39	1959	59%
8635000	N 03° 07' 00"	E 35° 37' 00"	Lodwar	70	1940 [4]	97%
8736002	N 03° 32' 00"	E 35° 53' 00"	Loiyangalani	26	1973	35%
8636001	N 03° 41' 00"	E 36° 16' 00"	Allia Bay	20	1980	45%
8536001	N 04° 19' 00"	E 36° 14' 00"	Ileret	42	1959	60%

Notes:
1. *Data availability based on Kenya Meteorological Department (KMD) digital data availability.*
2. *Earlier data in some cases exists in hardcopy form.*
3. *This table abstracted from Avery, 2010 (AFDB Study) and updated with the latest data from KMD.*
4. *Data for Lodwar 1921-81 from Norconsult report dated 1983 (Norconsult, 1983).*
5. *Data for Omorate obtained from various sources including: Omo-Gibe Basin Master Plan (at "Kelem" / "Kaalam"); Sogreah, 2010 (at "Omorate"); Butzer, 1971 (at "Kaalam Mission") – see Section 10.4 on p116.*
6. *Data for Fejij available 1985-89 in the Master Plan (Woodroofe et al, 1996, Table A1, Vol. VI, A1, p44).*

Table 33: Average monthly and annual rainfall measured around Lake Turkana

Station No Stn Name	*Jan mm*	*Feb mm*	*Mar mm*	*Apr mm*	*May mm*	*Jun mm*	*Jly mm*	*Aug mm*	*Sep mm*	*Oct mm*	*Nov mm*	*Dec mm*	*Annual mm*
Lower Omo Omorate [1]	15	18	36	89	50	18	39	4	5	20	17	24	335
Lower Omo Fejij [8]	6	36	54	85	41	38	13	8	30	26	38	36	411
Lower Omo Kaalam [9]	11	22	42	69	40	19	18	8	15	17	29	19	309
8535001 [2] Todenyang	11.8	23.6	53.3	70.0	46.2	8.9	17.8	9.8	8.1	17.0	42.4	15.3	324.1 [3] [4]
8635000 [2] Lodwar	8.3	6.8	25.7	44.2	23.0	5.4	14.6	10.5	7.2	11.4	22.5	12.2	192.0
8736002 [2] Loiyangalani	6.2	9.8	23.7	31.7	20.8	8.2	5.4	1.2	2.9	6.4	31.1	4.3	151.6
8636001 [2] Allia Bay	6.8	11.7	33.6	52.5	13.2	6.9	14.6	1.8	3.7	6.9	21.7	32.1	237.8
8536001 [2] Ileret	16.3	13.8	46.9	65.0	34.8	5.8	8.2	5.0	2.9	12.0	60.6	24.1	280.4

Notes:
1. *Monthly data from Sogreah report (Sogreah, 2010). Omorate is in Ethiopia, on the Omo River, not far from the lake, and is assumed representative of the Lower Omo / delta area. This station could be Kaalam Mission – see Note 9 below.*
2. *Monthly data from KMD and analysed by Avery, 2010 (AFDB Study).*
3. *Updated series for Lodwar obtained 2008-11 (this study). No new data available at other stations.*
4. *Mean annual rainfall reduces to 256 mm if 1967 data is excluded.*
7. *Data for Omorate obtained from Sogreah 2010 (at "Omorate") – see* Table 29*, on p118.*
8. *Fejij data 1985-89, altitude 600 masl: Woodroofe et al, 1996, Vol. VI, A1.*
9. *Kaalam data (no dates), altitude 440 masl: Woodroofe et al, 1996, Vol. VI, A1.*

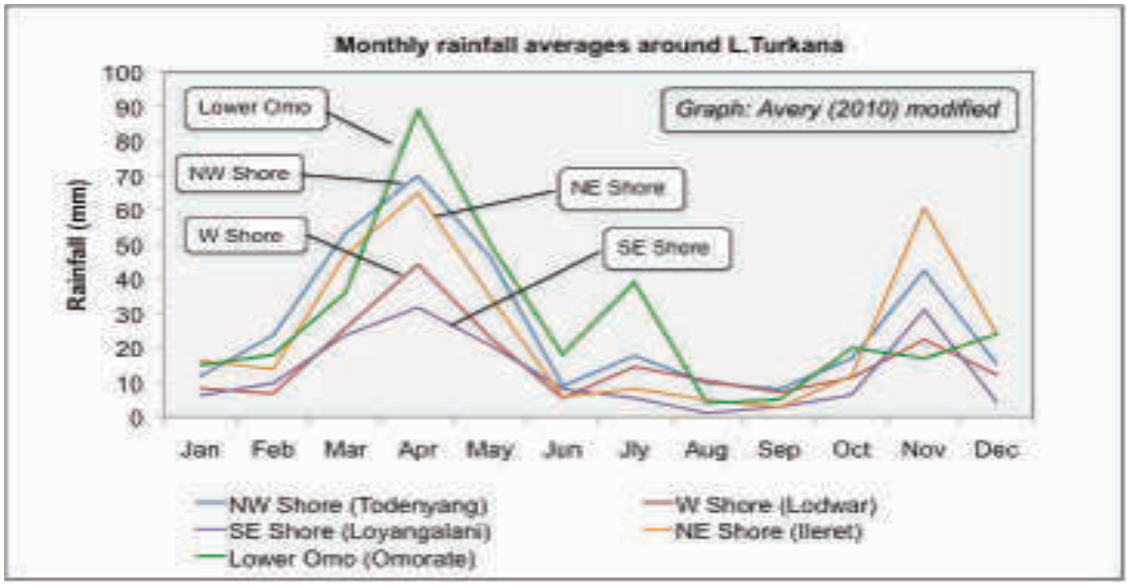


Figure 41: Average monthly rainfall cycle along the shores of Lake Turkana

Source of data: Monthly data from Kenya Meteorological Department, Nairobi.
Source of graph: From Avery, 2010 (AFDB study).

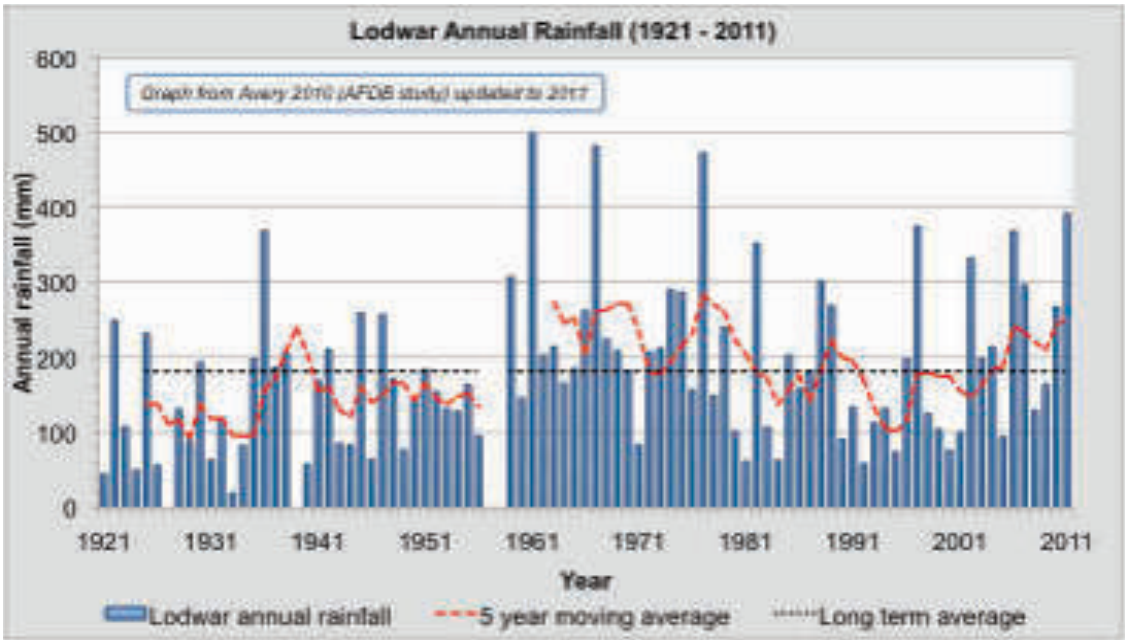


Figure 42: Annual rainfall fluctuations at Lodwar (near the western shore of Lake Turkana)

Source of original graph: 1940 – 2008 data published by Avery, 2010 and updated to 2011.
Source of data 1921 - 1981: Norconsult report (Norconsult, 1983).
Source of data 1940 - 2011: Kenya Meteorological Department, Nairobi.

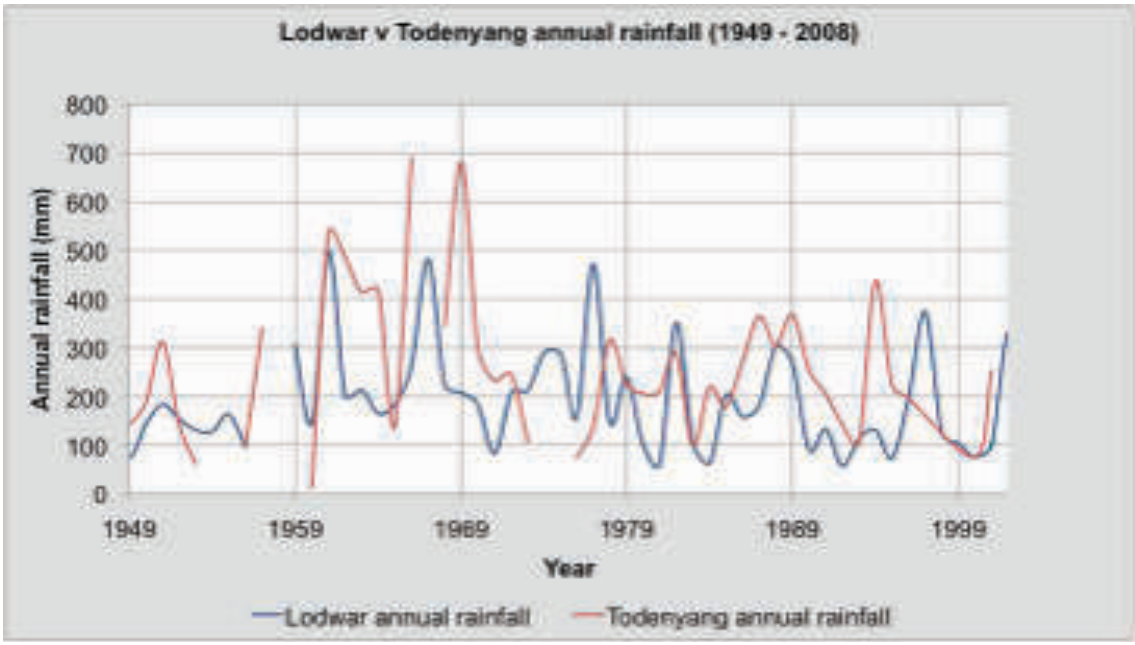


Figure 43: Lodwar and Todenyang annual rainfall comparison

Source of data: Kenya Meteorological Department.

11.5 Lake Turkana evapotranspiration and open water evaporation losses

The analysis in this section was originally presented in the AFDB hydrological study reports dated 2009 and 2010 (Avery 2009; Avery, 2010). This has been updated in this report and results contrasted with other studies published since the AFDB study.

Lake Turkana is located within a very arid environment, with a potential evaporation rate ten times the annual rainfall (Avery, 2010). In arid areas, the evaporation assessment is critical in regard to open waters in reservoirs and lakes (ibid). The consistently high potential evapotranspiration is applicable throughout the lake environs, as shown in Figure 45 on p133. Data for Ethiopia is not included in the figure, but data published for the Lower Omo is consistent, with a slightly lower value 2,293 mm/yr reported for Omorate in the plains about 20 kilometres north of the lake's Omo delta (Sogreah, 2010).

Avery's report to AFDB reviewed various methods of assessing open water evaporation losses for the purpose of calculating the amount of water inflow needed to sustain the lake level (Avery, 2010). As the lake is a closed basin, and as water is not abstracted from the lake, "evaporation+seepage" losses are the sole outflows (apart from some groundwater interchange). The theoretical basis of evaporation calculation considered by some to be the most suitable in Kenya, is the Penman method (Avery, 2010; citing Kalders, 1988). The Penman method enables derivation of potential evapotranspiration from meteorological data. Such meteorological data is however often not available. However, there is a full meteorological station at Lodwar, not far from the lake, and there is also climate data available for Lokitaung from FAO's 'Climwat' database.

The calculated Penman evapotranspiration rates for Lodwar Meteorological Station are reproduced in Table 34, p132 (ibid). The data for meteorological stations throughout Kenya was used by Kenya's Ministry of Water Development to derive a potential evapotranspiration contour map for the entire country, the relevant portion of which is reproduced in Figure 45 (p133) for the lake and its environs.

Note the following comments on climate based on the data in Table 34 (ibid):

1. The average daily temperature varies little through the year.
2. The hours of daily sunshine vary little through the year.
3. The calculated daily potential evapotranspiration is almost constant.

The annual potential evapotranspiration in Lodwar is 2,625 mm/yr (7.2 mm/day), and Figure 45 shows the 2,600 mm/yr contour encircling the lake, and declining towards cooler higher altitude areas.

Evaporation rates are traditionally measured using evaporation pans (ibid). However, the pan data cannot be applied directly to determine the water evaporated from a lake surface such as Lake Turkana. The actual evaporation loss from a large open water surface is very much less than measured from a pan. The ratio of "pan / open water" evaporation has a typical value in the range 0.60 to 0.70, known as the "pan coefficient" (Avery, 2010; citing Linsley, Kohler, Paulhus), but the coefficient can be as low as 0.35 depending on pan siting, wind speed and the environment in which the pan is placed (FAO, 2000: Irrigation & Drainage Paper No. 56, Table 5). The daily wind speeds at Lodwar average 2.35 m/s (Table 31, p122), humidity is in the "medium" range, so based on the FAO report, the "pan coefficient" is in the range 0.55 to 0.75 (FAO, 2000).

An evaporation tank located next to the lake on Longech Spit near Kalokol, (during the Lake Turkana Project, 1972 - 1975), recorded evaporation at the rate 5.8 m/yr (15.9 mm/day) (Avery, 2010; citing Hopson et al 1982). This pan data also confirmed there are no seasonal changes in evaporation, and that "relatively high evaporation rates persist throughout the year" (Avery, 2010; citing Ferguson & Harbott, 1982). Wind speeds at Longech varied in the range 2 to 5 m/s (Ferguson & Harbott, Fig 1.34). For conditions at this location, a pan coefficient 0.45 could be expected (based on Table 5 of FAO's Report No.56). Application of this pan coefficient to the measured lakeshore pan evaporation yields the following potential open water evaporation rate for the lake surface:

Pan Coefficient = 0.45 (FAO Report 56): Daily evaporation = 0.45 x 15.9 = 7.2 mm/day.

Ferguson & Harbott also presented data from a Piche evaporimeter from which an estimate of 3.2 m/yr (8.8 mm/day) was derived (referenced by Avery, 2010).

Ferguson & Harbott noted that the 5.8 m/yr (15.9 mm/d) Longech pan measurement might have been affected by the fact that the water temperature in the pan was three degrees higher than in the lake water body (ibid). This is a valid point, but on the other hand, the water temperature in the pan will very likely have dropped at night due to the chill factor of the fierce winds and the cooler night temperatures associated with desert regions, with the reverse effect on evaporation rate (Avery, 2010).

Ferguson & Harbott also examined lake level recession rates as another means of assessing evaporation (Avery, 2010). They observed that the lake level falls at a constant rate during the first part of the year. They assumed that at this time of year, water input from the Omo River is "minimal" and that rainfall is "minimal". They studied the recession rates for lake level data from 1945 to 1975, and measured a recession rate of 2.335 m/yr (6.4 mm/day). They then assumed this to be the actual lake evaporation rate. Whilst it is reasonable to assume minimal rainfall on the lake surface, Avery concluded that some Omo inflow should be allowed for older data. Avery determined that by including a small flow component, the evaporation rate derived from recession rate would be higher than 6.4 mm/day. Avery noted that Lake Turkana experiences ferocious dry winds off the adjacent hot desert areas, and the wave action and surface turbulence can also be considerable, all of which contributes to a high evaporation expectation (ibid).

For Avery's previous study, satellite radar altimeter lake level data was downloaded for the period 1993 – 2008 (courtesy of USDA-FAS) (Avery, 2009; & 2010). This data comprised an averaged lake level every 10 days for a satellite overpass roughly mid-lake. The lake level changes were computed, and the values ranked into an ascending series, and then plotted in Figure 44 (p133 below), with the following results (Avery, 2010):

- *Highest value*: 10.5 mm/day.
- *Value exceeded 2% of the time*: 8.2 mm/day.
- *Value exceeded 5% of the time:* 7.1 mm/day.

- *Value exceeded 10% of the time:* 6.3 mm/day.

For this study, the satellite lake level database has been extended to include the year 2011, but the previous analysis findings above are not altered.

In February 2012, the Omo River was dammed for the purpose of diverting water for irrigation of new sugar plantation, a little upstream from Omorate, and the river was practically dry (illustrated in Photo 1, p47). Hence the lake recession at this time provided a very accurate indication of the daily evaporation loss from the lake surface during that month. This extra data has not yet been obtained in this study.

Unfortunately, there was no coincident river inflow data in the period since 1992 with which to separate out the individual components in the water balance equation (Avery, 2010). The only Omo River lake inflow records were collected in the period 1977 – 1980 (ibid). From January to May 1977, the Omo flows were very low, but not zero, and the 5% exceedence low flow was still equivalent to 0.5 mm/day addition to the lake surface (ibid). Unfortunately, there was no lake level data for that period (ibid).

Avery's previous studies tested the integrity of the water balance model in the only way possible, by means of double mass curve analysis. This standard procedure in hydrology will expose departures and discrepancies in database sequences. The cumulative Omo runoff derived from the lake level model was compared with the cumulative runoff of the various available flow sequences, some being actual measured flows at Omorate (1972 - 75) and others being simulated flows presented in the Omo-Gibe Basin's Master Plan (ibid). Using other "simulated" data is not ideal as such analysis is equally prone to bias, but it was an interesting comparison since very different methodologies had been applied.

The double mass curves were reported by Avery to achieve water "balance" at an evaporation rate loss in the range 7.2 to 7.8 mm/day. Avery noted this to be comparable to the 7.2 mm/day Penman calculated evapotranspiration rate for Lodwar Meteorological Station (Table 34 overleaf). Note that percolation losses from the lakebed were assumed negligible, and would have been included within the lake recession measurements attributed to evaporation. Hence the assumed evaporation loss was a "total loss" inclusive of any groundwater exchange, and also took into account the salinity effects on evaporation. It also assumed the lake evaporative surface area to be as per the Hopson hypsometric data, a reasonable assumption, but one that could usefully be verified by the more recent bathymetric survey conducted as part of the Tullow Oil company's exploration.

At the time that Avery was working with the AFDB team (2009-10), the Gibe III dam contractor produced a belated report on Gibe III's impact on Lake Turkana Levels (Salini & Pietrangeli, 2010). This was four years after construction commenced. There was an uncanny resemblance to the methodology of the Avery 2009 study for AFDB. It is of interest to note that Salini adopted "Turkana average annual evaporation rate = 2.9 mm/yr" (Salini et al 2010, p34). This averages at 7.9 mm/day, which is within the water "balance" range reported by Avery (Avery, 2009, & 2010). Salini's 7.9 mm/day is higher than Avery's adopted 7.2 mm/day, because the Salini runoff estimate into the lake was correspondingly 10% higher.

Three years later, UNEP's 2012 draft report on Gibe III's impact on Lake Turkana's levels was circulated on the internet. Of particular interest here is that UNEP determined that the "over-the-lake evaporation" from 1998 - 2009 varied from 5.9 mm/day to 7.3 mm/day. The UNEP figure for 2009 is identical to the value adopted in the Avery 2009 & 2010 reports to AFDB. Avery's methodology was conventional double mass comparison analysis, whereas the UNEP team had access to sophisticated satellite sensing data.

Table 34: Modified Penman evapotranspiration for Lodwar Meteorological Station

Month	Average Temp °C	Dew Point Temp °C	Sun Hours Daily hr	ET Daily mm/day	ET Monthly mm/mth
Jan	28.85	15.05	10.0	7.0	216.6
Feb	29.70	15.55	9.9	7.3	203.2
Mar	30.25	16.80	9.2	7.5	232.5
Apr	29.85	18.80	8.9	7.2	215.0
May	29.65	18.95	10.0	7.0	218.2
Jun	29.15	17.50	10.1	6.9	206.6
Jul	28.35	17.30	9.4	6.6	204.3
Aug	28.65	16.80	9.9	7.2	222.2
Sep	29.55	16.40	10.4	7.5	225.9
Oct	30.05	16.70	9.9	7.8	241.1
Nov	29.15	16.80	9.6	7.1	213.8
Dec	28.70	16.35	10.2	7.3	225.6
				Total / yr	2,625.3

Source: Ministry Water Development, Kenya (Kalders, 1988), Lodwar Meteorological Station, No. 8635000 (see location on Figure 44 *on p133). (Altitude 506 metres above mean sea level).*

Notes: ET = Evapotranspiration = 2,625.3 mm/yr = 7.2 mm/day.

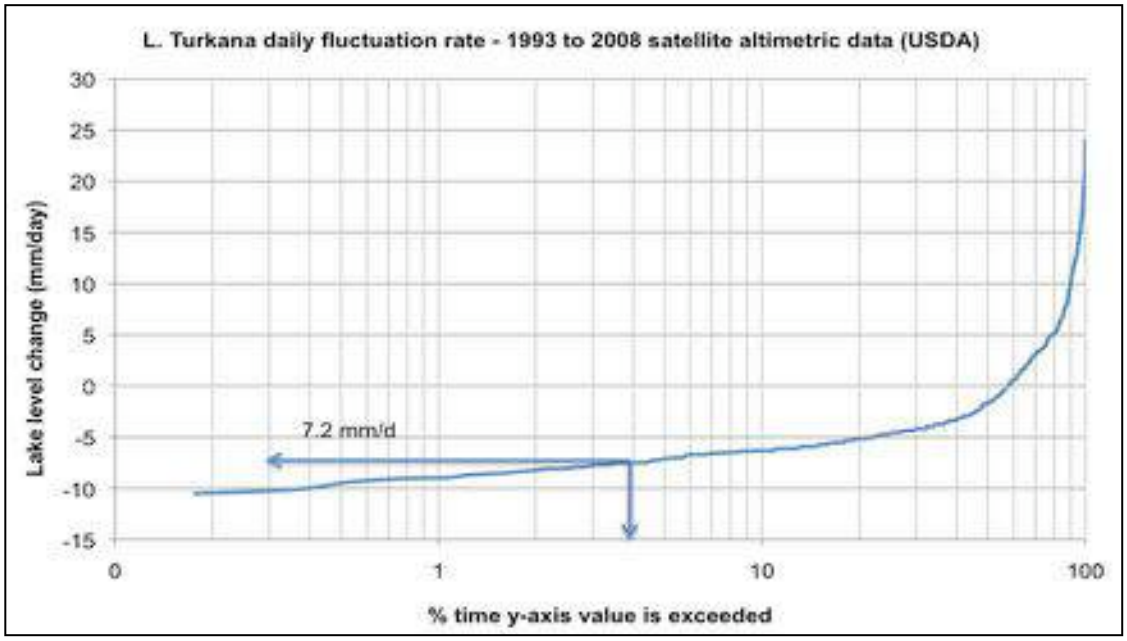


Figure 44: Daily lake level fluctuation rates

Source of original graph: Avery, 2010 (AFDB study).

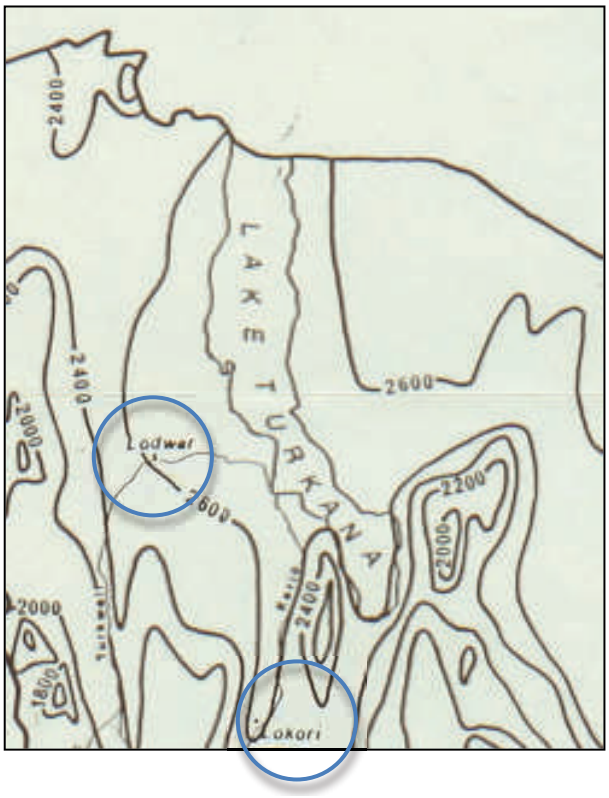


Figure 45: Annual potential evapotranspiration around L.Turkana (mm/yr)

Map Source: Ministry of Water Development, Kenya (Kalders, 1988).
Note Lodwar located to the west of the lake, and Lokori to the south (encircled blue).
Note that at Omorate 20 km north of the lake ET = 2,293 mm/yr (Section 10.4 on p116).

11.6 Summary of changes and impacts on Lake Turkana

It is evident from previous reports that the Omo River influences the lake in several respects, as follows (as summarised by Avery, 2010):

- The river carries salts, minerals and essential nutrients into the lake.
- The river-borne sediments create a productive delta zone, and sediments are also distributed throughout the lake by currents. Sediment deposits in the lake at the estimated rate 4.3 mm/day (estimated in the 1972 - 1975 study of Hopson et al, 1982).
- The Omo river flow patterns vary through the year, and control the cyclical rise and fall in lake level, which causes inundation and recession of the littoral zones of the shore margins.
- The inflowing flood periods change the prevailing lake currents and circulation patterns.

Hence, from the foregoing, Avery summarised the following changes that need to be considered in regard to the impacts of the proposed hydroelectric and other proposed development schemes affecting the Omo River's flows (Avery, 2010):

- Sediments and minerals, which naturally pass down the river to the lake, will be intercepted by the impounding reservoirs (Gibe III and Gibe IV). The reduction in number of flood peaks will also reduce the sediment transport capacity of the river since the bulk of sediments are moved during peak flood periods. The reduction of floods will reduce bank overtopping, which will in turn reduce the areas from which the flood flows wash off nutrients. The reduction in bank overtopping will affect the recharge of pastures, and will impact the replenishment of wetlands in the delta.
- Nutrient inflow patterns to the lake will alter, not only because of the dam storage reservoirs through interception, and quality changes during storage in the impounded reservoirs, but also potentially through chemicals resulting from development activities within the Omo River's drainage zone, notably agricultural chemicals.
- Consumptive use of water within the Omo Basin will reduce the volume of water reaching the lake, which will in turn reduce lake levels, and will lead to concentration of salts and increasing salinity and reduced biomass. If lake level fell to 3.1 metres below the 1972 datum, the historically most productive fishing area of the lake in Ferguson's Gulf will be rendered dry.
- The river inflow patterns will be altered through regulation by dams on the Omo River, with physical effects on the lake itself, as follows:
    - The lake's annual cyclical rise/fall change cycle will alter.
    - The lake currents will alter during the flood periods.
    - The pattern of nutrient inflow will be regulated.

12 LAKE TURKANA - HYDROLOGY BASELINE DATA

12.1 Omo River flow data

In 2009, the AFDB Consultant requested all available historic flow data from the Ethiopian Water Resources Authority (EWRA) in Addis Ababa (Avery, 2009). The Omo River flow near the point of entry to Lake Turkana was no longer gauged, and the only available historic data provided was a table of monthly discharges for Station 93002 with measurements from 1977 - 1980. The gauging station was located shortly before the Omo delta, at Omorate, with details as follows:

Table 35: River gauging station at Omorate

Station No:	93002
River Name:	Omo River
Station Location:	Omorate (sometimes referred to as Omo Rate)
UTM Co-ordinates:	172733 531223
Catchment area:	*73,738 km^2*

Table sourced from AFDB study (Avery, 2010).

The Omo basin's hydrology was studied in detail in the Omo-Gibe Integrated River Basin Development Master Plan Study submitted in December 1996 – referred to throughout this report as "the Master Plan" (citation: Woodroofe et al, 1996). In the absence of any long series flow data, the Master Plan study simulated a flow series for the Omo River at Omorate by means of a rainfall / runoff model (ibid, Vol. VI, A1).

The Master Plan's simulated flow data series for the Omo inflow into Lake Turkana was reproduced in the AFDB studies with some arithmetic adjustments, and that table is reproduced in Table 36 on p139 (Avery, 2010).

The AFDB study contrasted the Master Plan's simulated flows for the period 1977 - 1980 with the EWRA river discharge measurements for the same time period. The cumulative EWRA flows and the cumulative Master Plan simulated flows were reported similar (see Figure 46, p138), but the monthly average values show that the Master Plan model has not fully reflected the bi-modal flow peaks shown by the EWRA measured data (on p138 in Figure 47). The AFDB study concluded that the Master Plan's model was influenced to a greater extent by the upper moist catchment rainfall, which is uni-modal, and to a lesser extent by the lower drier catchment, whose rainfall is bi-modal (see later sections of this report for catchment rainfall pattern variations) (Avery, 2010).

However, the lower catchment contribution is volumetrically less significant, and it is very clear that the Master Plan's simulated cumulative runoff matched the measured runoff almost exactly in Figure 46 after 48 months, although the model under-estimated in earlier months, and over-estimated in later months. As the Master Plan's simulated cumulative flow over the 48-month available record period was well validated, the simulated flows could thus be used with confidence.

The Omo River simulated annual flow series from 1956 - 1994 was extended by the AFDB study to 2008, by back-calculation of flows using satellite lake level measurements and a lake water balance model (described later in this report), and the flows were reported consistent (Avery, 2010). The Omo's annual flow sequence has been further extended by this study to 2011, using the same modelling methodology, and the extended graph of annual flows is presented in Figure 48 (p140).

The Omo-Gibe Basin Master Plan reported that there has been an increase in the runoff in the Omo Basin as a consequence of deforestation since the 1980s (Woodroofe & Associates, Vol. VI, A1, P.C8; EEPCo, Salini / Studio Pietrangeli / Agriconsulting etc). These observations are

consistent with the findings in Figure 48 (p140), which shows that in the later years, the inter-annual variations are much more variable, with much lower annual flows occurring. The Master Plan simulated flows incorporated these changes.

The most recent catchment changes in the Lower Omo include large areas excised from national parks and a wildlife reserve, with natural habitat removal and replacement by sugar plantation, commencing in 2011.

A photograph of typical terraced hillside cultivation within the upper Omo Basin is included overleaf amongst two other images, all images being described below (photos are from the Consultant's personal Photo Archive):

- *Top Image:* This shows the extensive terracing introduced in highland areas to arrest the soil loss through land clearance for agriculture in hilly terrain.
- *Centre Image:* This photograph shows severe soil erosion seen near Arba Minch (near the mid Omo basin's eastern catchment boundary).
- *Bottom Image:* This image shows the Omo River at Omorate, photographed not far from the delta, showing the steep banks of the river, the busy human activity along the river, and a locally made dugout canoe.

Ethiopian highland cultivation with terracing

Soil erosion near Arba Minch (near eastern catchment boundary)

River Omo at Omorate, not far from the Omo Delta

Photo 6: Ethiopian highlands and the Lower Omo

Source: Sean Avery Photo Archive.

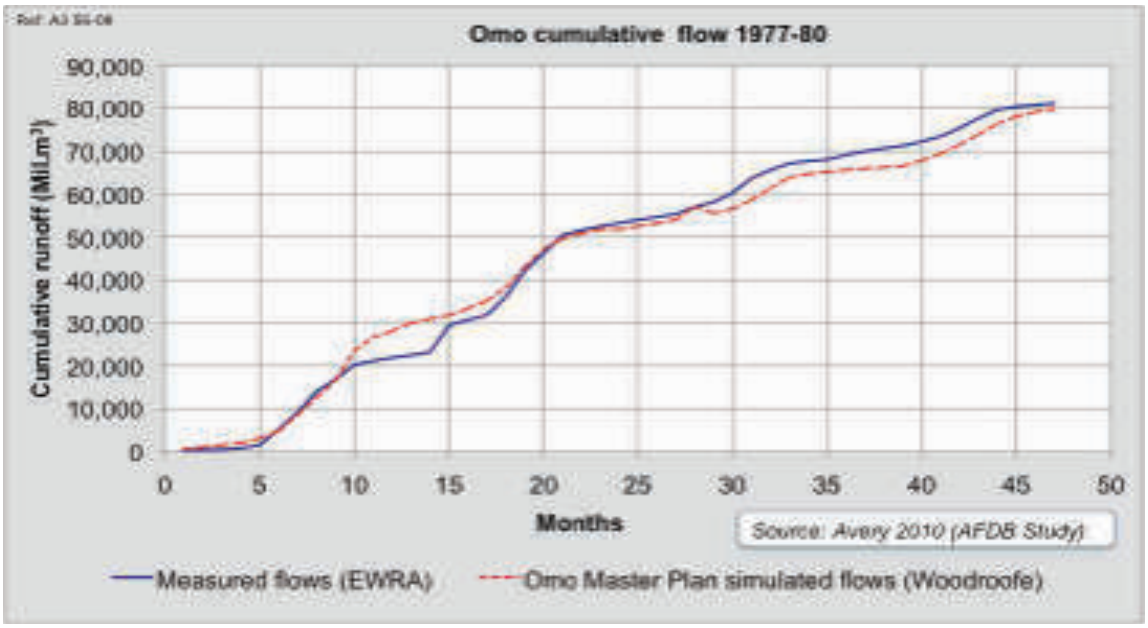


Figure 46: Omo River simulated & measured runoff compared from 1977 - 1980

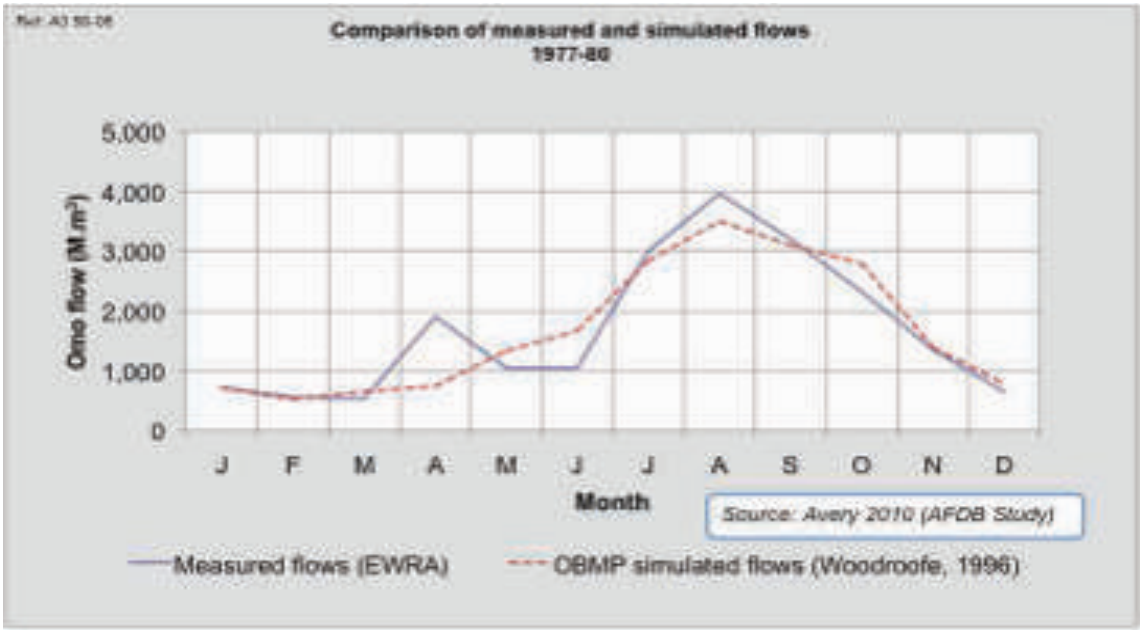


Figure 47: Omo River average monthly simulated & measured runoff compared from 1977 - 1980

Table 36: Simulated Omo river flows near Lake Turkana (see note to table)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s
1956	153	105	143	380	476	508	654	1469	1732	1078	353	236	607
1957	191	155	282	489	867	762	1237	1330	532	354	237	120	546
1958	138	106	114	151	131	513	905	1228	1602	594	285	172	495
1959	176	158	171	118	278	233	733	932	1029	959	251	164	434
1960	135	118	214	118	950	643	755	1309	1083	388	225	136	506
1961	100	117	133	199	256	365	741	1630	1476	846	932	380	598
1962	270	204	260	213	399	706	942	976	1329	483	305	178	522
1963	171	161	205	274	560	519	952	1399	1280	566	593	248	577
1964	200	161	229	134	497	418	737	857	1384	1047	333	263	522
1965	176	129	154	277	233	428	651	963	455	551	340	137	375
1966	104	128	231	227	156	201	1046	1105	736	460	211	122	394
1967	111	93	252	121	349	485	928	1178	1517	917	605	244	567
1968	197	172	186	219	394	457	600	1064	1071	383	213	166	427
1969	159	110	207	91	177	349	800	944	695	250	154	83	335
1970	144	77	202	105	306	478	853	1406	1107	767	249	156	488
1971	143	90	115	115	515	396	872	1249	1047	661	282	183	472
1972	142	145	158	225	323	361	808	907	864	385	304	120	395
1973	114	91	85	137	336	309	1063	1364	1496	506	284	149	494
1974	127	104	200	123	583	383	873	1441	1520	474	249	164	520
1975	145	140	160	156	513	679	1193	1924	1721	654	417	274	665
1976	249	208	243	176	667	837	1189	1262	1115	557	399	206	592
1977	236	159	192	172	409	664	1412	1499	1542	2562	1226	546	885
1978	420	346	338	313	592	690	1169	1785	1599	913	471	351	749
1979	276	261	313	176	406	396	775	1019	972	310	194	152	438
1980	132	101	133	490	680	822	891	926	677	392	245	121	468
1981	108	101	317	181	307	245	865	1229	1687	668	215	121	504
1982	119	84	87	88	364	338	520	1223	841	1057	419	211	446
1983	150	99	159	152	405	331	571	1861	1730	1496	452	241	637
1984	185	136	151	214	444	442	823	1171	892	306	240	135	428
1985	107	73	137	209	469	340	718	1374	1090	386	236	115	438
1986	86	110	190	129	338	452	811	811	920	361	138	98	370
1987	66	55	145	129	502	293	396	647	546	384	152	72	282
1988	78	57	62	85	125	204	1747	2761	2064	1509	488	117	775
1989	99	119	187	186	241	238	806	1163	1326	543	213	192	443
1990	89	135	187	126	263	367	800	1786	1629	863	371	190	567
1991	180	128	160	162	320	455	1018	1503	773	415	210	125	454
1992	84	82	101	128	314	525	942	3035	1848	1479	569	389	791
1993	313	228	207	326	878	932	1313	1645	1513	941	386	237	743
1994	195	148	200	177	537	506	1244	1485	1039	484	547	196	563
Mean Monthly	161	133	185	192	425	468	906	1355	1217	717	359	193	526

Notes on table:

This table was originally published in a report to AFDB (Avery, 2010).

Avery reproduced monthly flows from Table C7, Vol. VI, A1, Woodroofe et al., 1996, with totals and averages re-computed.

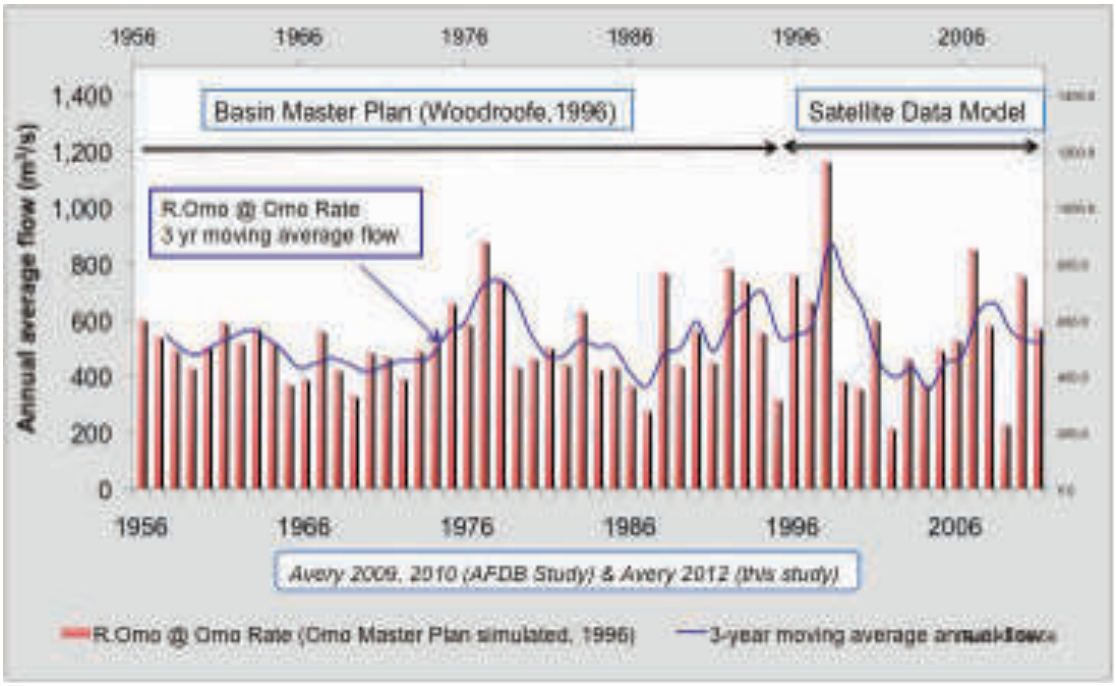


Figure 48: River Omo annual flows at Omorate, Ethiopia, just before reaching Lake Turkana, from 1956 to 2011

12.2 Lower Omo flooding

The Omo River periodically floods and inundates adjoining areas, particularly in the plains of the Lower Omo, much of this low lying area having been Lake Turkana's former palaeo lakebed. This inundation is part of the normal hydrological cycle. The ecology of the Lower Omo area has depended on seasonal inundation, as does the traditional recession agriculture that developed in this area, and also the pastures are dependant. These facts are stated throughout the literature, and example citations are included below.

The study of flooding in the Lower Omo is beyond the scope of this report and the Consultant had recommended a separate study of the history of the Omo River's flooding and the ecological benefits and disadvantages of all-important seasonal flood inundation.

However, with the commissioning of both Gibe III and Gibe IV, seasonal inundation will cease to happen, unless engineered through water releases from the dams or through the irrigation canal networks. The changes to seasonal inundation will have ecological consequences and groundwater stores will no longer be replenished in the same way.

Sogreah stated: "The river overflows its banks and floods the land along its borders. Areas 30-50 metres large and some hundreds of metres long are flooded. The water recedes 2-3 weeks later to allow planting from September to October. Heavy flooding also renews oxbow lakes, such as Lake Dipa, giving access to large areas of well-inundated land for cultivation" (Sogreah, 2010, p36).

Sogreah further stated: "The majority of the lower Omo population is dependent upon access to local natural resources and particularly highly dependent on the Omo River flood cycle" (ibid). This repeats what has been stated by several studies, including Avery, 2010. As Sogreah stated: "it is recognised by all that the dam construction will disrupt the entire subsistence economy of the Lower Omo Valley and will totally modify traditional livelihoods based on flood-recession cultivation along the river banks and throughout the delta" (ibid).

Figure 49 on p142 is included for interest. This useful aerial image was presented in the EEPCo 'Downstream EIA' to demonstrate the extent of flooding on selected occasions in the recent past, especially in 2006 (Agriconsulting & Mid-Day, 2009).

The 'Downstream EIA' included the statement: "These extreme high peak flows cause a serious threat especially to the Dasenech population having destructive effects on human and animal life, private assets and public infrastructure" (Agriconsulting & Mid-Day, 2009, p42).

The 'Downstream EIA' states that one of the benefits of Gibe III is the "regulation of the flows" (ibid, p43), which will reduce the scale of floods.

Figure 49 (p142) is not sufficiently detailed and does not in itself give rise to particular concern, as the significant ponding (shaded light blue) comprises water collected in the former Sanderson's Gulf, a tectonic depression NW of the lake that is fed by the Kibish River and other ephemeral watercourses. The "hot spots" shaded red are predominantly within the Omo delta zone, which is an area that is ecologically dependant on such flood occurrences, and the Dasenech community will be well accustomed to this and the benefits of floods adding nutrients to the delta.

Both Agriconsulting & Mid-Day, and Sogreah, mention loss of life due to flooding in the Lower Omo. The 2006 floods were reported by aid agencies to be "the worst in years", affecting "more than 1 million people in Somalia, Kenya, Ethiopia and Rwanda" (UNICEF, December 2006). It is also pertinent to note that the loss of life in the Lower Omo's August 2006 floods may not have been as bad as estimated, perhaps a fraction of what was reported (Pers.Comm., 2012).

At least two field workers reported that the Dasenech were unable to name a single human casualty of the 2006 floods although livestock were lost (ibid). The people also reported the flood peak to have been unusually sudden and there was speculation amongst the people that the flood was caused by an unexpected release from the Gibe I reservoir upstream (ibid). This seems unlikely though, in view of the distance from Gibe I to the Lower Omo and the attenuation that would occur.

The same field workers reported the following poignant Dasenech comments on the 2006 floods:

"…Among the Dasenech, the year of 'big flood' is memorized as 'the year when we never feel hunger'. In contrast, the year of 'small flood' is remembered as 'the year of starvation'…"

Increasing flood magnitudes are the expected consequence of catchment change, which in turn is a consequence of increasing population demand (such as extending cultivation), exacerbated by poor land management practices in the Omo Basin as a whole. The images presented earlier are indicative of the challenges of catchment degradation (see Photo 6 on p137).

The challenges of catchment degradation are not new, and they were noted many years back in the Omo-Gibe Basin Master Plan itself (Woodroofe et al, 1996). Hence people in the Lower Omo bear the consequences for human activities in the middle and upper basin, and the more people there are, the higher the likelihood of discernible impacts.

The consequences of floods are now widely used as an argument to support the construction of storage dams that will capture and regulate these floods. This is an engineering solution that can be effective, but the root cause of poor catchment management should not then be disregarded, as the investment costs of storage dams are considerable, and the lifetime of these structures will be reduced through storage loss to sedimentation.

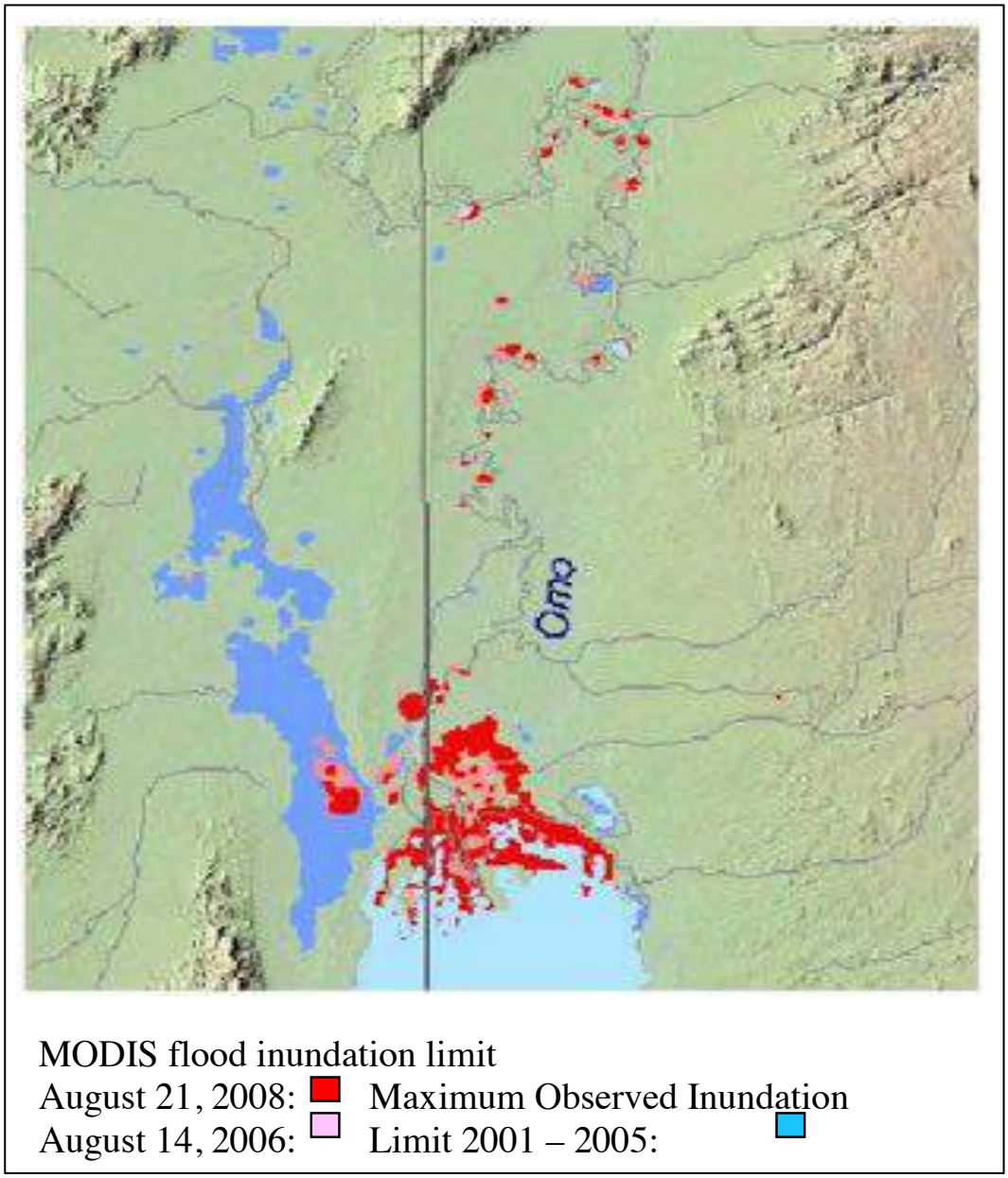


Figure 49: Areas of flood inundation

Source: EEPCo Gibe III 'Downstream ESIA' (Agriconsulting & Mid-Day, 2009).

13 LAKE TURKANA BATHYMETRY & LEVEL CHANGES

13.1 Historic bathymetric data

All previous studies have cited the all-important bathymetric survey for Lake Turkana undertaken during the 1972 - 1975 Lake Turkana Project (Hopson et al; Ferguson & Harbott, 1982) – see Figure 51 p145 (Avery, 2010). The lake contour datum was the lake level in September 1972 (1972 Zero Lake level = 365.4 masl approx, plus or minus 5 metres).

Tullow Oil undertook a new bathymetric survey for oil exploration purposes during 2011 and 2012. This data was requested in November 2011 but has not yet been released by either Tullow, or Tullow's client Kengen.

The following lake characteristics were measured during the 1972 - 1975 bathymetric survey. The survey related to the 1972 lake level (Hopson et al, 1982), and the lake's physical characteristics will of course expand and shrink as the lake rises or falls naturally (Avery, 2010):

- The lake was 257 kilometres long in 1972;
- The lake width varied from 44 to 13 kilometres, and averaged 31 kilometres.
- The mean depth was 31 metres, and the maximum depth was 114 metres.
- The lake surface area measured approximately 7,560 km^2 in 1972, though less today.
- The volume of water stored at the 1972 level was 237 km^3, 28% being stored within the top 10 metres of the lake.

NIVA & KMFRI amended the Hopson bathymetric map (see Avery, 2010, for details, citing NIVA, 1988). The NIVA & KMFRI study was undertaken from 1985 - 1988, and the lake had dropped 5 metres in level since the time of the 1972 - 1975 Lake Turkana Project reported by Hopson et al (ibid). NIVA & KMFRI added the then exposed lower 1988 shoreline to the original Hopson bathymetric map. NIVA & KMFRI adopted the lower level prevailing at the time of their study as their bathymetric zero datum (Zero = 360.4 masl), and they adjusted the Hopson bathymetric contours relative to this lower datum – see Figure 52, p146. Hence, the NIVA & KMFRI datum and associated contours are 5 metres lower (ibid), which can cause confusion.

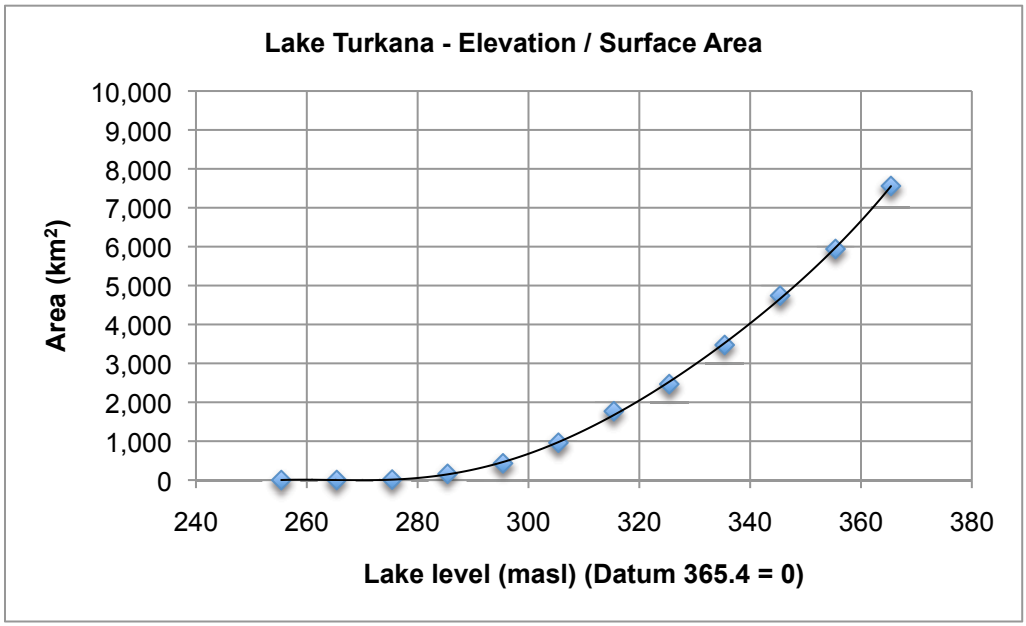
The original hypsometric data datum used by Hopson (Datum: Lake Level 0 = 365.4 masl) was retained by Avery for the AFDB study, and was used to create elevation / area / storage curves for the lake – reproduced in Figure 50 on p144, and Table 37 overleaf. These relationships were also expressed mathematically for ease of application within the water balance modelling. The Hopson zero lake datum was determined to be equivalent to a surface elevation 365.4 metres above mean sea level, based on survey done by the UK's Ministry of Defence on 22nd June 1972 (Ferguson & Harbott, 1982, reported in Avery, 2010).

It is obvious that a reduction of lake levels will result in a reduction in volume of water, resulting in the shrinking of the shallower northern end of the lake in particular (Avery, 2010). This fall in lake level will cause the River Omo to more deeply incise its channel through the existing delta, and there will be an extension of the delta south into Kenya (ibid). A reduction in lake level greater than 3.1 metres below the 1972 Zero datum would leave Ferguson's Gulf dry (ibid).

Table 37: Lake Turkana's 'Level / Area / Volume' tabulation

Lake Level metres	Lake Area km^2	Lake Volume km^3
0	7,560	238
-10	5,900	170
-20	4,700	116
-30	3,700	75
-40	2,300	46
-50	1,770	25

Note: Lake Level 0 = 365.4 metres above sea level (Hopson et al, 1982).



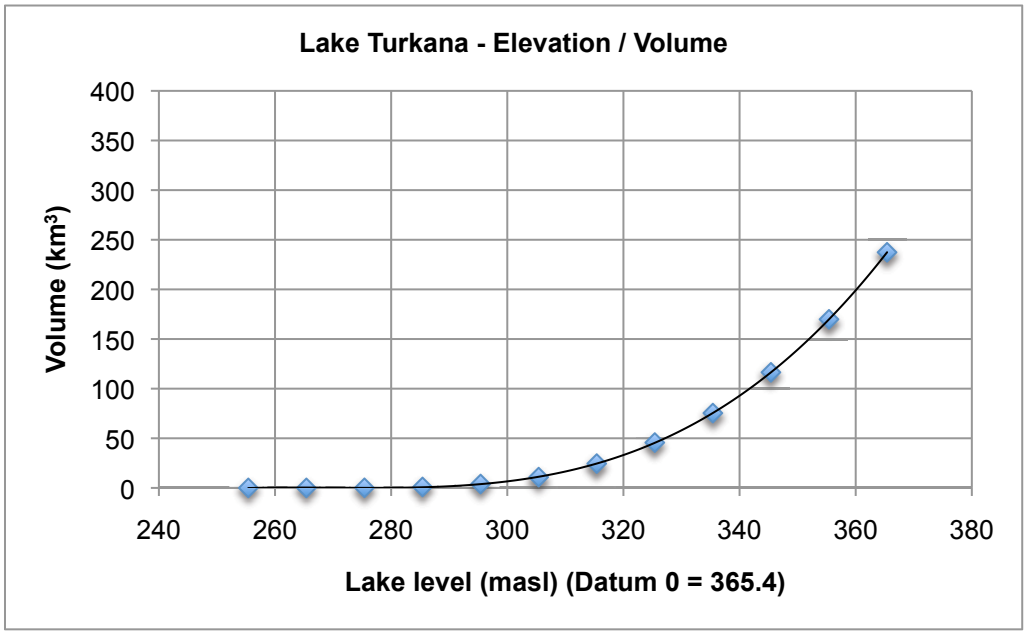


Figure 50: Lake Turkana's 'Elevation / Area / Volume' curves

Graphs reproduced from AFDB Hydrology studies (Avery, 2010).
Source of data: Derived from bathymetric survey tabulation of Hopson et al, 1982.

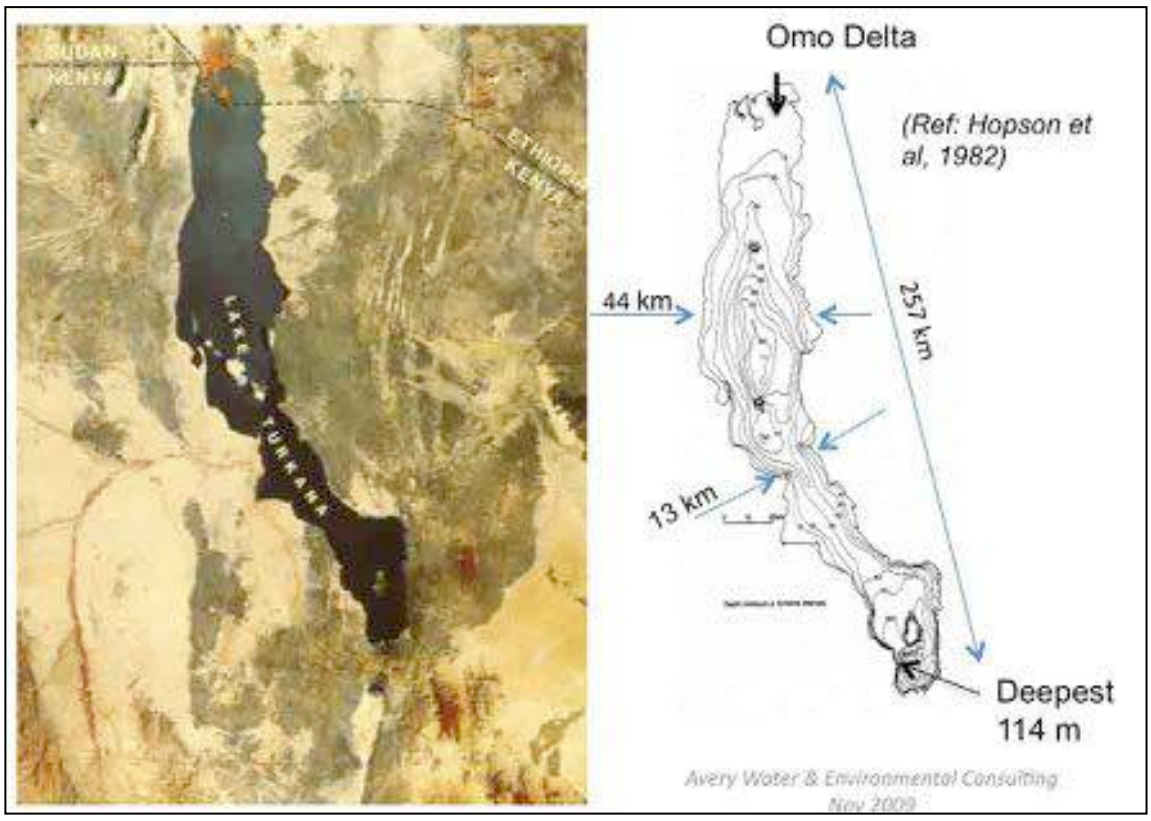


Figure 51: Lake Turkana bathymetric contour map

Graph reproduced from report to Avery, 2010 (AFDB study).

Bathymetry data source: Ferguson & Harbott, 1982.

Notes:

The "shoreline" in the contoured map is the lake water level in Sept. 1972, i.e. Lake Level Zero datum adopted at that time: Bathymetric Contour 0 = 365.4 metres above sea level (masl).

The lake level in late 2010 was slightly lower than in Sept. 1972 (about 363 masl).

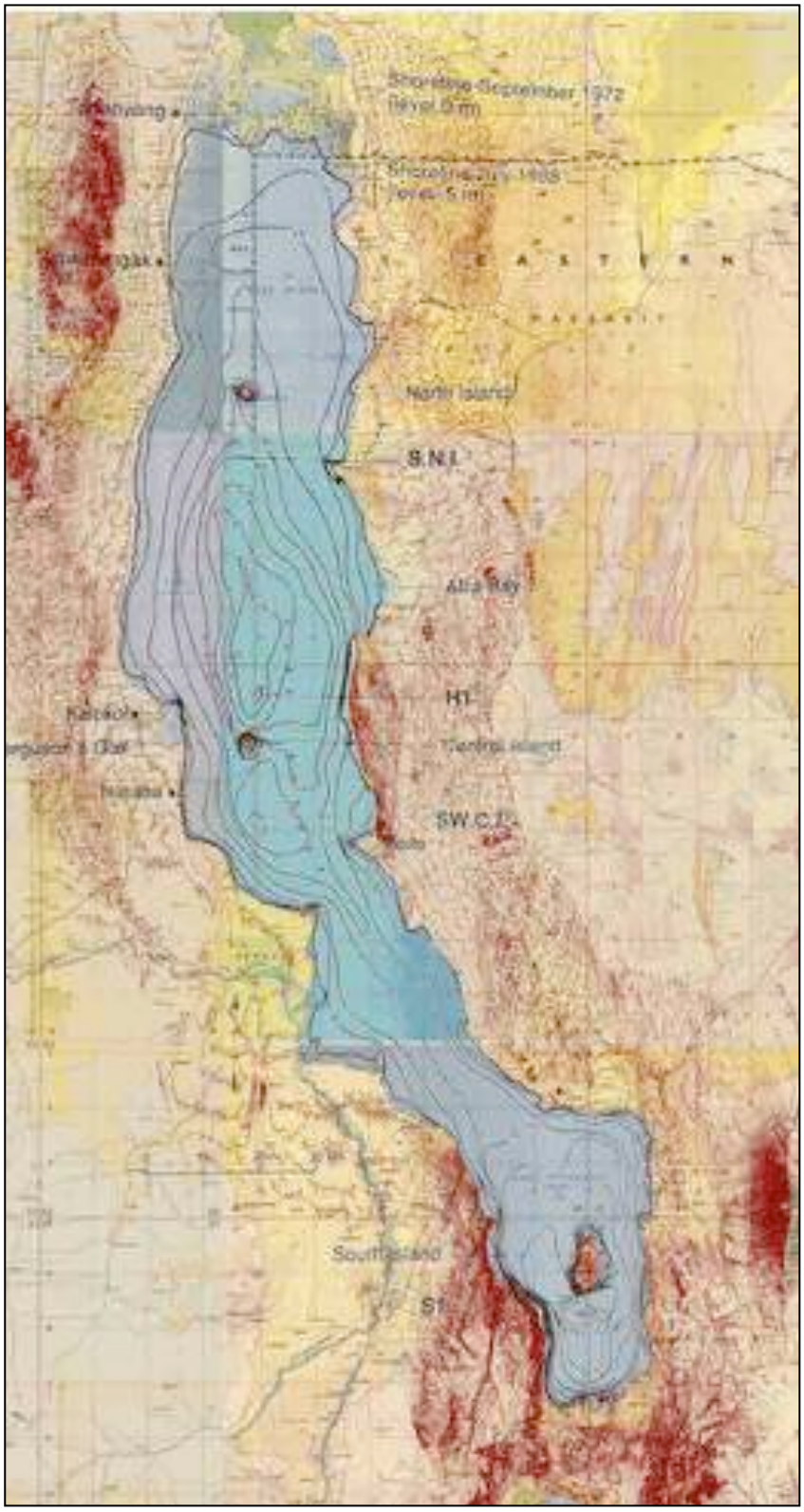


Figure 52: Lake Turkana – Bathymetric contour plot and shore zone map

Reproduced from the hydrological studies reported to the AFDB (Avery, 2010).

Sources: Bathymetry taken from NIVA & KMFRI (NIVA, 1988).
Zero Datum: Contour 0 = 360.4 masl. (Note: 5 metres lower than Figure 51 *datum).*

Imagery superimposition on Survey of Kenya 1:250,000 base mapping purchased from Ramani, Nairobi (Avery, 2010).

13.2 Omo delta historic imagery

The AFDB reports reproduced some interesting images of the delta, also reproduced in this report in Figure 53 on p148, which show changes in the delta over time (Avery, 2010; Source: USGS website).

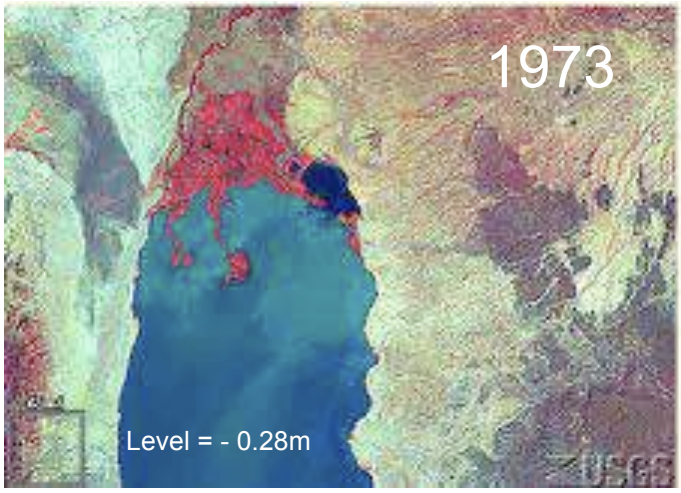
The images described below are of general / historical interest (reproduced from Avery, 2010). They show a very small portion of the delta, and hence are not easily comparable with the USGS 1973, 1989, and 1995 imagery above.

Figure 54 on p149 is an image of the tongue of the Omo delta in 2009 (Agriconsulting S.p.A & Mid-Day International, 2009).

Figure 55 on p149 is a historic aerial photograph of the delta channel snaking out into the lake, dating from the period 1972 - 1975 (Hopson et al, 1982).

Figure 53: Omo Delta imagery showing changes over time

Source of images: USGS website.

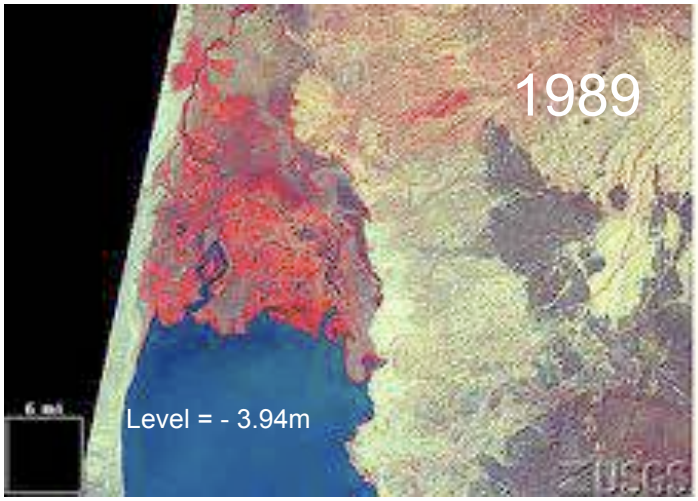


Notes:

1973: A large part of the delta can possibly be seen submerged, probably dating from the level rise following the1940s and 1950s low period (AFDB study - Avery, 2010).

1989: Lake level 3.7m lower than in 1973. Very close to lowest ever level. Hence much larger delta area is exposed by the lower water level (ibid).

1995: 2.4m higher than 1989, 1.2m lower than 1973. Delta not reduced much since 1989, but much larger than in 1973 (ibid).



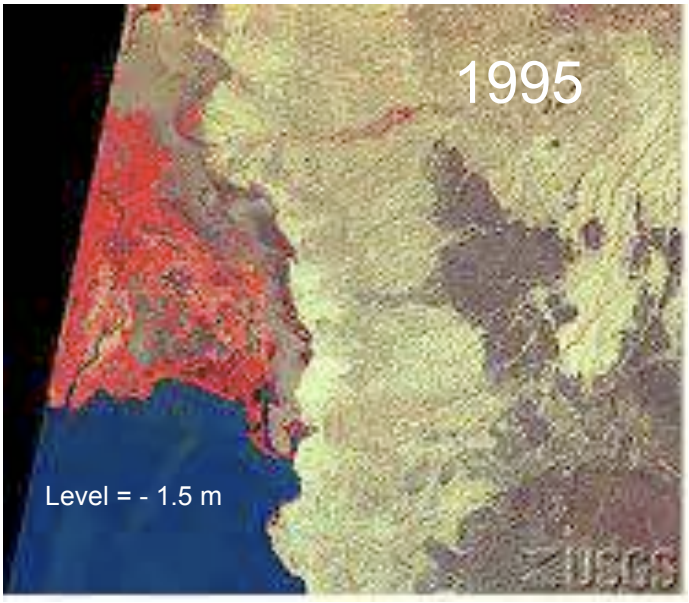


Figure 54: Omo Delta, 2009

Source of image: EEPCo Report (Agriconsulting S.p.A & Mid-Day International, 2009).

Figure 55: Omo Delta 1972 - 1975

Source of historic image: Hopson et al, Vol.1, 1982.

13.3 Lake Turkana water level gauge records

Much has been published on the lake level fluctuations over time, especially because of the palaeontological interest attached to Lake Turkana and the Omo delta, for instance the following (summary from report to AFDB – Avery, 2010):

"…Butzer (1971) reviews and rationalises sedimentary, written and photographic evidence of changing lake levels over the previous 90 years, primarily to clarify the temporal basis of submergence - emergence patterns in the Omo Delta region…" (Ferguson & Harbott, 1982).

Lake water level measurement within Kenya has lacked continuity. The history is as follows (ibid):

- 1949-62: Lake level gauge operated at Ferguson's Gulf by the Water Development Department, Nairobi.
- 1962-66: Lake level gauge submerged by rising lake level, and records ceased.
- 1962 onwards: Intermittent records of lake level.
- 1971-75: Lake level gauges set up by the Lake Turkana Project in Ferguson's Gulf (Hopson et al, 1982).
- 1975-84: Three spot readings between 1976 and 1985 (NIVA's Figure 4-1-2, 1988).
- 1985-88: Records collected by Lake Turkana Limnological Study (NIVA, 1988).
- 1988-date: No daily lake level data. The data is taken "occasionally due to logistical challenges" (Pers.Comm., KMFRI, reported by Avery, 2010). MoWD take readings "from a reference point". It was not possible to locate the reference point or datum, and a new staff gauge was only recently established off Longech Spit at Ferguson's Gulf, and prior to that, a "theodolite" was used (Pers.Comm., KMFRI Research Station, Kalokol, 2009).
- 2010: Regular gauge reading re-established by Kenya's Ministry of Water & Irrigation (Avery, 2010, Pers.Comm., MoWI, 2010).

In Ethiopia, there are no lake level records. Station 93003 (Lake Rudolf @ Kelem) is listed as "Not operated" (Woodroofe et al, 1996, Vol. VI, A1, C5; cited by Avery, 2010).

Butzer's valuable work on lake level fluctuations from 1880 to 1970 was subsequently extended by the Lake Turkana Project (Hopson et al, 1982), and then extended again by the Lake Turkana Limnological Study (NIVA, 1988). The gap from 1976 to 1985 was "infilled" by NIVA & KMFRI who jointly undertook the study.

Figure 56 on p151 overleaf presents the Butzer record extended by NIVA & KMFRI to 1988 (NIVA, 1988; reported in Avery, 2010).

It is important to note the -3.1 metres lake level at which Ferguson's Gulf becomes dry in Figure 56. The "0" lake level in the figure is the lake level in September 1972, the level on this date having been adopted as the level datum for the Hopson bathymetric survey (Datum: 0 = 365.4 masl) (Hopson et al, 1982).

The Gulf was reported to have "distinct algal flora", there was a high primary production of algae, and the fish yields were "phenomenally high" (ibid). It was reported to be the most productive fishing zone on the lake (Hopson et al, 1982). Hence its destruction due to falling lake level was considered important to local fishermen at that time.

The character of the Gulf much later in 2010 was reported very different (Avery, 2010). Sedimentation was reported, and the western shore was reported invaded by the alien tree *Prosopis juliflora* (Pers.Comm., Dr.Ojwang, KMFRI, 2010; Ngece, 2010). More details can be found elsewhere (Mbogo, 2010). The invasion of *Prosopis juliflora* throughout the area was observed during the field expedition of this study in 2012. The boat landing area on Kalokol beach is choked with *Prosopis juliflora*, and ongoing suffocation of reed beds in the Turkwel delta was also observed. Hence, the importance of the Gulf to fishermen had changed since 1972.

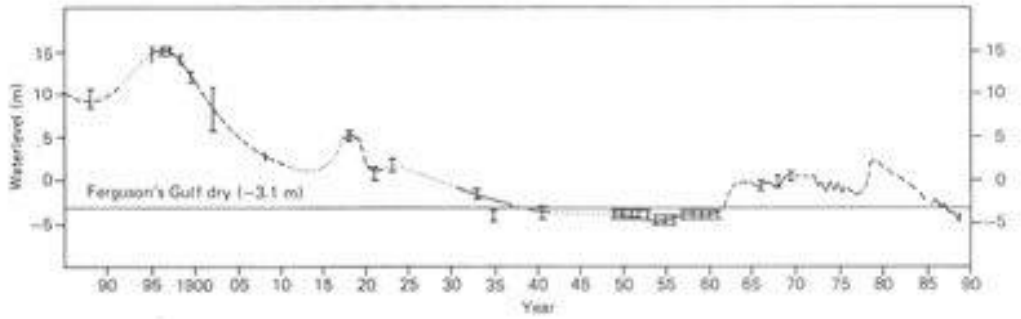


Figure 4.1-1 Water level of Lake Turkana 1888-1988. 0 m = ca. 365 m above sea level. Data from 1888-1970 from Butzer [1971], 1971-1975 from Hopson [1982].

Figure 56: Lake Turkana water levels to 1990

Sources: Butzer, 1971; Hopson et al, 1982; NIVA & KMFRI (NIVA, 1988).

13.4 Satellite radar altimeter lake level readings

The United States Department of Agriculture's Foreign Agricultural Service (USDA-FAS), in co-operation with the University of Maryland (UMD) and the National Aeronautics Space Administration (NASA), routinely monitors lake level variations throughout the world (Avery, 2010). Several satellites are, or have been, collecting radar altimeter data at time intervals varying between 10 and 35 days, as shown in Figure 59 (p155).

The satellite orbit is 1,336 kilometres above earth. The satellite track over Lake Turkana over Lake Turkana is shown in Figure 60 (p155), and the lake level data available since 1992 is reproduced in Figure 61, collected by various satellites (ibid).

The radar altimeter measurements reflect the mean of several readings along the chosen transect, and accuracies are likely to be 10 cm rms (10 centimetres root mean square) (Pers. Comm., Birkett, UMD, 2009; reported by Avery, 2010). The Lake Turkana satellite transect crosses the central sector of the lake, on a line from north of the Kerio / Turkwel deltas on the western shore, to Ileret on the NE shore (see Figure 60, p155). The lake is subject to strong winds for long periods every day, and hence there will be wind "set-up", namely tilting of the lake water surface with highest water levels towards the north-west of the lake. As the satellite's track point crosses near mid lake, Avery assumed that the level measurements are representative of the lake as a whole (Avery, 2010). The winds also create waves, which can affect measurement (ibid). Comparison with good validation data from a fixed lake gauge would be useful, and was attempted, but not very successfully (ibid) – discussed later in this report.

This satellite lake level data is also available for other lakes in the region, hence permitting comparison of regional lake level trends (ibid).

The following other satellite data sources were also checked by Avery for his AFDB study, and the Turkana data was reported identical (ibid):

- *European Space Agency (ESA) / de Montfort University River and Lake System:* NASA / CNES satellite Jason-2 and Envisat, data on the internet.
- *Hydroweb, GOHS / LEGOS:* Altimetric water level data-base on the internet.

13.5 Lake gauge data compared with satellite radar altimeter readings

The Kenya Marine & Fisheries Research Institute (KMFRI) operates a research station not far from the western shore of Lake Turkana at Kalokol, north of Lodwar. This research station was visited in 2012.

The annual data series of lake levels from 1880 to 2008 was provided by KMFRI to the AFDB Consultant in 2009, and the graph of levels is reproduced in Figure 57 below (from Avery, 2010). From its 1896 peak, the lake declined 20 metres to its lowest recorded level in the 1940s and 1950s, before rising sharply in response to the 1961 floods, and then 26 years later dropping to close to its lowest levels again in 1988 (ibid).

The historic pre-1988 data was based on work done by Butzer, Hopson et al, NIVA & KMFRI, and Kolding (ibid). KMFRI thus provided the extended data sequence from 1988 to 2008 (ibid).

The KMFRI 1988 to 2008 data had anomalies addressed in the report to AFDB (Avery, 2010). Avery concluded that this KMFRI data included a datum shift relative to the earlier series, most likely as a consequence of the datum shift between the Hopson 1972 - 1975 study period and the later 1985 - 1988 NIVA & KMFRI study period (ibid). The reported datum shift was 5 metres, and the effect of downshifting the later KMFRI data by this amount is shown in Figure 57 (reproduced below from Avery's report). The resultant downshifted sequence (blue dotted line) was consistent with data presented in another publication with which KMFRI was involved (ibid), reproduced in Figure 58 overleaf. The Johnson & Malala zero datum in Figure 58 overleaf appears to tally more closely with the level at which Ferguson's Gulf dries up, being slightly above the Hopson datum.

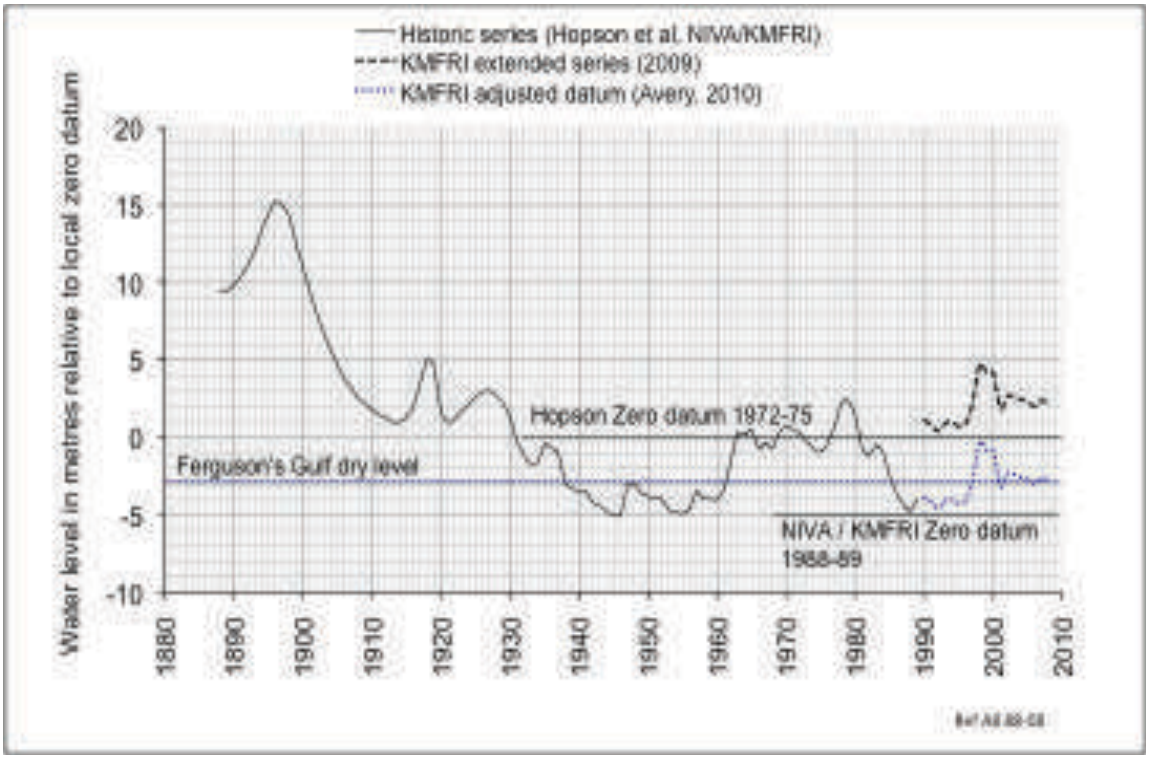


Figure 57: Lake Turkana 1888 – 2008: Annual water level series *(Avery, 2010)*

Source of lake levels: KMFRI, Kenya, but adjusted to one consistent datum (Avery, 2010).

Hopson Datum: Lake Level 0 = 365.4 masl (plus or minus 5 metres) (Hopson et al, 1982).

NIVA & KMFRI Datum: Lake Level 0 = 360.4 masl (plus or minus 5 metres) (NIVA, 1988).

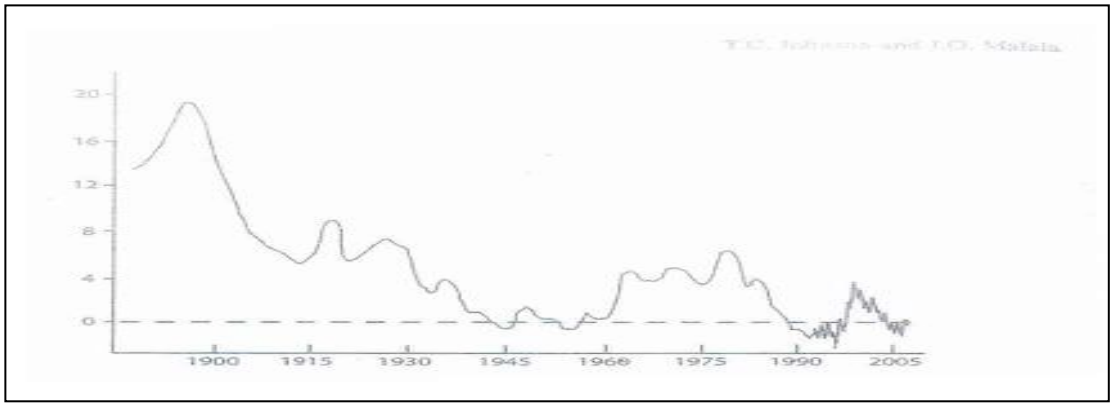


Figure 58: Lake Turkana's lake levels *(Johnson & Malala graph)*

Source of Graph: Paper by Johnson and Malala, 2009 (reproduced from Avery, 2010).

13.6 Satellite radar altimeter data compared with lake level gauge data

The radar altimeter data in Figure 61 (p156) was derived from three different satellites, and the data transition from one satellite to the next was subjected to a period of calibration (USDA-FAS / UMD).

The USDA-FAS satellite radar altimeter data was compared with the GOHS / Legos data, and after adjusting to a common datum, the curves were reported almost identical (Avery, 2010).

The fixed lake gauge data was compared with the satellite radar altimeter data in Figure 62, p157 (ibid). The lake gauge data "zero" datum was stated to be relative to Lake Level 0=365.4 masl (the Hopson zero datum = September 1972 lake level), but is more likely to be Lake Level 0=360.4 masl (NIVA & KMFRI datum), as discussed above. The USDA-FAS satellite data uses the prior 10-year satellite database mean as its datum, and hence the satellite data datum in Figure 62 is arbitrary, and varies, and is not linked to the other lake datums in use. This study has reduced all data to a common datum.

When compared to the satellite data, the lake gauge's level data shows the following conspicuous anomalies, best seen by reference to Figure 63, p157:

1. The large drop recorded by the lake gauge in 2001 is improbable.
2. The lake gauge shows declining lake level since 1999. The satellite data also shows declining lake level since 1999, but in contrast to the lake gauge, the satellite lake levels bottomed out in mid-2006, changing to an ascending trend which persisted until 2008.
3. The satellite data's bottoming out and trend reversal in mid-2006 was compared with other regional lakes in Figure 64 on p158. All lakes are consistent, showing an increasing water level trend from 2006. Both Lake Victoria and Tanganyika have outlets, unlike Lake Turkana, which is a closed basin with no outlet, but the outlets from Lake Victoria and Lake Tanganyika are "naturally regulated".
4. The big Omo River floods reported in July 2007 (EEPCo Report by Agriconsulting et al, 2009) are reflected in the subsequent 1.25 metre rise in the satellite measured lake level (see Figure 63 on p157). The lake gauge data in the same figure missed this known rise altogether, instead recording an imperceptible change in spite of the 2007 Omo floods.

The lake gauge data was unfortunately decided to be unreliable (Avery, 2010).

The annual cyclical changes shown for the various lakes are interesting to note.

13.7 Establishing satellite data mean sea level datum

The GOHS / Legos satellite lake level data series is reproduced in Figure 65, p158, as this data is usefully expressed relative to mean sea level (masl). This is 'useful' because the topographical mapping of the lake surroundings is also relative to mean sea level. Avery compared the GOHS / Legos datum with the datum established by Hopson et al. (Avery, 2010). The Hopson Zero Datum was taken to be the lake level in September 1972, which pre-dated the satellite radar altimeter database. It had earlier been established that the 1972 "Zero Datum" equated to 365.4 masl, but this was stated to be plus or minus 5 metres, which is a wide range. It was decided to compare the Hopson and GOSH mean sea level datums.

Avery noted that the wetness condition of Ferguson's Gulf was a useful lake level benchmark when looking at satellite imagery (Avery, 2010). The Gulf is known to become dry at the level -3.1 metres, which is equivalent to 362.3 masl on the 1972 datum (365.4 – 3.1 = 362.3 masl), and it will be obvious from satellite imagery whether the Gulf is wet or dry.

Landsat imagery for Ferguson's Gulf since 1984 was downloaded through the USGS website, and sample images are reproduced in Figure 66, p159 (from Avery, 2010). There were gaps in the imagery, and the quality was variable due to cloud cover, but the available data was studied, and notes on findings were included in Figure 65, p158 (ibid). The text notes on the graph broadly confirm Ferguson's Gulf being "dry" below 362.3 masl. At lake levels below 362.3 masl, images showed an "indistinct outline" for the Gulf. Above 362.3 masl, images showing the Gulf clearly "wet" and hydraulically linked to the lake.

The Omo Delta imagery was also downloaded and compared for two different years for which lake levels were similar – see Figure 67, p159. The image dated 1989 was intentionally selected to pre-date the satellite data period, whereas 1995 was selected intentionally to post-date the commencement of the satellite data collection. The images were selected such that the water level was computed to be the same (based on the adopted datum). The delta extent was found to be much the same in the 1989 and 1995 images, perhaps slightly extended in 1995 due to sediment deposition. The similarity in delta extent tended to verify the comparability of the Hopson and GOSH mean sea level datums (Avery, 2010).

However, the datum still needs to be verified. During this study, three further attempts at datum reconciliation were made:

1. During their field trip in January 2012, the Consultant's team climbed to the peak of North Island in search of the Government survey beacon positioned there many years ago (Pers. Comm., Ramani, 2010). The 'Trig point' is marked on Survey of Kenya mapping. The intention was to measure the level difference between the 'Trig point' beacon and existing lake level. The beacon had unfortunately disappeared without trace, either vandalised for the metal within the beacon structure, or possibly destroyed by sulphur fumes from the many active volcanic vents along the peak's ridge, combined with the relentless erosive force of the fierce lake winds.
2. In November 2011, high precision GPS data was requested from the Tullow Oil bathymetric survey team, but this data was not provided. This data source will be pursued, as the data is important to refine the lake's evaporative surface and to link this to satellite level data (for the reasons below).
3. In January 2012, communication was established with a team from the University of Potsdam in Germany, which surveyed palaeo shorelines in the Suguta Valley and Lake Turkana (Pers. Comm., Yannick Garcin, January 2012). This team used high precision GPS equipment and recorded the lake level on 11th June 2008 to be 360 masl (Elevation datum EGM96) (ibid). Garcin advised that the SRTM reading on the same date was 361 masl, and considered that this "supported his data" (Pers. Comm., 2012). The GOSH level on the same date in Figure 65, p158 was 362.5 masl. The Garcin and GOSH datums are thus roughly 2.5 metres apart, and the SRTM and GOSH datums are 1.5 metres apart. Garcin has noted that "the SRTM instrumental error for Africa is 1.54 metres" (Pers. Comm., Garcin, August 2012; citing Becek, 2008), which is consistent with

the GOSH / SRTM differences. Hence, overall, there is good correlation with the mean sea levels previously established.

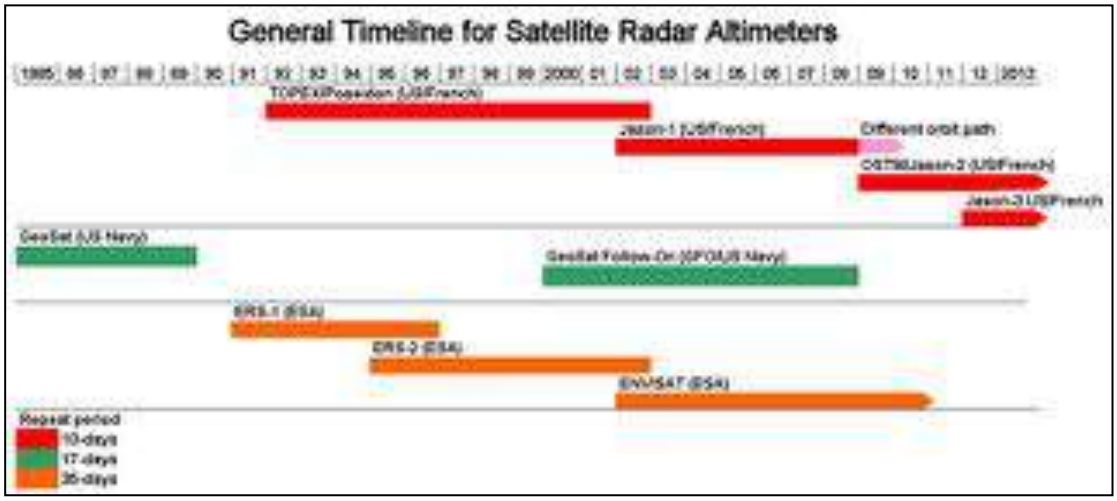


Figure 59: Satellite radar altimeters – Timeline since 1992

Source: USDA-FAS website.

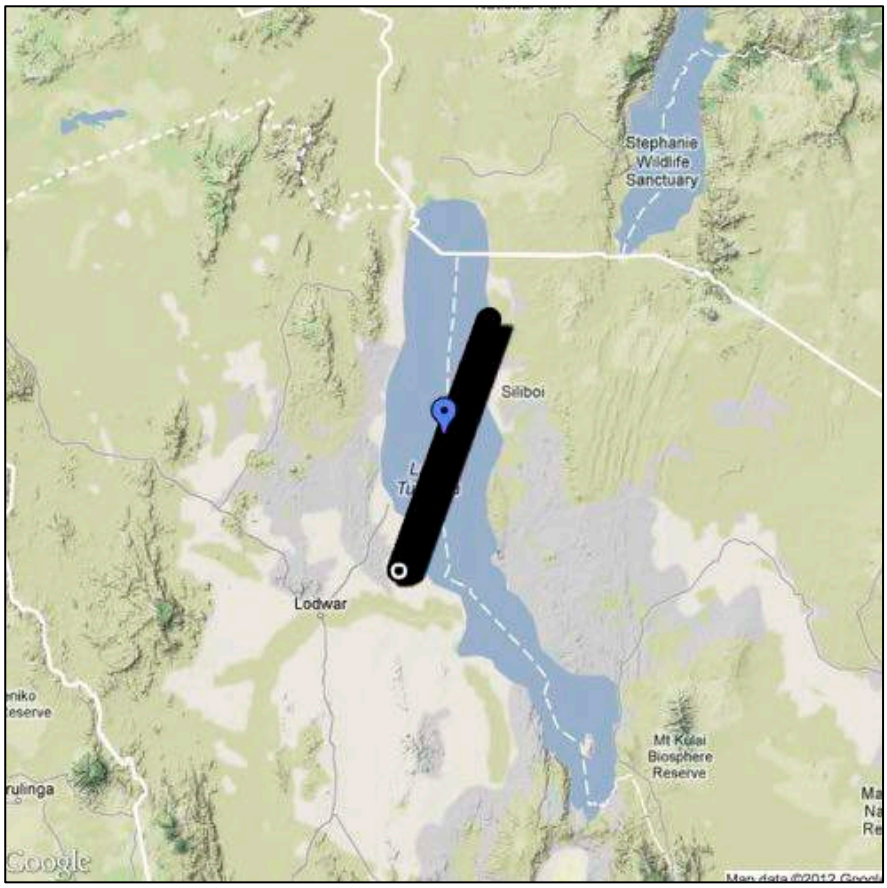
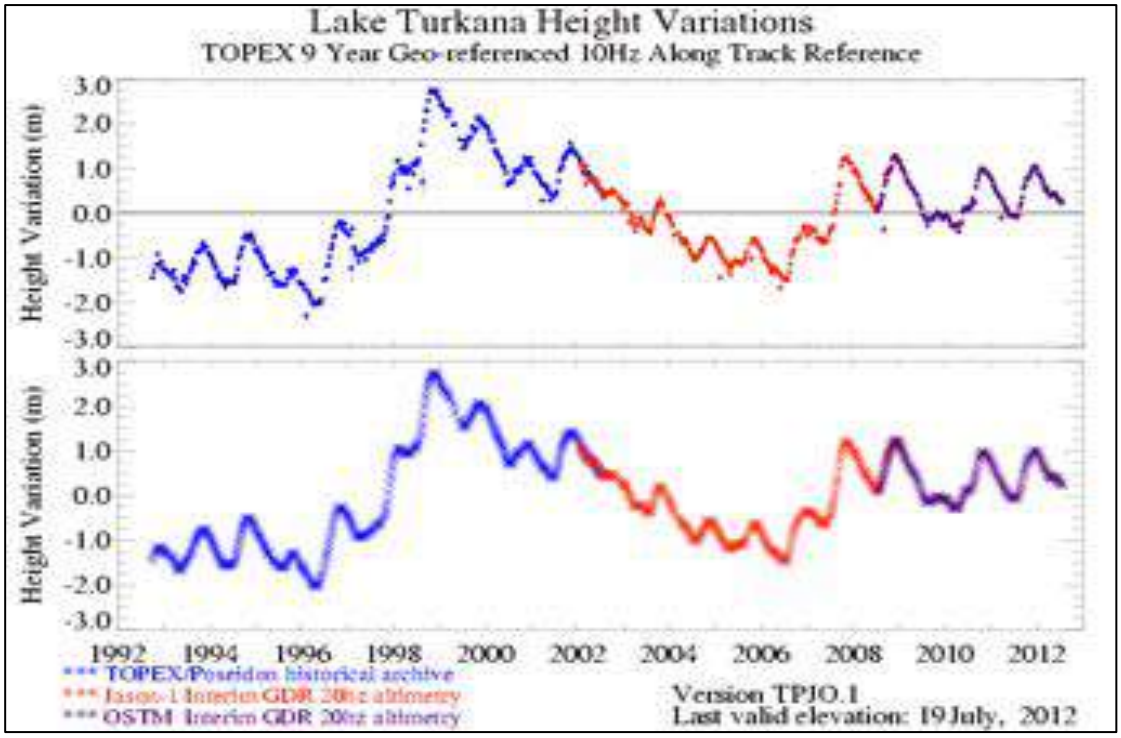


Figure 60: Satellite radar altimeter track over Lake Turkana

Source of image: USDA-FAS website.



Notes on graphs:

1. *The "Zero datum" for the dataset is the average of the 10-year dataset plotted.*
2. *The USDA / NASA / Raytheon / UMD team acknowledges the AVISO Data Centre at CNES and the NASA Physical Oceanography DAAC for the provision of Topex / Poseidon and Jason altimetric datasets.*
3. *Two graphs are plotted. The lower graph is "smoothed"; the upper graph shows the true "scatter" of plotted data.*

Figure 61: USDA satellite radar altimeter measurements

Source of satellite radar altimetry: USDA-FAS website (updated July, 2012).

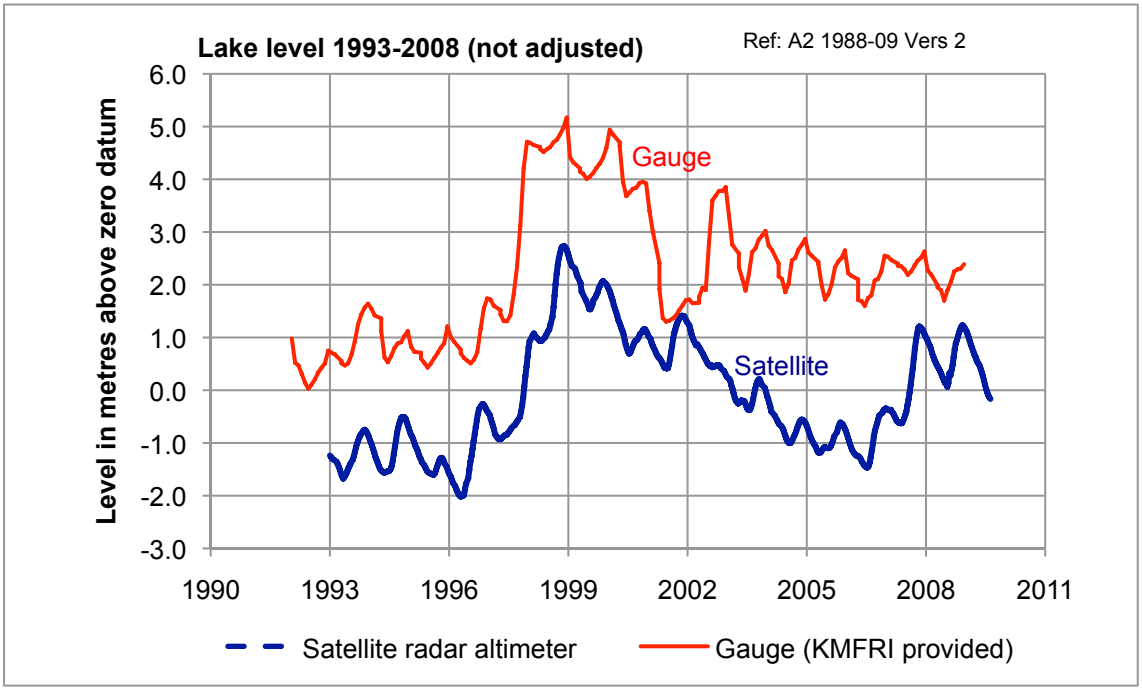


Figure 62: Lake Turkana "Gauge" and "Satellite" lake level data comparison

Sources: "Gauge" data (KMFRI); "Satellite" data (USDA-FAS); Graph plotting (Avery, 2010).

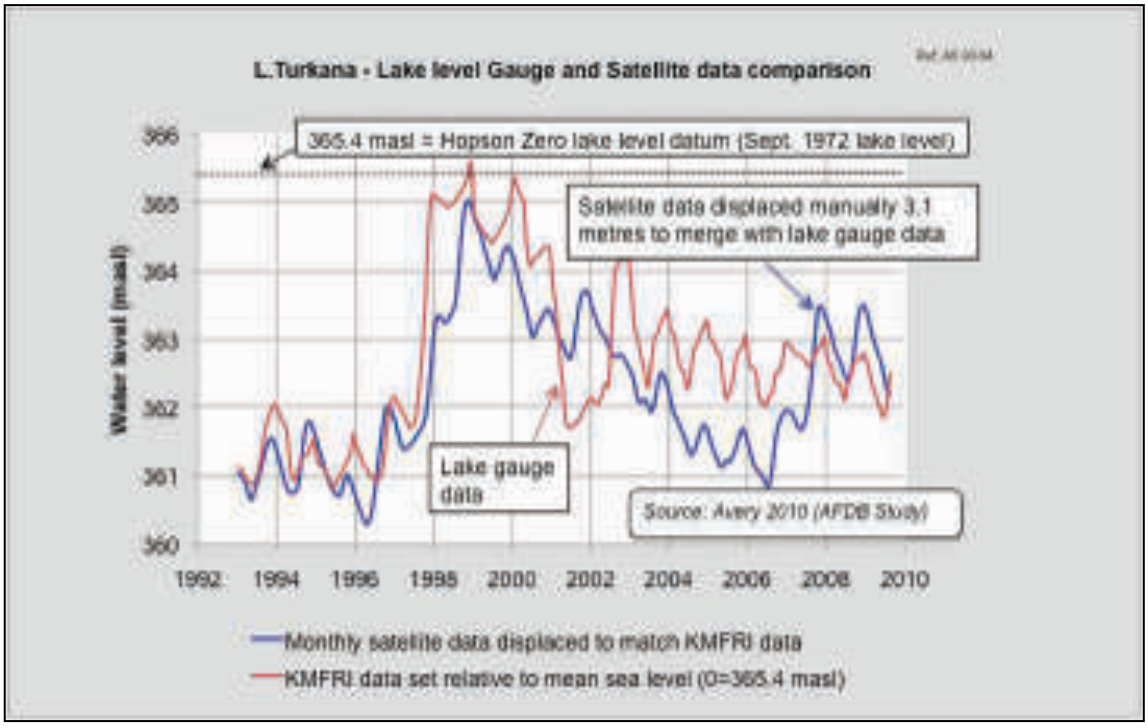


Figure 63: L.Turkana "Gauge" and "Satellite" data superimposed

Sources: "Gauge" data (KMFRI); "Satellite" data (USDA=FAS); Graph plotting (Avery, 2010).

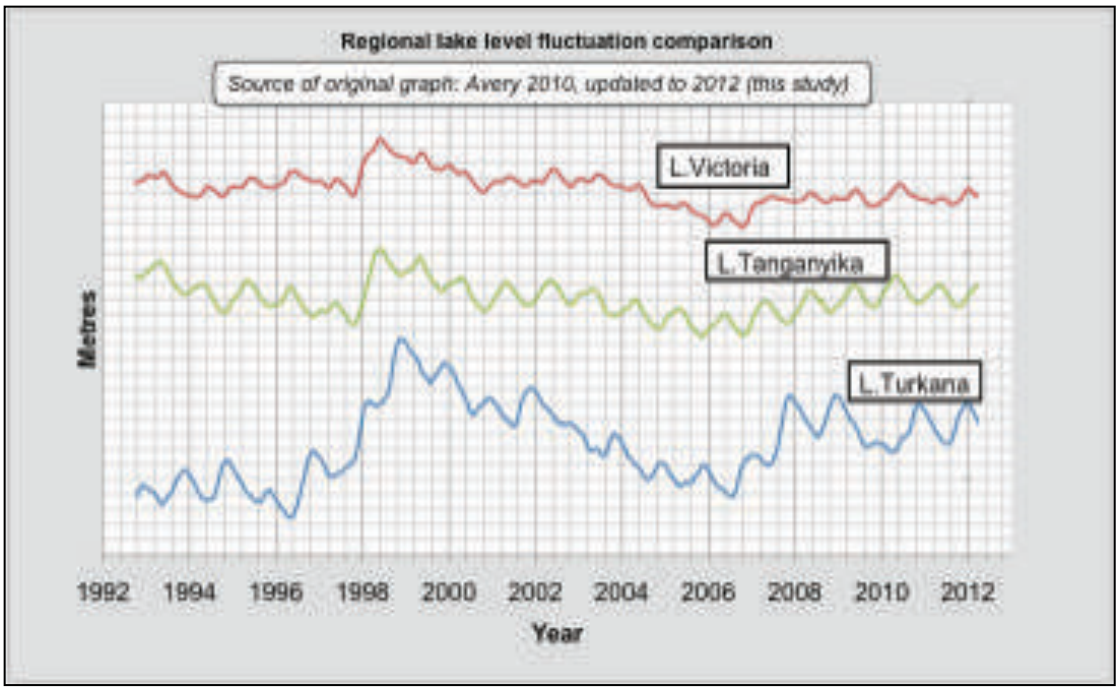


Figure 64: Regional lake level comparisons

Source: USDA-FAS satellite radar altimeter data.

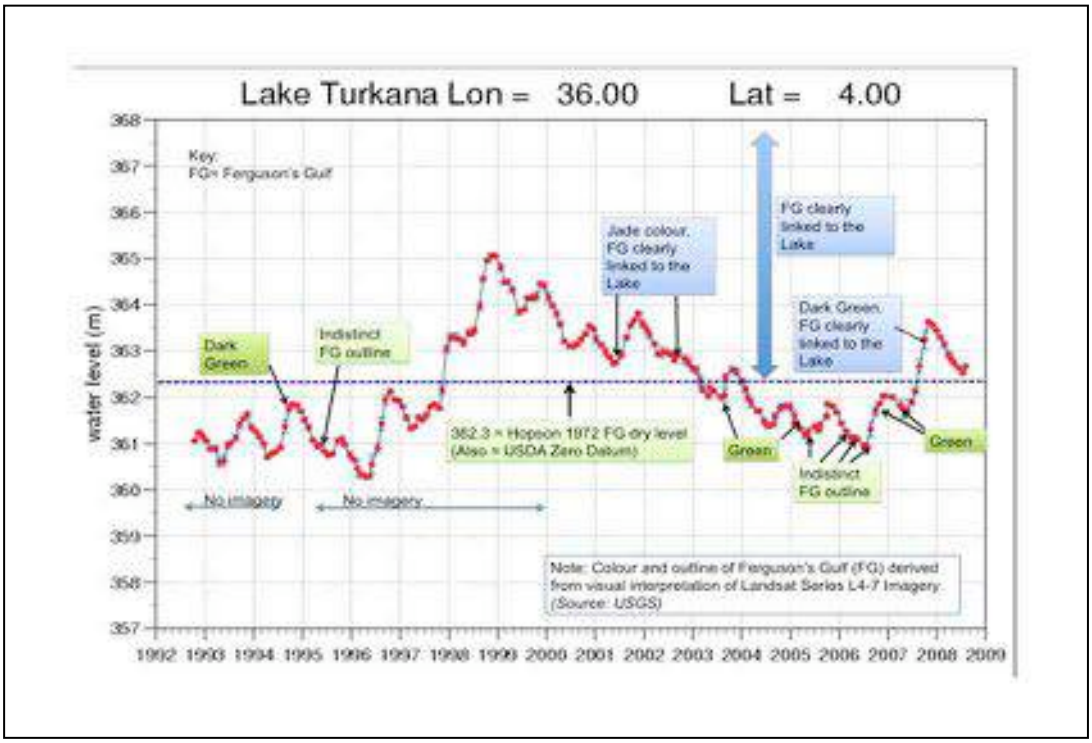


Figure 65: GOHS / Legos satellite radar altimeter data and Ferguson's Gulf status

Sources: "Satellite" lake level data (GOHS / Legos); Graph plotting (Avery, 2010).

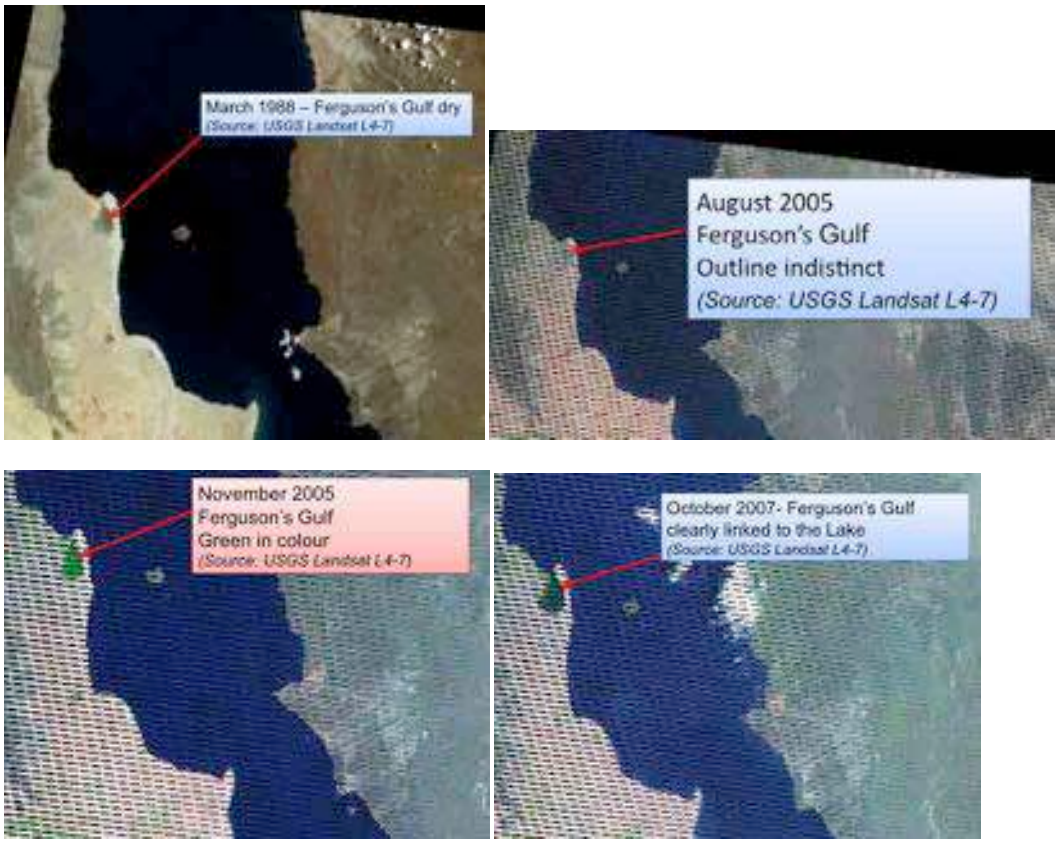


Figure 66: Various sample Landsat images of Ferguson's Gulf

Imagery Source: USGS website
Interpretation: Avery, 2010

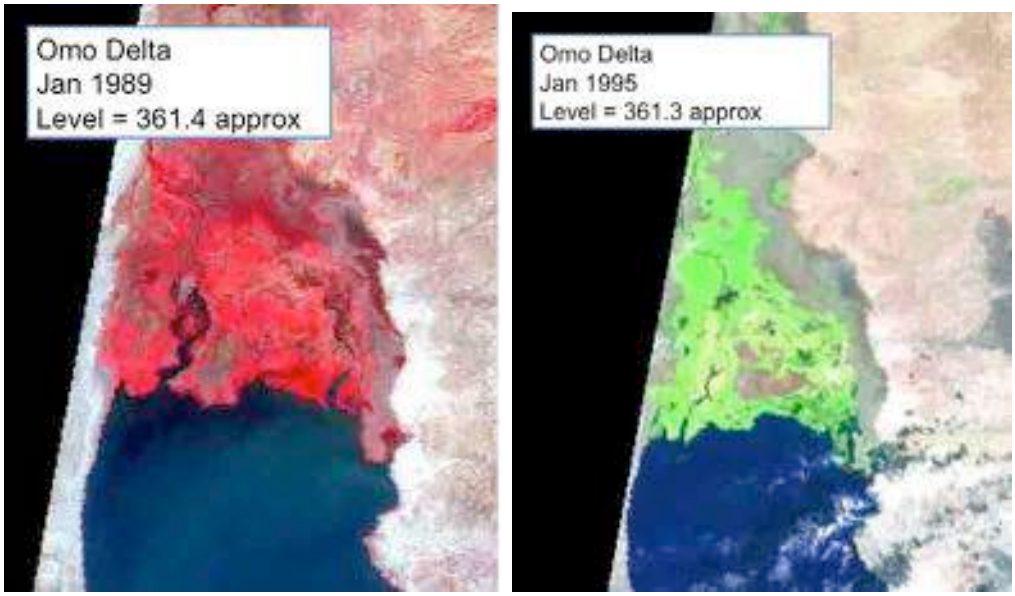


Figure 67: Omo Delta in 1989 and 1995

Image Source: USGS website, Landsat imagery L4-7
Interpretation: Avery, 2010.

13.8 Effect of falling lake levels on shoreline

Figure 50 (p144) shows that at "zero" datum level (Lake Level 0 = 365.4 masl), the lake holds a volume of 238 km^3, and 6.7 km^3 of water is stored per metre depth, with 28% of the lake volume being stored within the top ten metres of the lake (Avery, 2010).

The volume required to fill the Gibe III reservoir is equivalent to a little over two metres depth on the Lake (ibid). A similar volume will be required for Gibe IV.

Figure 68 (p161) is the Hopson datum bathymetric map with depth zones highlighted. The following is apparent (as reported to AFDB by Avery, 2010):

1. *Depth Zone 0-20 metres:* Twenty metres below the 1972 lake level, the volume stored will halve, and the northern end of the lake will shrink south within Kenya by about 40 kilometres. The shoreline location at the southern end of the lake will be slightly impacted, and there will be shrinkage of the shoreline elsewhere between 1 and 10 kilometres.
2. *Depth Zone 20-40 metres:* Forty metres below the 1972 lake level, the lake volume will reduce from 238 km^3 to only 42 km^3, and the lake will separate into two small lakes, one small lake located in the central sector, and the other small lake within the southern sector of the present lake. North Island will cease to be an island, Central Island will almost join the mainland, and the southern lake will be seasonal. The northern lakeshore will shrink 60 kilometres south, and the Omo River length will increase by this distance.

Reducing lake water level will lead to down-cutting of inflowing river channels in response to the increased hydraulic gradient resulting from the drop in the lake water table. These possibilities were mentioned in the Omo-Gibe Basin Master Plan (Woodroofe et al, 1996).

The reduced lake water level will also draw down the interconnected water table around the lake. The extent of this drawdown influence is uncertain.

The crater lakes on Central Island and at the southern end of the lake will drop by the same amounts, potentially becoming dry (they are hydraulically linked with the main lake and follow its level).

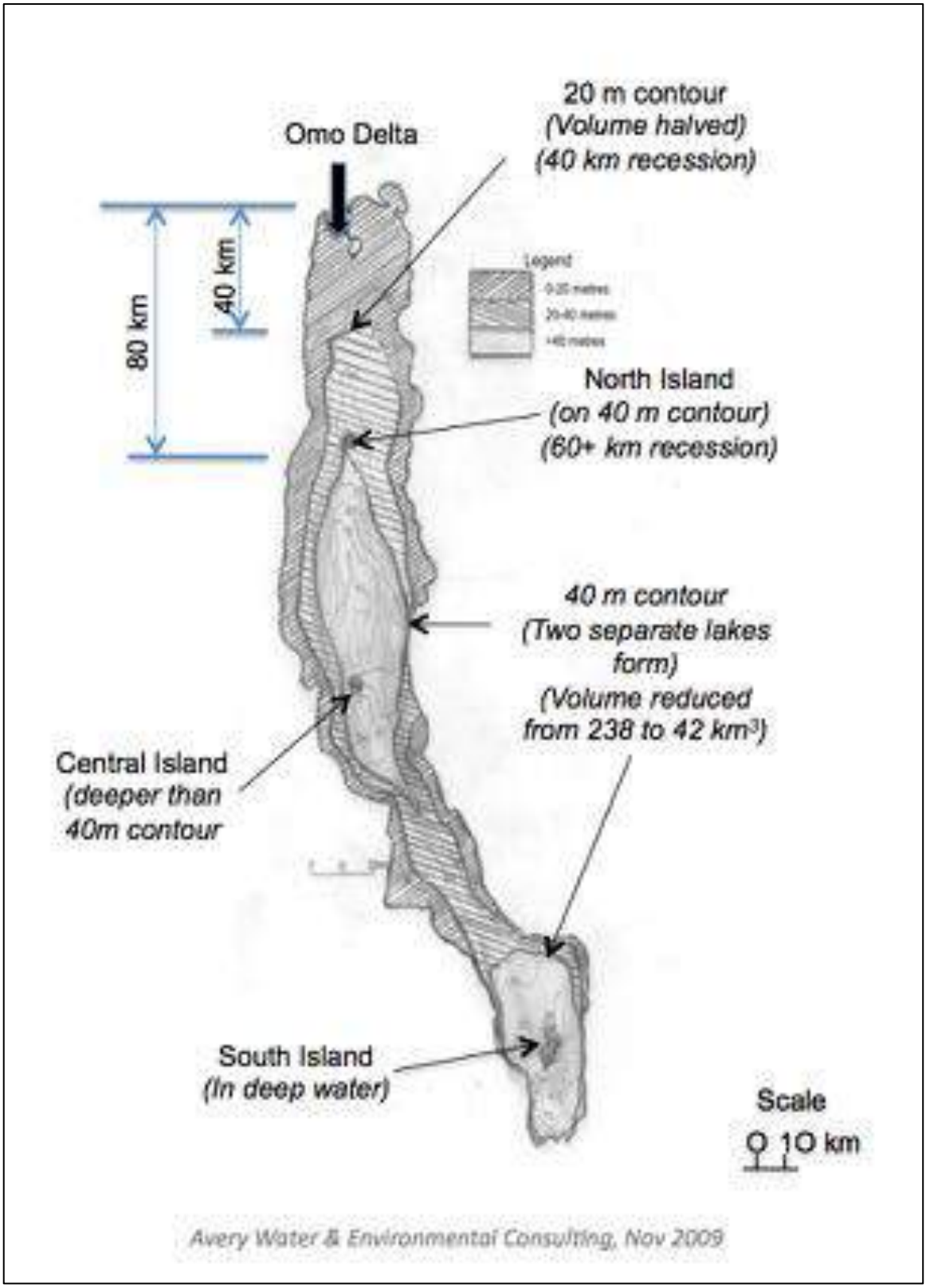


Figure 68: Lake Turkana depth zones

Source of hydrographic survey data: Hopson et al, 1982.
Source of map overlay and shading: Report to AFDB (Avery, 2009; and Avery, 2010).

14 LAKE TURKANA SALINITY LEVELS

14.1 Natural salinity progression in the Lake

Lake Turkana has been closed and without outlet ever since it became disconnected from the Nile River system about 7,500 years ago (Butzer, 1972) or perhaps 6,500 years ago (Garcin et al, 2012). Evaporation rates are more than ten times the rainfall (Avery, 2010). A volume equivalent to the entire annual Omo River flow is evaporated annually (ibid). Water is retained in the lake for only about 13 years, leaving behind the minerals carried into the lake by the rivers. Hence the lake water is slightly saline with electrical conductivity higher than fresh water, but the levels of salinity are very much lower than they might be (Hopson et al, 1982). The present salinity levels are equivalent to a lake only 600 years old (ibid). Hence, the salts are being removed through other processes, and at a considerable rate (ibid).

It has been proposed that the salt loss is a consequence of sediment / water interactions (Yuretich, 1976). For instance salts precipitate, and are used in the formation of other material, and are absorbed (ibid). In particular, calcium, magnesium and potassium salts are lost through this process, leaving sodium as the dominant cation (NIVA, 1988; citing Yuretich et al). Interestingly, the process is accelerated at electrical conductivity levels > 1,000 μS/cm (ibid). Carbonate and bicarbonate are the dominant anions, giving high alkalinity, approximately 24 meq/L (ibid).

The following summary findings were concisely reported in the 1982 Lake Turkana Project Report (repeated below, almost verbatim in the AFDB report from Ferguson & Harbott, 1982):

- The lake is well mixed with minimal temperature stratification with depth. Oxygen levels tend to reduce below 6 metres (beyond the photosynthesis zone which is the depth that light penetrates).
- The strong south-easterly winds create surface water currents to the north-west. The SE wind induced current creates a deep reverse bottom current, but this pattern is adjusted during periods of high inflow from the Omo River. Sediments from the Omo River have been shown to reach the south end of the lake (Yuretich, 1976).
- The mean electrical conductivity of the lake during the study period 1972 - 1975 (at 25^{o}C) was about 3,500 μS/cm, ranging from 200 μS/cm near the Omo Delta during the flood season, to over 4,700 μS/cm in Ferguson's Gulf. In contrast, the Omo River "fresh" water electrical conductivity was about 80 μS/cm (electrical conductivity is a measure of salinity).
- Previous historic lake conductivity measurements were reported for the "Central Sector" of the lake, showing an increasing trend, as follows:
    - 2,860 μS/cm (Beadle, 1932);
    - 3,190 μS/cm (Fish, 1954);
    - 3,630 μS/cm (Talling & Talling, 1965).
- Due to the loss of ions to the sediments, it was suggested that the lake electrical conductivity would continue to increase at the rate 0.45 μS/cm per year, and that this rate is sufficiently slow for it to be ignored as a factor likely to affect fisheries in the foreseeable future (Hopson et al, 1982).
- However, any changes that might take place within the basin resulting in changes in the composition of the major inputs, particularly in the River Omo, should be monitored.

The joint NIVA & KMFRI Lake Turkana Limnology Project also presented conductivity measurements (NIVA, 1988), and reported levels of 3,800 μS/cm in August 1988, and reported an increase of 500 μS/cm over the period 1984 to 1988 due to evaporation. The period was particularly dry and the lake was declining to one of its lowest recorded levels, hence accelerating the concentrating of salts.

14.2 Recent Lake Turkana electrical conductivity data

The AFDB report presented electrical conductivity data from various sources, reproduced in Table 38 overleaf on p164, and further measurements taken in January 2012 are tabulated in Table 39 on p165. A lake conductivity measurement 3,850 μS/cm was reported in the 1996 Omo-Gibe Basin Master Plan study report is also tabulated (Vol. XI, F2). This reading is high, and the reason is not obvious, as it is not known exactly where it was measured.

KMFRI provided data from 1997 to 2002 (reported by Avery, 2010). Readings were usually higher within Ferguson's Gulf, as the Gulf is shallow, there is high evaporation, and it is shielded from the wind-induced mixing that occurs in the main lake.

The readings tabulated overleaf in Table 38 did not extend beyond 2002 and were reported not having changed much since readings in 1965 (Avery, 2010). More recent studies were reported confirming that conductivity (EC) levels in the main lake have remained fairly constant over the last 30 years (Mbogo, 2010, citing Ojwang et al, 2007; cited in Avery, 2010).

This study's 2012 readings in the main lake off Central Island demonstrate that the lake salinity levels have not changed since 2002, perhaps because the natural increase in salinity has been offset by the increased freshwater inflow evidenced by the rising lake level trend since 2006.

14.3 Lake Turkana – Temperature and electrical conductivity profiles

A lake surface water temperature profile was measured in January 2012 from the Omo Delta to South Island, and this is presented in Figure 69 on p166. The deeper waters of the southern sector of the lake were nearly 5^{o}C cooler during this period. This is consistent with expectations based on the findings of the previous studies of Hopson et al, 1982.

An electrical conductivity (EC) profile from the Omo Delta to South Island was measured in January 2012, and is presented in Figure 70 on p166. As would be expected, the EC level rises progressively south and away from the dilution effects of the Omo River's freshwater inflow.

In contrast, an EC measurement in the lake just offshore from the Turkwel delta showed no dilution effects on conductivity due to the very low flow contribution by the Turkwel River (highlighted light blue in Table 39 on p165).

14.4 Central Island Lakes - Electrical conductivity profile

Figure 72 and Figure 73 (on p167) are Google Earth images of the islands in Lake Turkana, including Central Island with its three crater lakes.

The electrical conductivity (EC) was measured in January 2012 in all three of Central Island's crater lakes. The measurements are plotted in Figure 71 (on p166).

The EC levels measured in the crater lakes were much higher than in the main lake, being 10,705, 28,000 and 18,000 μS/cm respectively for Crocodile, Flamingo and Tilapia Lakes (otherwise named Crater Lakes 'A', 'B' and 'C' by Hopson et al).

In former times, Lake Turkana's water surface elevation was about 100 metres higher, and at that time, all three of Central Island's crater lakes were totally submerged. As Lake Turkana's

water level fell, the crater lakes formed as separate self-contained lakes bounded within individual crater rims. These crater lakes have continued to be replenished with water through some rainfall and underground percolation from the main lake. The crater lakes' levels have thus "followed" the nearby main lake level, but the salinity levels have become concentrated through isolation and evaporation.

Tilapia Lake was last connected to the main lake in 1972 (Hopson et al, 1982). Crocodile Lake was last connected in about 1902 (ibid), as its crater rim is at a higher elevation. Flamingo Lake was last connected some time prior to 1896, as its crater rim is at an even higher elevation, measured by the field team to be about 30 metres above the present lake level.

Although more concentrated in salts, Hopson et al reported only slight changes in the cationic composition of Crater Lake A's chemistry (ibid). Based on the readings in the table below, the salinity of Crater Lake 'A' increased only slightly between 2001 and 2012.

Table 38: Electrical conductivity data for Lake Turkana

Date	Ferguson's Gulf µS/cm	Main Lake µS/cm	Crater Lake 'A' µS/cm
1932	-	2,860 (5)	-
1954	-	3,190 (6)	-
1965	-	3,630 (7)	-
1976	-	-	9,540 (8)
1996 (1)	-	3,850 (1)	-
22/10/1997	4,800 (2)	3,400 (2)	-
08 – 10/1999	4,974 (2)	3,290 (2)	-
20/12/2000	5,930 (2)	3,270 (2)	-
31/03/2001	5,520 (2)	3,360 (2)	-
14/03/2001	-	3,420 (2)	10,590 (2)
22/02/2002	6,900 (2)	3,830 (2)	-
08/01/2012	-	3,668 (3)	10,716 (4)

Note: '-' signifies no data found.

Note: There was no historic data found for Crater Lakes 'B' and 'C'.

Conductivity Data Sources:
(1) Sampling date uncertain (Omo Basin Master Plan, Vol. XI, F2, Page 14, Woodroofe et al, 1996);
(2) KMFRI, 2009;
(3) University of Oxford Consultant's Field Team: Measurement in the main lake off Central Island;
(4) University of Oxford Consultant's Field Team: Measurement in Crocodile Lake on Central Island;
(5) Beadle, 1932;
(6) Fish, 1954;
(7) Talling and Talling, 1965;
(8) Yuretich, 1976.

Table 39: EC measurements throughout Lake Turkana in January 2012

Date	Sample Location	General Locality	EC uS/cm	pH Units	Temp ° C
5-Jan-12	Kalokol Beach	Eastern shore	3,598	9.42	31.2
5-Jan-12	South of North Island	N.Island	3,598	9.40	30.0
5-Jan-12	North Island	N.Island	3,663	9.41	31.2
6-Jan-12	Lake off Todenyang	NW shore	2,953	9.30	29.9
7-Jan-12	Lake off North Island	N.Island	3,426	9.39	27.8
8-Jan-12	Lake off Omo Mouth	Omo Delta	2,538	9.30	29.5
8-Jan-12	Omo Mouth	Omo Delta	1,425	8.60	28.3
8-Jan-12	Within Omo Delta	Omo Delta	980	7.74	28.4
8-Jan-12	Main Omo Mouth	Omo Delta	206	8.35	29.7
8-Jan-12	Omo Delta Channel	Omo Delta	195	7.92	29.4
8-Jan-12	Lake off Selicho	NE shore	2,831	9.36	29.1
8-Jan-12	Lake off Campi ya Turkana	Eastern Shore	3,639	9.41	27.7
8-Jan-12	Central Island	C.Island	3,668	9.40	28.5
9-Jan-12	Crocodile Lake (C.Island)	C.Island	10,705	9.26	28.8
9-Jan-12	Lake off Central Island	C.Island	3,778	9.44	29.7
9-Jan-12	Flamingo Lake (C.Island)	C.Island	37,900	9.72	32.2
9-Jan-12	Flamingo Lake (C.Island)	C.Island	38,552	9.70	34.7
9-Jan-12	Tilapia Lake (C.Island)	C.Island	18,338	9.71	30.7
10-Jan-12	R.Turkwel Delta	Western shore	360	9.19	34.8
10-Jan-12	Lake off Turkwel Delta	Western shore	3,854	9.34	30.4
10-Jan-12	South Island	S.Island	3,808	9.42	25.8
12-Jan-12	R.Turkwel Delta	Western shore	286	8.64	31.2
13-Jan-12	Springs at Lobolo	Western shore	518	8.59	30.4
13-Jan-12	R.Turkwel @ Lodwar	Lodwar	234	8.34	26.0

Notes: Measurements by Oxford University Consultant's Field Team (using YSI portable water quality multi-parameter meter).

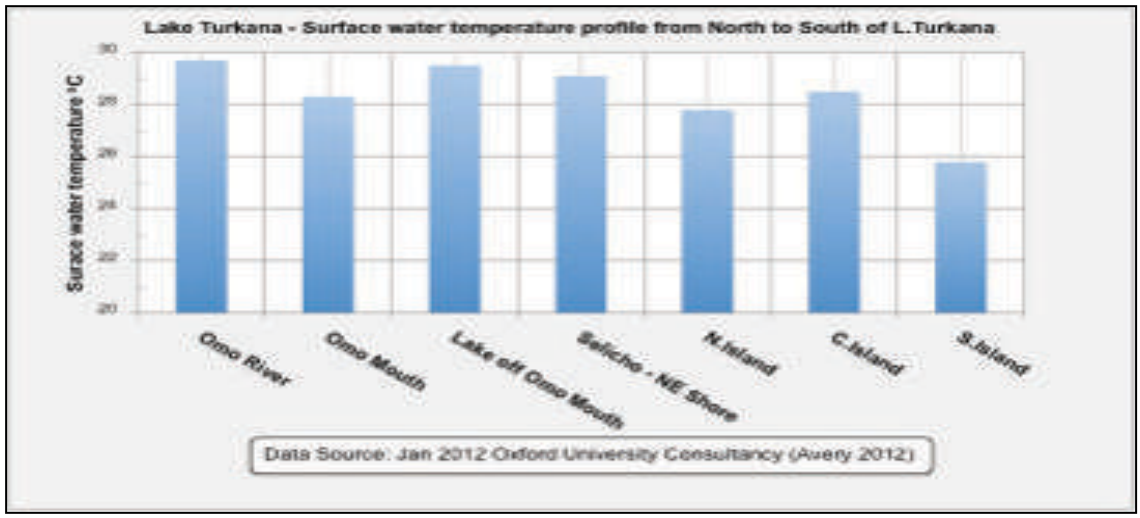


Figure 69: Surface water temperature profile along Lake Turkana in January 2012

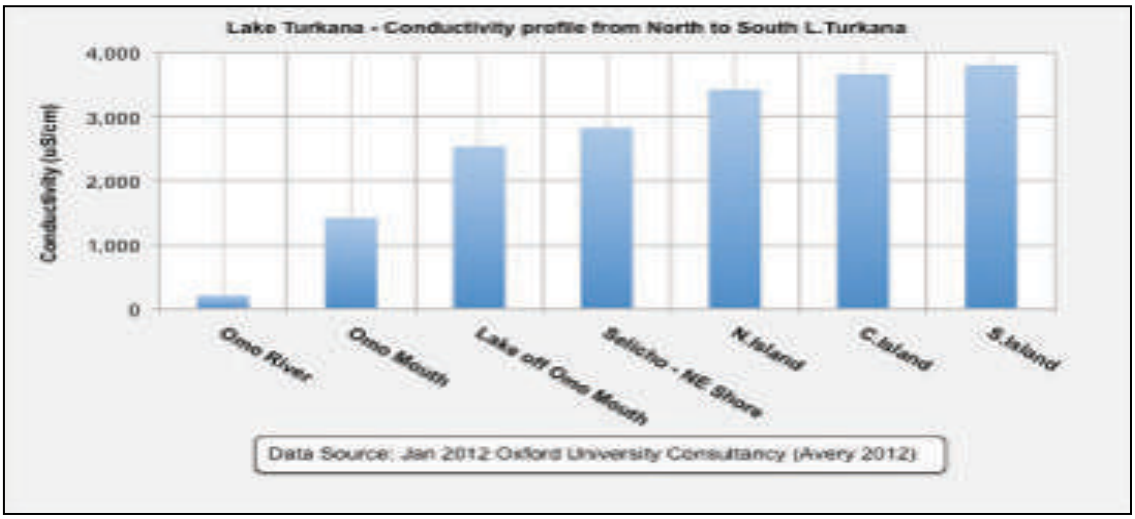


Figure 70: EC profile along Lake Turkana in January 2012

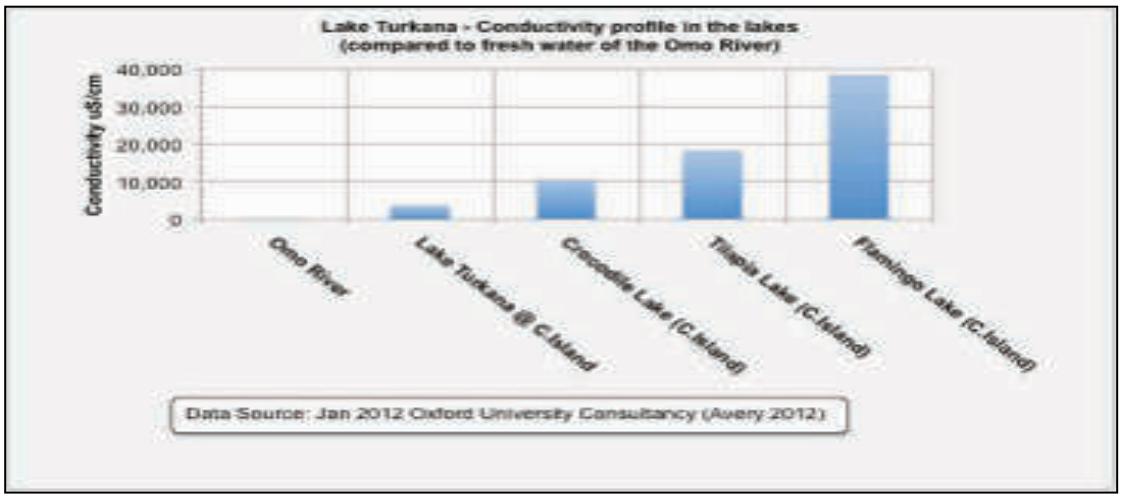


Figure 71: EC profile comparing the Omo River with Turkana's various lakes in January 2012

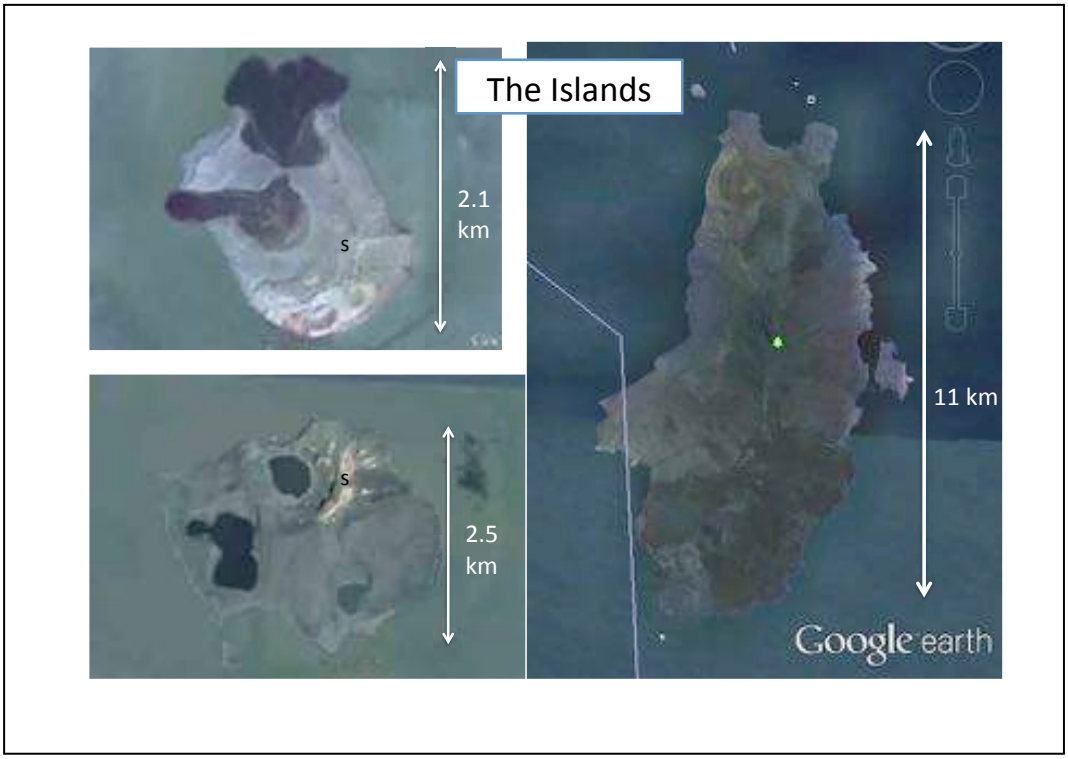


Figure 72: Lake Turkana's islands

Top Left: North Island.
Bottom Left: Central Island (with its 3 crater lakes).
Far Right: South Island.
"S" signifies sulphur vents.

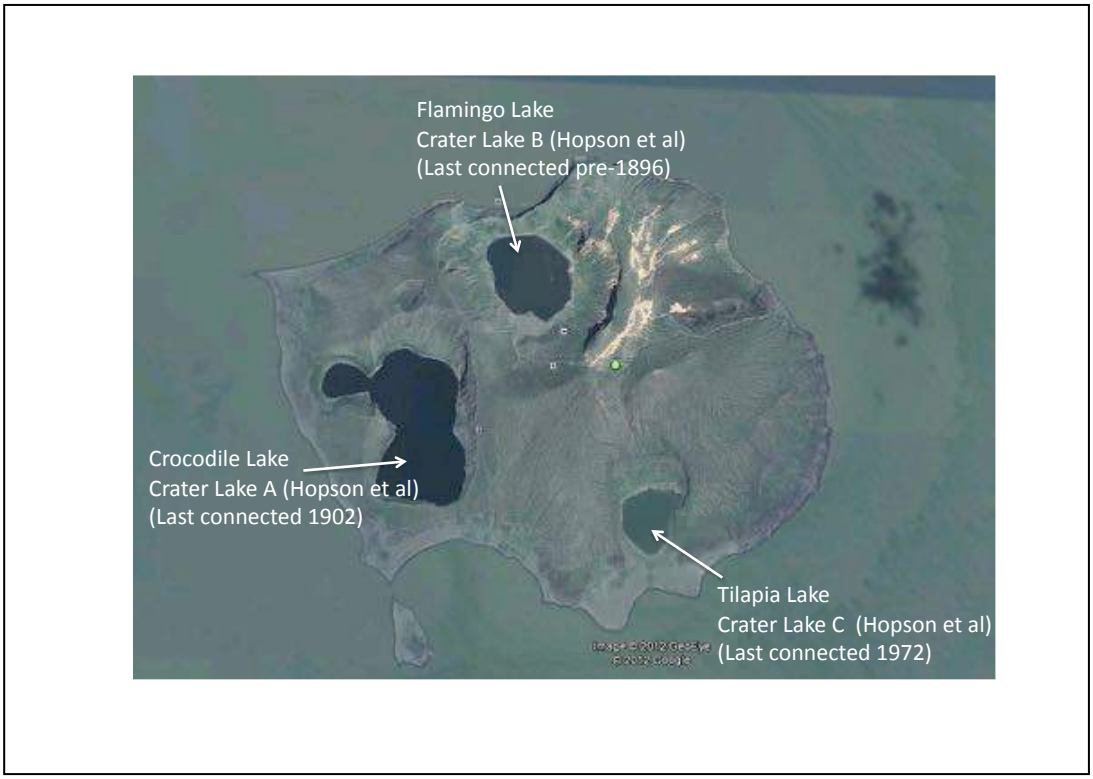


Figure 73: Central Island's three crater lakes

14.5 Other African lakes - Electrical conductivity data

A comparison with EC data in other African lakes is presented in Table 40 below (from Avery, 2010).

The classic paper of Talling and Talling (1965) arbitrarily classified lakes into three classes according to ionic content (ibid), as follows:

- Class I: Low ion concentration: Conductivity < 600 μS/cm; Alkalinity < 6 meq/L
- Class II: Higher ions: Conductivity 600 to 6,000 μS/cm; Alkalinity 6 to 60 meq/L
- Class III: Saline lakes: Conductivity 6,000 to 160,000 μS/cm; Alkalinity > 60 meq/L

The Class I lakes all enjoy wide diversity of fish. Lake Turkana is amongst the most saline in Class II, and is the most saline of the lakes still with varied fish resources (ibid), although with less diversity than other African Great Lakes (Muska et al, 2012). In contrast, the more saline lakes such as Lakes Nakuru, Elmenteita, Bogoria, Magadi, Natron and Manyara have limited fish life in the form of hardy specialist saline tolerant small cichlids (*Alcolapia* spp) that have evolved to survive in the lower ionic content springs feeding these lakes, and their associated lagoons. The small cichlids in Lake Nakuru were introduced into the lake from Lake Magadi's springs and lagoons because they are salt tolerant.

Table 40: Comparison of African lake electrical conductivities @ 20°C

Lake Name	Country	Conductivity μS/cm	Data Source	Class of Lake
Lake Magadi	Kenya	160,000	Talling et al, 1965	III
Lake Manyara	Tanzania	94,000	Talling et al, 1965	III
The Ocean	Global	43,000	-	III
Lake Bogoria	Kenya	35,700	Talling et al, 1965	III
Lake Abiata	Ethiopia	10,700 to 30,000	Talling et al, 1965	III
Lake Shala	Ethiopia	20,400 to 29,500	Talling et al, 1965	III
Lake Elmenteita	Kenya	22,500 to 43,750	Talling et al, 1965	III
Lake Nakuru	Kenya	9,000 to 160,000	Vareshi, 1982	III
Lake Rukwa N	Tanzania	5,120	Talling et al, 1965	II
Lake Turkana	Kenya	2,860 to 3,300	Talling et al, 1965	II
Lake Langano	Ethiopia	2,220	Talling et al, 1965	II
Lake Kivu	Rwanda	1,240 to 4,000	Talling et al, 1965	II
Lake Edward	Uganda	878 to 1,130	Talling et al, 1965	II
Lake Albert	Uganda	675 to 730	Talling et al, 1965	II
Lake Tanganyika	Tz / Malawi	610 to 620	Talling et al, 1965	II
Lake Baringo	Kenya	416	Talling et al, 1965	I
Lake Naivasha	Kenya	318 to 400	Talling et al, 1965	I
Lake Chad	Chad	300 to 900	FAO, 1994	I
Lake George	Uganda	165 to 207	Talling et al, 1965	I
Lake Malawi	Malawi	220 to 235	Talling et al, 1965	I
Lake Tana	Ethiopia	151 to 174	Talling et al, 1965	I
Aswan Reservoir	Egypt	162	Talling et al, 1965	I
Kariba Lake	Zim / Zambia	93 to 120	Talling et al, 1965	I
Lake Victoria	E.Africa	91 to 98	Talling et al, 1965	I

Data Source: Talling et al 1965, and others as listed.
Table Source: updated from Avery, 2010.

14.6 Seepage losses from the lake determined from lake chemistry

It has been reported by British Geological Survey (Dunkley et al, 1993) that Yuretich & Cerling concluded from Lake Turkana's chemical balance that there is no major sub-surface flow from the lake to the west and south. Hence water losses from the lake were assumed to be predominantly evaporative, with minimal seepage loss to the groundwater table (Avery, 2010).

14.7 Salinity increase with volume reduction and effects on fisheries

Any dramatic reductions in river inflow will lead to a reduction in lake volume. Salts will concentrate. To put this into perspective, if the lake level fell 20 metres, the lake volume would halve, hence the salinity level would double, although salts are constantly being removed through a process that is not fully understood.

A doubling of the lake salt concentration will lead to "changes in fauna and flora" (Mbogo, 2010). The lake salt concentration would need to increase 8-times to reach the threshold at which "most typical plants and animals are eliminated" (ibid).

Hence reductions in lake inflows are of concern.

It is interesting to note the much higher EC readings that occur within the crater lakes on Central Island, and that Crater Lake 'A' ("Crocodile Lake" in Figure 73, p167) still hosts five fish species found in the main lake, namely *Clarias lazera, Synodontis schall, Sarotherodon niloticus, Haplochromis rudolfianus* (Hopson et al, 1982). Hopson concluded that with the exception of *Mormyrids*, "…fishes in the main lake will adapt to increasing ionic concentrations and will not be adversely affected by high salinity in the foreseeable future…" (ibid., p1565, Chapter 5).

It should be mentioned that the species diversity in Crater Lake 'A' is very much less than in the main lake, as would be expected, and is restricted to a few species only (FoLT, 2010), which have survived since the time the lake was at one with the main lake. The vulnerability of the fish and the food chain to increasing salinity in Lake Turkana remains to be tested, and the salinity limits remain to be established, but clearly the fish diversity in the crater lakes is very much diminished through increasing salinity and isolation. These crater lakes do not directly benefit from the annual nutrient influxes of the Omo River, such nutrients being filtered through percolation from the main lake.

15 LAKE TURKANA - WATER CHEMISTRY

15.1 Introduction

The reviews in this Chapter were previously presented in a report to the AFDB (Avery, 2010), and have been re-structured and updated.

Kenya's published water quality standards are tabulated below, separately for domestic, livestock and irrigation purposes, and the unsuitability of the lake water quality is demonstrated.

Water samples collected during fieldwork for this study have been tested. The results are not included as anomalies were found. A lake conductivity profile measured in January 2012 has however earlier been included in Figure 70 on p166, and water quality measurements taken in all three crater lakes on Central Island have earlier been presented (Table 39 on p165, and Figure 71 on p166).

15.2 Lake Turkana water chemistry

Lake Turkana was once a freshwater environment. Since the lake's catchment descended into aridity, the lake has been a closed basin, with ever increasing salinity consequent upon relentless evaporation.

Table 41 overleaf summarises water quality data for Lake Turkana from early publications. Immediately apparent are the high dissolved solids, high sodium and chlorides, unacceptably high fluoride levels, high pH.

Table 42 overleaf compares the major ion concentrations in the Omo River and the lake with the WHO standards for potable water quality. The Omo River's major ion levels are well below WHO limits, whereas the lake ion levels are far in excess (except Calcium).

Table 41: Composition of Lake Turkana waters

(Original data published in parts per 100,000 and converted here to parts per million, ppm or mg/L)

	1 Tod. ppm	2 Omo R Ppm	3 LT ppm	4 Lokit. ppm	5 LT ppm	6 LT ppm	7 Ileret ppm	8 FG ppm
Alkalinity as Carbonate	308	Nil	320	600	500	130	248	500
Alkalinity as Bicarbonate	823	156	765	458	599	376	912	820
Ammonia-saline	n.d.	n.d.	n.d.	n.d.	0.48	0.16	0.32	0.5
Ammonia-Albuminoid	n.d.	n.d.	n.d.	n.d.	0.8	0.12	0.72	0.36
Chlorides (as Cl)	440	28	412	403	431	193	428	520
Sulphates (as SO_4)	40	Trace	24	32	21	trace	15	50
Nitrites (as NO_2)	n.s.	n.s.	trace	n.s.	n.s.	p	n.s.	P
Nitrates (as NO_3)	n.s.	n.s.	n.s.	n.s.	n.s.	p	n.s.	P
Calcium (as Ca)	5	11	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Magnesium (as Mg)	7.9	6.6	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Iron (as Fe)	n.d.	n.d.	n.d.	n.d.	0.014	0.03	0.7	0.3
Silica (as SiO_2)	n.d.	n.d.	n.d.	n.d.	1,990	1,035	2,030	2,300
Total hardness	40	50	35	30	30	20	20	20
Total solids	n.d.	n.d.	n.d.	n.d.	1,990	1,035	2,030	2,300
Fluorides	12.5	1.0	17.2	11.3	9.3	3.87	9.2	8.6
pH	10.3	7.6	10.6	n.s.	10.4	8.7	8.5	8.5

Data Source: Walsh & Dodson, 1969, tabulated in report to AFDB report (Avery, 2010).

Notes on Table above: n.d.= "not determined"; n.s.="not stated"; p="present".

Sample Localities: 1=Lake Turkana, Todenyang (north-western shore); 2=Omo River; 3=Lake Turkana (exact location not given); 4=Lake Turkana near Lokitaung (north-western shore); 5=Lake Turkana (exact location not given); 6=Lake Turkana (exact location not given); 7=Ileret (north-eastern shores of Lake Turkana); 8=Ferguson's Gulf (FG).

Table 42: Major ions in the River Omo and Lake Turkana's waters

Ion (Hopson et al)	Average for R. Omo ppm	Average for L.Turkana ppm	WHO (1984) "Guideline Value" ppm (or mg/L)
Cl^-	1.66	514	250 (taste)
Na^+	6.83	753	200
K^+	1.38	17.6	-
Mg^{2+}	2.74	2.3	No value
Ca^{2+}	8.79	4.7	<100 – 200 (taste)
F^-	No data	10 to 11	1.5

Data Source: Hopson et al 1982, table reproduced with WHO guidelines from Avery, 2010.

15.3 Definitions of "salinity"

Various classifications exist to define "salinity". Wikipedia defines "saline water" as "a general term for water that contains significant amounts of dissolved salt". Other references refer to "saline water" as water that is unsuitable for human consumption, typically waters with dissolved salts levels exceeding 1,000 ppm.

The US Geological Survey (USGS) produces a classification as follows (Wikipedia):

Table 43: US Geological Survey "Salinity" categories

Salinity Range	USGS "Salinity" Category
1,000 to 3,000 mg/L	"Slightly saline"
3,000 to 10,000 mg/L	"Moderately saline"
10,000 to 35,000 mg/L	"Highly saline"

Source: Table from Avery, 2010. Lake Turkana is "Slightly saline".

15.4 Lake water "potability" for humans, and associated health risks

Kenya's water quality standards for rural and community water supply include "limits" tabulated in Table 44 below (MoWD, JICA Sectoral Report C, 1992).

Based on the USGS classification in Table 43 above, Lake Turkana's waters are "slightly saline". Based on drinking water standards, the waters are "saline".

Table 44: Water quality standards for rural and community water supply

	Lake Turkana	Permissible level (1)	Limit (1)	Guide Value (Max allowable) (2)
EC (μS/cm)	3,500	750	2,000	No value given
Total dissolved solids (ppm)	2,440			1,200
Fluoride (mg/L or ppm)	10 to 11	1.5	3.0	1.5
Iron (mg/L or ppm)	0.014 to 0.7	0.3	1.0	No value given

Notes: The table includes selected parameters only. Refer to Sources for full list. Table originally presented in Avery, 2010.

Sources: (1) MoWD / JICA Sectoral Report C, 1992; (2) Second Schedule, EMCA Water Quality Regulations, (2006).

The conductivity of the lake water is 3,500 μS/cm, which equates to dissolved salt content 2,440 ppm (Hopson et al, 1972; Wood & Talling, 1988). Normal drinking water in an urban water supply would have conductivity 50 to 100 μS/cm. The lake water salinity is almost double the "Guide Value" for rural water supply in Kenya. Lake Turkana's water is nonetheless utilised by local people when they have no alternative source of drinking water, but there are significant health risks attached, especially for infants and growing children.

The lake's 500 ppm chloride level is double the WHO 250 ppm "Guideline Value" for human consumption. This limit is based on "taste" considerations.

The fluoride level at >10 ppm is well in excess of acceptable limits for both human and livestock. The potential adverse health risks are tabulated in Table 45 below (from WHO, 1984).

Any visitor to Turkana will notice the discoloured teeth of many local people living near the lake, due to the high fluoride levels (although mottling of teeth due to fluoride is not unusual in Kenya).

There are many people brought up drinking the lake water who are suffering from crippling fluorosis. One old man interviewed during the field trip in January 2012 denied that drinking lake water caused his disease. Instead he stated his skeletal deformation "was a curse" and that he preferred to drink lake water because "it tasted better" and because "one does not need to add salt to food". Even though international NGOs were installing a new water supply nearby from a protected spring, this old man claimed he was ignorant of the consequences of high fluoride in the water.

Fluoride level is a critical factor to determine. Figure 74 below is a useful relationship correlating EC measure to fluoride levels in Turkana's shallow alluvial aquifers (Norconsult, 1983). If 3 mg/L fluoride is taken as the upper limit, the guideline EC limiting value would be about 1,700 μS/cm. This is useful for field checks with a portable EC meter.

Table 45: Potential adverse health effects of fluoride in water *(WHO, 1984)*

Fluoride Level	Lake Turkana Fluoride	Potential Adverse Health Effect
> 1.5 mg/L		Teeth mottling can occur
3.0 to 6.0 mg/L		Skeletal fluorosis can occur
> 10 mg/L	10 to 11 mg/L	Crippling fluorosis can occur

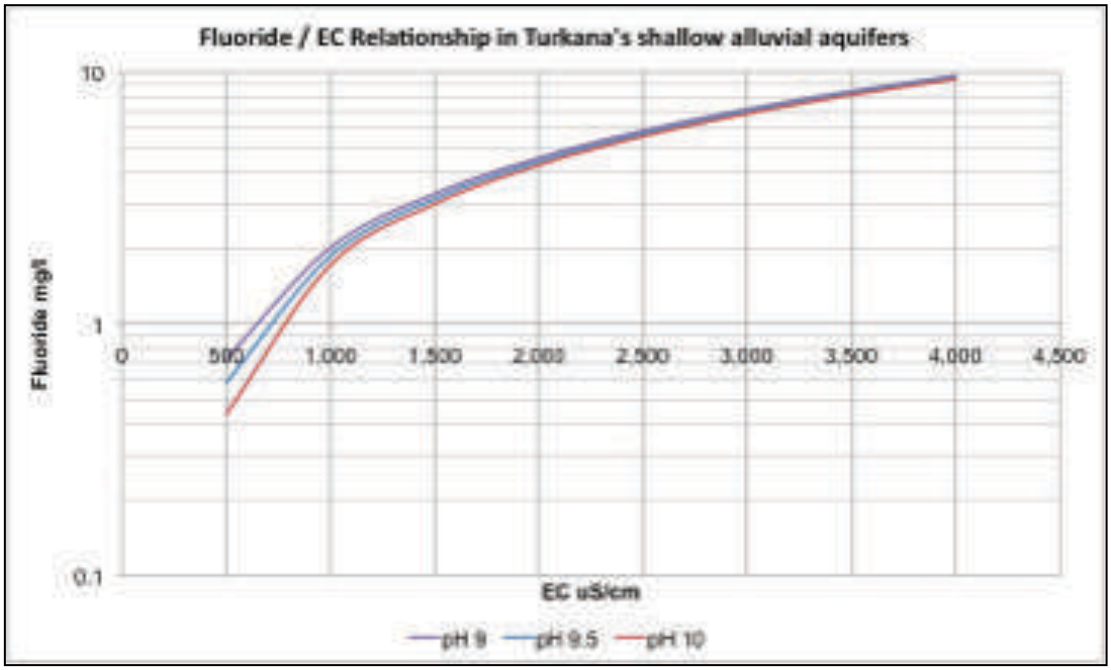


Figure 74: Fluoride / EC relationship in Turkana District's shallow alluvial aquifers

Source of relationship equations from which graph derived by this study: Norconsult, 1983

15.5 Lake water "potability" for livestock and health risks

Kenya's Ministry of Water's guidelines for livestock water quality are reproduced in part in the following Table 46. The lake water is suitable for livestock in all respects except "fluoride", whose concentration is almost double the "Limit".

Table 46: Lake water quality compared with Kenya guidelines for livestock

	Lake [2] ppm	Threshold [1] ppm	Limit [1] ppm
TDS (total dissolved solids)	2,440	2,500	5,000
Fluoride	10.0 to 11.0	1.0	6.0
Chloride	514	1,500	3,000
Sodium	753	1,000	2,000
Magnesium	2.3	250	500
Calcium	4.7	500	1,000

Sources:

(1) MoWD / JICA, 1992;

(2) Hopson et al, 1982, Table 1.17.

The lake's dissolved salt concentration 2,440 ppm is just below the 2,500 ppm "Threshold" recommended for livestock use in Kenya, but the concentration can double before the Kenya 5,000 ppm "Limit" for livestock is reached. Hence, livestock could tolerate further increases in salinity, except where fluoride is concerned. Livestock tolerance for chloride in water varies with the livestock unit in question, being in the range 1,200 to 5,600 ppm, with the Kenyan upper limit set at 3,000 ppm. Hence, the lake's chloride levels are well within acceptable limits for livestock.

Livestock such as sheep, cattle and horses reportedly can drink saline water with reasonable safety up to the salinity range 7,800 to 10,900 μS/cm (NSW Dept of Primary Industries). Local guidelines proposed in the MoWD's JICA National Master Plan suggest a TDS (total dissolved solids) "Limit" of 5,000 ppm, which equates roughly to 7,800 μS/cm, which is similar to the lower end of the NSW range above. The lake water is well within these TDS limits.

Kenya's Range Management Handbook for Marsabit District has commented on the use of lake water by livestock (MoLD, 1991). The Handbook states that "camels and small stock are watered on the lake on a permanent basis", but that "cattle are known to take ill effect" (ibid). The Handbook further stated: "Local people prefer to water their animals from other sources in the vicinity, if these are within reach" (ibid, p55). The Handbook stated that drinking lake waters "bears the danger of digestive disorders and occurrence of fluorosis in humans and animals" (ibid, p81).

Similar views are expressed in the later dated Handbook for Turkana District (MALDM, 1994), in which the following is stated:

- "…The water of Lake Turkana is generally not suitable for either humans or animals. Fluoride levels are excessive and the water is alkaline…" (ibid, p87).
- "…Near the Omo Delta the water is 'better' quality. The inhabitants of Todenyang use water from the Omo Delta in time of need…" (ibid).
- "…In general livestock rarely water at the lake because negative side effects are regularly encountered except in more tolerant stock like camels..." (ibid). Note that this is in contrast to the eastern shore in Marsabit District where livestock rely heavily on the lake for their water supply, as there are few other water sources. Livestock in Turkana District can always use boreholes, shallow wells and springs.

Hence drinking the lake water is a last resort, even for livestock.

15.6 Irrigation water standards

Typical water quality guidelines for irrigation water are presented in Table 47 below. Salt tolerant crops might cope with water salinity up to 5,000 μS/cm, whereas salt sensitive crops require water <700 μS/cm EC. The lake's conductivity, TDS and chloride levels are all in the "Very High" salinity hazard category in Table 47. Hence the lake water is unsuitable for irrigation under normal conditions.

Kenya's "Standards for Irrigation Water" are partly reproduced in Table 48 below. All "permissible levels" are exceeded by the lake water quality.

The Omo River and delta, with its fresh water (EC 80 μS/cm) and suspended sediments from the Ethiopian highlands, is a stark contrast to the lake, offering the opportunity to local people to cultivate / irrigate along the banks in an otherwise dry area.

There are numerous windmill and portable motorised pumps to be seen along the Omo River banks (Sogreah, 2010). The Lower Omo is today the focus of large-scale irrigation development promoted by the Ethiopian Government (Oakland Institute, 2012).

As saline water can intrude up the river from the lake, the irrigation intakes need to be well upstream on the Omo River, beyond the zone of saline intrusion. Groundwater that is influenced by recharge from the lake is equally poor quality.

Table 47: USDA Classification for irrigation water

Salinity hazard class	Low	Medium	High	Very high
Conductivity range, μS/cm	100 – 250	250 - 750	750 – 2,250	> 2,250
TDS, ppm	< 200	200 – 500	500 – 1,500	> 1,500
Cl, ppm	< 60	60 - 200	200 - 600	> 600
Irrigation suitability				Unsuitable

Source: Richards (1954).

Notes: TDS=Total dissolved solids; Cl=Chlorides.

Table 48: Kenya's "*Standards for Irrigation Water*"

Parameter	Lake values	Permissible Level [2]
pH	> 8.5	6.5 – 8.5
Fluoride, ppm	> 10.0	1.0
Chloride, ppm	> 500	0.01
Total dissolved solids, ppm	> 2,400	1,200

Note (2): Permissible levels from EMCA (2006), Ninth Schedule.

Note that selected parameters only are listed in the table above.

15.7 Bacteriological contamination of water

The adverse effects of bacteriological contamination of drinking water are obvious and are a risk associated with drinking untreated water from the lake, unprotected springs and wells. Bacteriological contamination is not dealt with in this report, as it is a public health issue.

The risks of water-borne disease are widespread, as traditional water sources are often unprotected, and sanitation awareness is poor, with open defecation being normal practise. Faeces can be walked on, and can be flushed into watercourses. The Public Health Officer at the Lodwar Hospital stated that people passing through areas of open defecation, may then draw water from unprotected water sources, carrying bacteriological contamination with them (see Field Assistant's Report in Volume II of this report - Annexes).

15.8 Chemical contamination of water

Chemical contamination can arise from human activities. These include chemicals from large-scale irrigation projects, from construction projects, from waste discharges from sugar factories, and from oil spillages. Study of these is beyond the scope of this report.

15.9 Conclusion on lake water "potability"

Local people and their livestock drink water direct from the lake. Whilst the local people tolerate the poor water quality, this is out of necessity, and they will request better quality water from passing travellers.

The lake water quality does not meet the standards required for either domestic or livestock use in regard to fluoride. Long-term reductions in Omo River inflow into the lake will exacerbate the situation, and will increase the significant health risks associated with the persistent traditional local practise of drinking the lake waters.

Various water sources are utilised by people around the lake, and these are likely to be of very much better chemical quality. These sources are described elsewhere in this report.

Routine water quality monitoring is recommended to continue to track trends in lake water quality.

It is of course possible to render the lake water potable through modern desalination treatment processes that reduce the fluoride to acceptable levels. Examples include reverse osmosis such as is being tested by Oxfam at Longech. Less "high tech" processes such as bone char removal can be appropriate for smaller needs. A full review of these options is beyond the scope of this report.

16 WATER RESOURCES AROUND LAKE TURKANA

16.1 Introduction to the water resources of the Lake Turkana surroundings

A useful brief review of water sources was presented in the AFDB hydrological study of Lake Turkana based on published geological surveys (Avery, 2010). That review has been expanded during this study based on past experience and further published data, notably the Range Management Handbook of Kenya, and the brief fieldwork done during the course of this study.

Traditionally, people living in Kenya's northern arid zones derive potable water from springs, and wells sunk into the beds of seasonal river channels. In colonial and recent times, some boreholes were drilled, and in more recent times some wells have been equipped with hand pumps or wind pumps. In some districts, small dams and pans are constructed to store surface water runoff, but these are less suitable where rainfall is erratic and evaporation rates high.

Lake Turkana is the largest permanent water body in Kenya's northern areas, but its water is unsuitable for human consumption (see previous chapter). Fluoride levels are excessive for both humans and livestock. Stockholders will seek alternative sources where possible, but camels and small stock do permanently water from the slightly saline lake, whereas cattle suffer "ill effects" (MoLD, 1991, p55). Hence the many waterholes and springs around the lake are preferred, and are very important water sources.

16.2 Northern end of Lake Turkana

People living at the northern end of the lake may have access to the perennial fresh water of the Omo River.

16.3 North-eastern shores of Lake Turkana – Ileret to Moite

See Figure 75: NE Shore (Moite to Ileret) - Water sources, on p183 (abstracted from MoLD, 1991). Key landmarks, waterholes and springs are identified on the map with yellow font numerals, and a legend is included.

The following comments are drawn from the literature:

"…The community at Ileret relies on near-surface water in the sandy sediment of the Il Eret River…" (Key et al, 1988). To the east there are various perennial springs, for instance at Buluk and Sabarei (not shown on the map).

"…Away from the lake, established waterholes and springs occur between the volcanic units on most of the large hill masses…" (Wilkinson, 1988).

In the 1980s, the Ministry of Water Development drilled water supply boreholes at Ileret Police Post and Sabarei Police Post (50 kilometres north east of Sibiloi National Park) but the water is too saline for practical use (Aquasearch, 2006).

"…Shallow groundwaters are the most important local water resource in terms of availability, though distribution about the broader area is uneven…" (ibid, p10).

"…Within and adjacent to Sibiloi National Park, there are a number of perennial shallow wells and springs…exploited for stock watering and potable purposes by Dasenech and Gabbra pastoralists…" (Aquasearch, 2006).

Perennial springs are found at Kokoi and at Jarigole (locations shown on Figure 75). Otherwise there are scattered waterholes that are permanent enough to have been mapped by the Ministry of Livestock Development.

There are a number of seasonal river channels entering the lake shown on Figure 75.

16.4 South-eastern shore from Moite south through Loiyangalani

See Figure 76: SE Shore (Moite to Loiyangalani and 'south end') - Water sources, on p184.

Between Moite and Loiyangalani, numerous seasonal river channels reach the lake. Between Moite and El Molo Bay, these watercourses can have sandy beds.

Since about 2010, the El Molo village has been supplied with water piped from the Ngobele Springs north of Loiyangalani (EC 799 μS/cm). The pipe was broken when the intake was visited in April 2012. The Ngobele springs surface within an eroded watercourse draining towards the lake from the slopes of Mt Kulal.

Loiyangalani Trading Centre itself is an "oasis" on the footslopes of Mt Kulal near the lake. Previous reports record that water is piped water from perennial alkaline hot springs (Ochieng et al, 1988). There are several spring eyes emerging amidst the shelter of doum palms. The Loiyangalani spring conductivity has earlier been reported to be 554 μS/cm (higher than Omo river water @80 μS/cm but very much less than the lake water @ 3,500 μS/cm - Hopson et al, 1982). On nearby Mount Kulal, there are numerous cold and tasteless springs (ibid).

The Loiyangalani spring quality was measured in April 2012 at two different points. The results are tabulated in Table 49 below. The water temperature varied between spring eyes, in this case being 33.9°C at El Molo Camp and 38.7°C at the Catholic Mission (the offshore lake water near S.Island was a cooler 25.8°C). The salinity readings are contrasted in the table below with a bottle of Keringet mineral water. The Loiyangalani spring water has double the mineral content of the bottled water, but is "potable", having a mineral content 1/6th of that found in the semi-saline lake water.

The Ngobele Spring water quality is similar to the Loiyangalani Spring water (see Table 49 below – note its cooler water, slightly higher dissolved solids, and higher pH).

Table 49: Water quality - Loiyangalani and Ngobele Springs

Date	Source	EC μS/cm	Temp °C	SPC μS/cm	TDS mg/L	pH
12/04/12	Ngobele (Q=1 L/s)	849	28.3	799	520	8.98
13/04/12	Loiyangalani: El Molo Camp	837	33.9	716	468	8.20
13/04/12	Loiyangalani: Catholic Mission	868	38.7	687	449	7.94
10/01/12	L.Turkana @ S.Island	3,808	25.8	nm	2,437	9.42
-	Keringet Bottled water	304	nm	269	175	7.59

Note: nm signifies "not measured".

16.5 Eastern shore summary – Range Management Handbook data

Kenya's Range Management Handbook includes a useful "Range Unit Inventory", applicable at that time (1991), with some key details summarised in Table 50 below. Generally speaking, the "water availability" was better than "forage availability". Hence, for pastoralists, the constraint at that time was "forage availability". This is evident from the permanent presence of livestock within Sibiloi National Park. The livestock losses in the recent droughts were due to lack of forage. The availability of forage is a function of rainfall, but also stocking density.

The Range Management Handbook lists some water quality parameters, but there was no data for the lakeshore sources of interest to this study.

Table 50: Range summary – eastern shore of Lake Turkana

Unit No	Range Name	Range Area km^2	Barren Lands %	No. of BHs	No. of Wells	No. of Springs	Constraint
1	Ileret	2,050	40%	1	3 (1)	-	Seasonal forage
2	Moite	4,020	60%	-	10	3	60% barren
5	Hurran Hurra	6,035	50%	1	10	1	50% barren, forage
3	Loiyangalani	1,390	(2)	-	1	4	Access difficulty, seasonal forage
4	S.Horr	980	0%	-	8	Many	Forage availability

Note (1): There are "several wells and waterholes along the lakeshore" (MoLD, 1991, p79).
Note (2): Vegetation in vicinity of Loiyangalani "severely degraded" (MoLD, 1991, p81).

16.6 South end of lake Turkana

See Figure 77: Southern shore (portion within Samburu District) - Water sources on p185. Key features mentioned below are numbered in yellow font numerals.

The "south end" is the most barren part of the lake, comprising the Barrier Volcanic complex, but not far south the Nyiru Massif rises with its contrasting forest-clad mountain range, and with perennial water sources reaching its base at Tuum, and also at two locations in the Horr Valley. A small stream crosses the road within South Horr itself, and the second larger stream crosses the road a short distance north of South Horr (the Kurungu River listed in Table 51 below).

Seasonal river channels reach the lake near the "south end". In this area, people resort to the lake itself, or springs (for instance at Parkati), or wells in seasonal river channels.

The perennial Kurungu River in the Horr Valley has excellent water quality, probably the best water to be found between South Horr and the Omo River.

Also tabulated in Table 51 is a water quality measurement for an excavated waterhole within the seasonal Barseloi lugga to the south of the Mt Nyiru range. This water is as highly mineralised as the springs at Loiyangalani, and is probably fairly typical of the quality of water in wells dug into seasonal sandy riverbeds (luggas).

Table 51: Water quality – Horr Valley and Barseloi Lugga (south of Lake Turkana)

Date	Source	EC µS/cm	Temp °C	SPC µS/cm	TDS mg/L	pH
14/04/12	Kurungu River near South Horr	181.3	22.5	190.3	123.5	8.26
10/04/12	Barseloi Lugga near Maralal	516	nm	479	312	8.54

Note: "nm" signifies "not measured".

16.7 South-western side of Lake Turkana

See Figure 78: SW Shore (South end to Turkwel Delta) - Water sources on p186.

See also Figure 79: NW Shore (Turkwel River to Todenyang) - Water sources on p187.

It is very conspicuous from the maps that wells follow the line of watercourses: "…Alluvial plain water is readily obtainable from shallow wells dug in the river bed…In the dry season the water level in these wells sinks rapidly…" (Ochieng et al, 1988).

Table 52 below presents water quality data for the area of the Turkwel River delta and the well-known Eliye Springs (a future 'resort city' locality).

Other perennial springs occur along the shoreline, for instance the Lobolo Springs north of the Eliye Springs. The EC level measured at Lobolo was practically identical to the EC measured at the Eliye Springs in 1982 (data in table below).

Table 52: Water quality – R. Turkwel and Lobolo Springs

Date	Source	EC µS/cm	Temp °C	SPC µS/cm	TDS mg/L	pH
10/01/12	L.Turkana off Turkwel Delta	3,854	30.4	-	2,269	9.34
10/01/12	River Turkwel in delta zone	360	34.8	-	196	9.19
10/01/12	South Island	3,808	25.8	-	2,438	9.42
13/01/12	Lobolo Springs	518	30.4	-	306	8.59
13/01/12	River Turkwel @ Lodwar	234	26	-	149	8.34
1982 (1)	Eliye Springs	550 (2)	-	-	330 (2)	9

Note (1): Source of data is the Range Management Handbook for Marsabit (MALDM, 1994).

Note (2): Na=1,435 ppm & F=2.9 ppm (both exceed "safe" thresholds) (MALDM, 1994, App, III.7).

16.8 North-western side of Lake Turkana

See Figure 79: NW Shore (Turkwel River to Todenyang) - Water sources on p187. As elsewhere in Turkana District, hand dug wells follow the line of watercourses. The following comment is abstracted from literature:

"…Springs occur on most of the large hill masses, notably at Lokitaung and elsewhere in the Labur and northern Lokitdok Hills…" (Walsh & Dodson, 1969).

The above summary is confirmed in the later Range Management Handbook for Turkana District (MALDM, 1994).

16.9 Western side of Lake Turkana Summary – Kenya Range Management Handbook

16.9.1 General

The Range Management Handbook for Turkana District encompassed an area 65,000 km^2 and a population in the range 143,000 to 165,000 people, mostly of the Turkana tribe (MALDM, Page vii).

The Handbook listed "over 7,000 water sources", although "they are not evenly distributed" (MALDM, 1994, p83).

"Traditional water sources, mainly shallow wells, are concentrated along major drainage lines" (Ibid). "They make up over 90% of all water sources" (ibid).

"Rock and spring pools are mainly found in mountainous areas" (ibid).

"Boreholes and wells have only been brought into the lowlands recently" (ibid).

"Compared with other districts in arid and semi-arid Kenya, Turkana District is exceptionally well supplied with water" (ibid).

"Even before the start of water development an adequate water supply existed for at least 75% of the district (Waita, 1985)" (ibid).

"However there are a number of areas within the district with very little water, especially during dry seasons (Map 17)" (ibid). Note: The areas referred to in Map 17 are in the NW of the district, not near the lake.

A study for UNICEF produced an updated database of water sources (UNICEF, 2006a). The diversity and distribution of sources is evident from Figure 80 on p188.

16.9.2 Springs

Of 30 springs listed in the Range Management Handbook, 70% were "mineralised" but "used by livestock" (MALDM, 1994).

The district area was 65,000 km^2, with access to springs summarised as follows:

- Over 9,000 km^2 of the district is within 10 kilometres of a spring (13.8%) (ibid).
- Over 15,000 km^2 of the district is within 10-20 kilometres of a spring (23%). "These distances can be covered by most animals within a day" (ibid).
- Thus, 36.8% of the district area was within reach of a spring (ibid).

16.9.3 River wells

These are the most abundant type of water source in the district. They are mostly shallow, under 10 metres deep (ibid).

Along major river watercourses, there were between 2.4 and 11.2 wells per kilometre of watercourse (ibid Table 3.3, p83).

16.9.4 Shallow wells

In 1994, the Turkana Rehabilitation Project had drilled over 300 shallow wells in the previous five years (ibid, p85). These wells were not for livestock, and were mostly in or near villages to provide clean drinking water. Most shallow wells were less than 10 metres deep. No water quality data was available but as the wells were shallow, quality was expected to be adequate (ibid).

16.9.5 Boreholes

In 1994, almost 500 boreholes had been drilled within the district. In one place, the Range Management Handbook says only 40 were operational (less than 10%), elsewhere the number operational is 285 (more than 50%) – see Figure 80 on p188. The boreholes tend to follow major roads, and many were drilled specifically for road building purposes, water quality was poor, and they were closed down (ibid, p85).

The Range Management Handbook questioned whether "there are still too many boreholes in relation to the available forage" (ibid, p86), and refers to a study dated 1962 which "warned against increasing the number of water supplies because the district was already overgrazed". The Handbook then says: "the situation has not changed with the increase in population and livestock. Therefore, it must be the aim of any water development plan not to encourage an increase in animal numbers" (ibid, p86).

16.9.6 Surface water storage through dams and pans

Water development in the district had mainly concentrated on development of boreholes, and there were very few dams or pans. Surface water storage requires suitable topography. Surface water sources are not favoured as they are prone to contamination, and are less reliable due to erratic rainfall and high evaporation losses. In the entire district, a study by Rural Focus for UNICEF identified 38 pans and 21 sand dams (UNICEF, 2006a).

16.9.7 Water quality

The Range Management Handbook for Turkana District provided useful commentary on water quality, which is summarised as follows:

1. "The water of Lake Turkana is generally not suitable for drinking by either humans or animals" (MALDM, 1994, p87).
2. "The water at Eliye Springs has high fluoride" (ibid).
3. Over 85 chemical analyses of boreholes were presented (ibid):
    a. A number exceed acceptable mineral content levels.
    b. Most boreholes have high iron content (mainly affecting taste).
    c. High fluoride levels often encountered.
    d. High salinity levels are encountered throughout the district.
    e. Manganese levels are high throughout the district (but not harmful).
    f. Salt level is the major water quality problem.
    g. In volcanic areas fluoride levels can prevent use of the water.
4. Water quality should be monitored as "mining" water was reported to lead to deterioration with increasing salinity with pumping. This means that regular sampling is important.

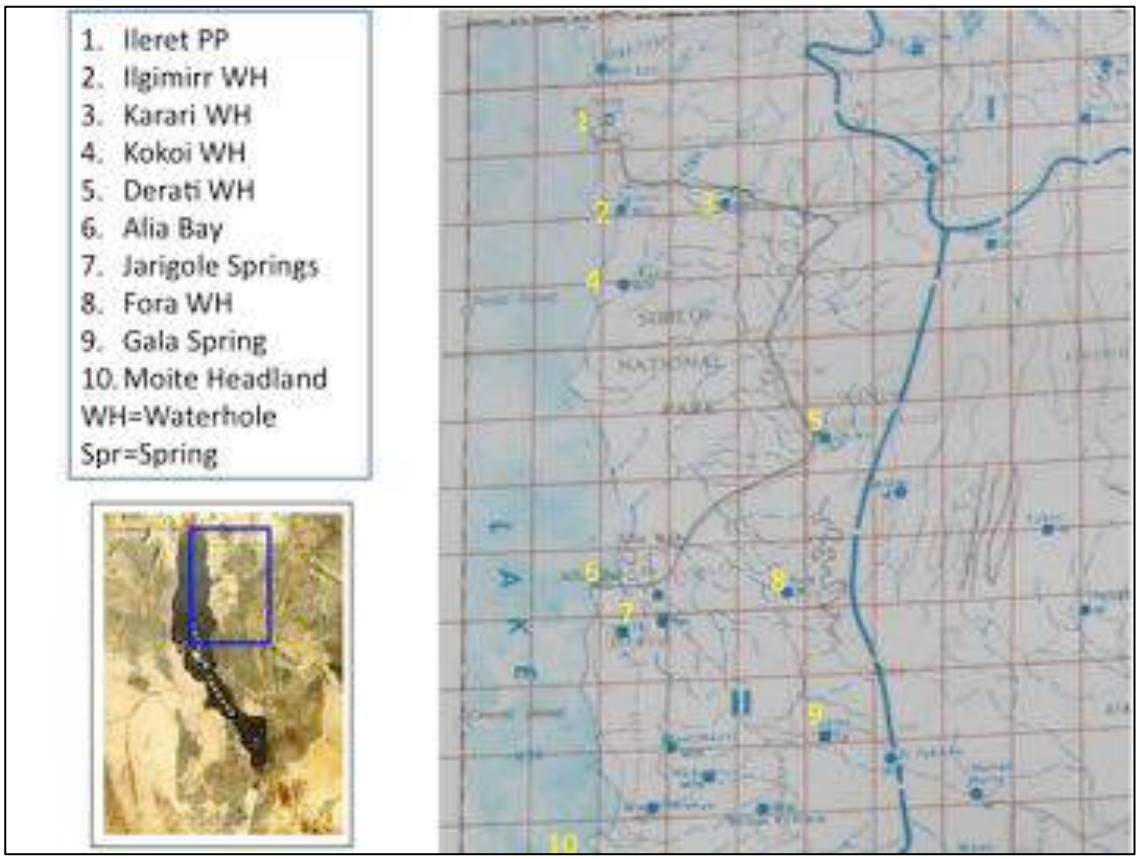


Figure 75: NE Shore (Moite to Ileret) - Water sources

Map Source: Range Management Handbook of Kenya for Marsabit (MoLD, 1991).

Map Symbol Legend:

- *Open blue dot: "Borehole"*
- *Solid blue dot: "Well" or "Waterhole"*
- *Solid blue rectangle: "Spring"*

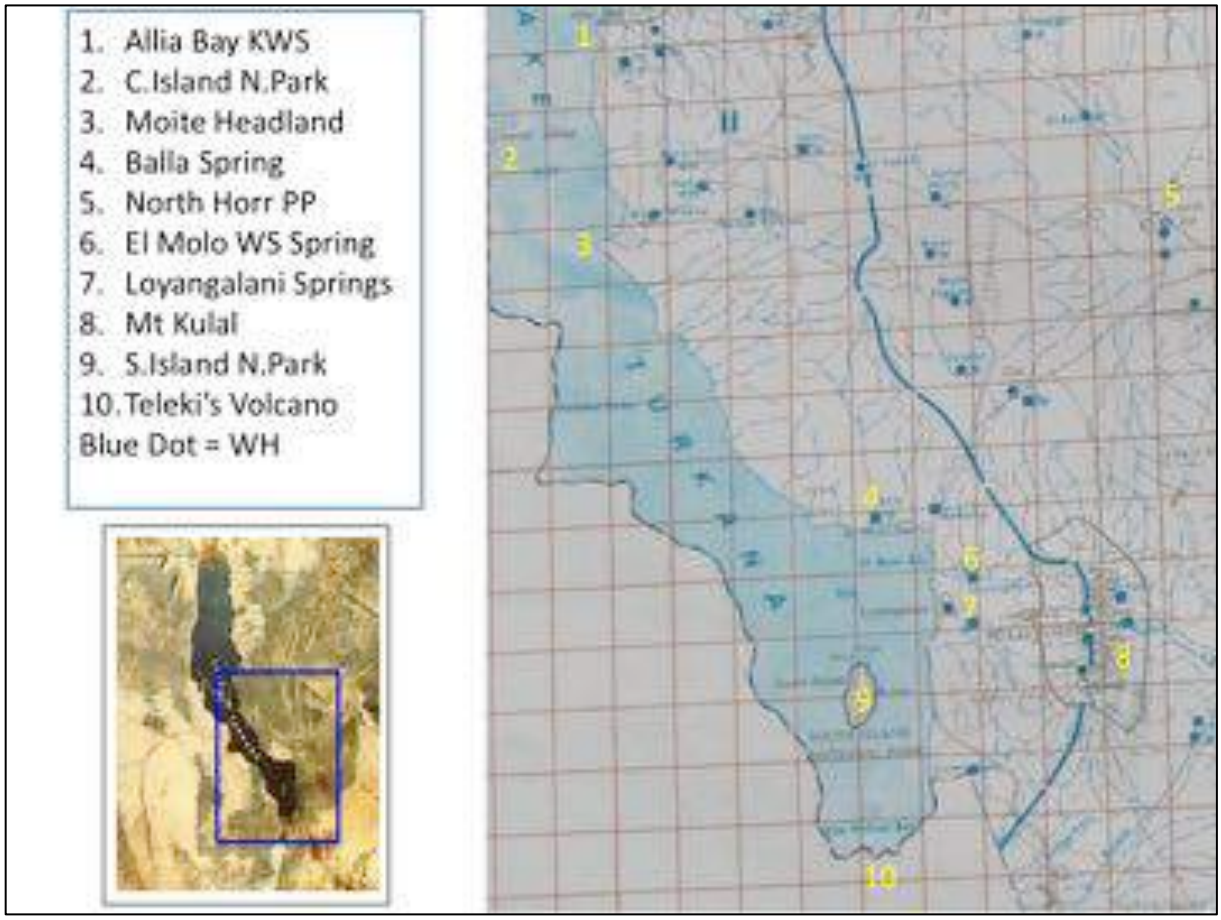


Figure 76: SE Shore (Moite to Loiyangalani and 'south end') - Water sources

Map Source: Range Management Handbook of Kenya for Marsabit (MoLD, 1991).

Map Symbol Legend:

- *Open blue dot: "Borehole"*
- *Solid blue dot: "Well" or "Waterhole"*
- *Solid blue rectangle: "Spring"*

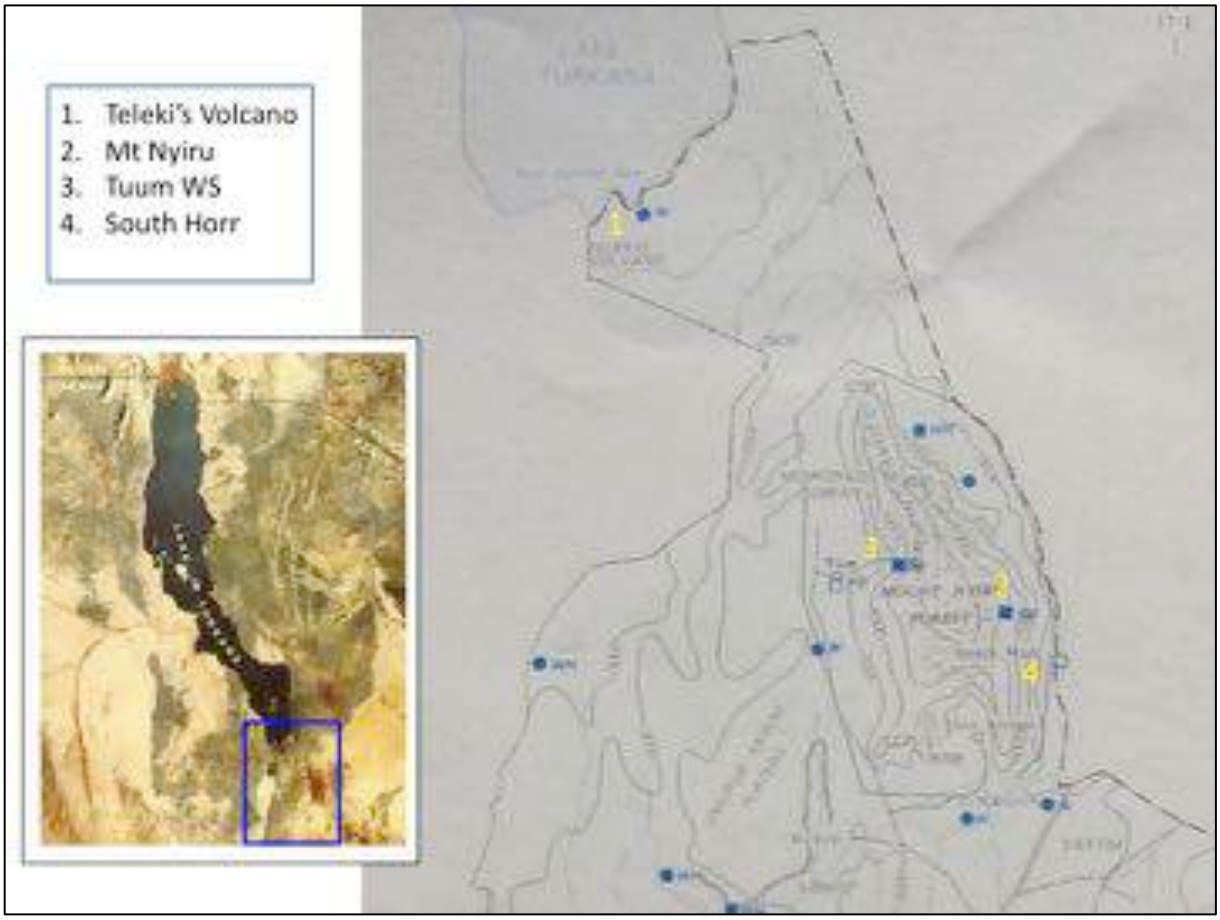


Figure 77: Southern shore (portion within Samburu District) - Water sources

Map Source: Range Management Handbook of Kenya for Samburu District (MoLD, 1992).

Map Symbol Legend:

- *Solid blue dot: "Well" or "Waterhole"*
- *Solid blue rectangle: "Spring"*

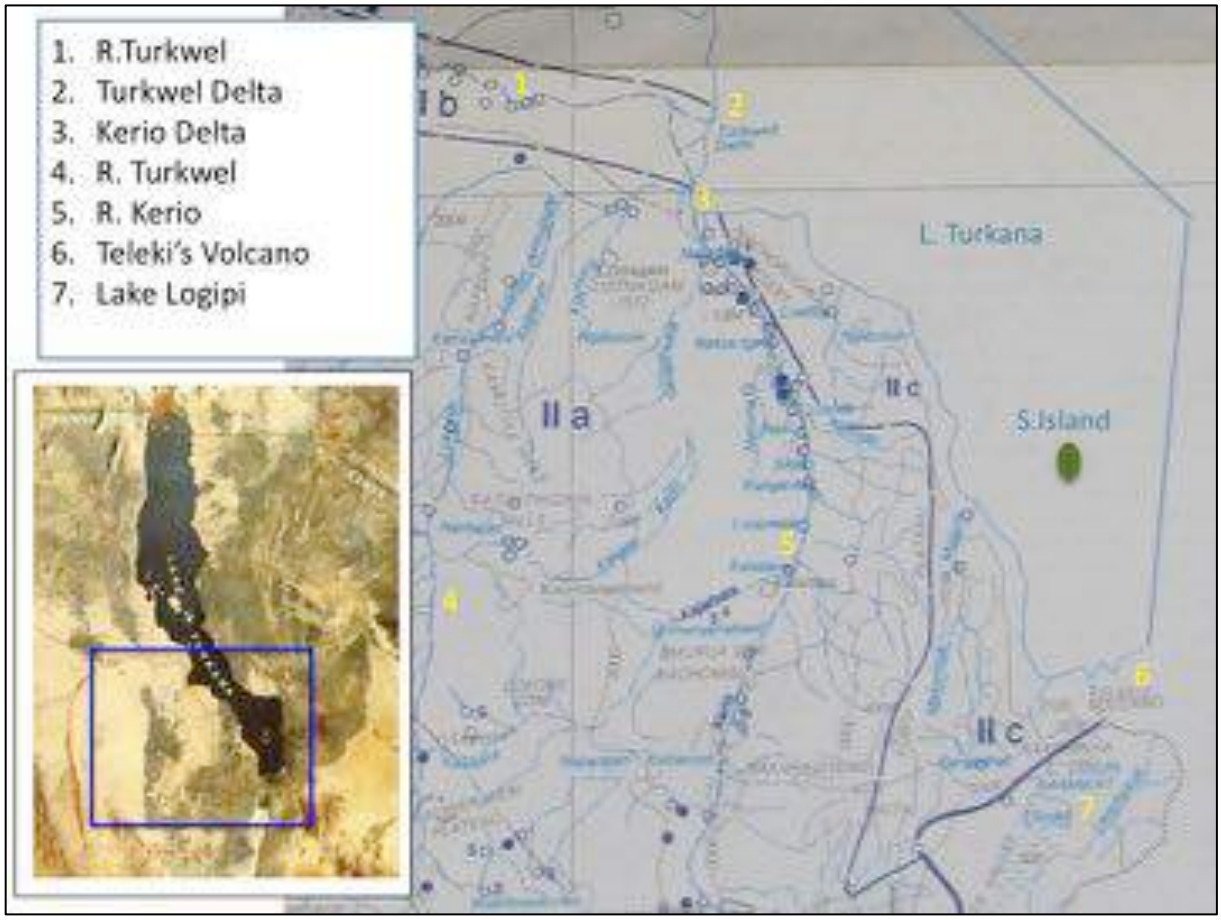


Figure 78: SW Shore (South end to Turkwel Delta) - Water sources

Map Source: Range Management Handbook of Kenya for Turkana District (MALDM, 1994).

Map Symbol Legend (note this differs from the Marsabit maps above):

- *Open blue dots: "Well"*
- *Solid blue dot: "Borehole"*
- *Solid blue rectangle: "Spring"*

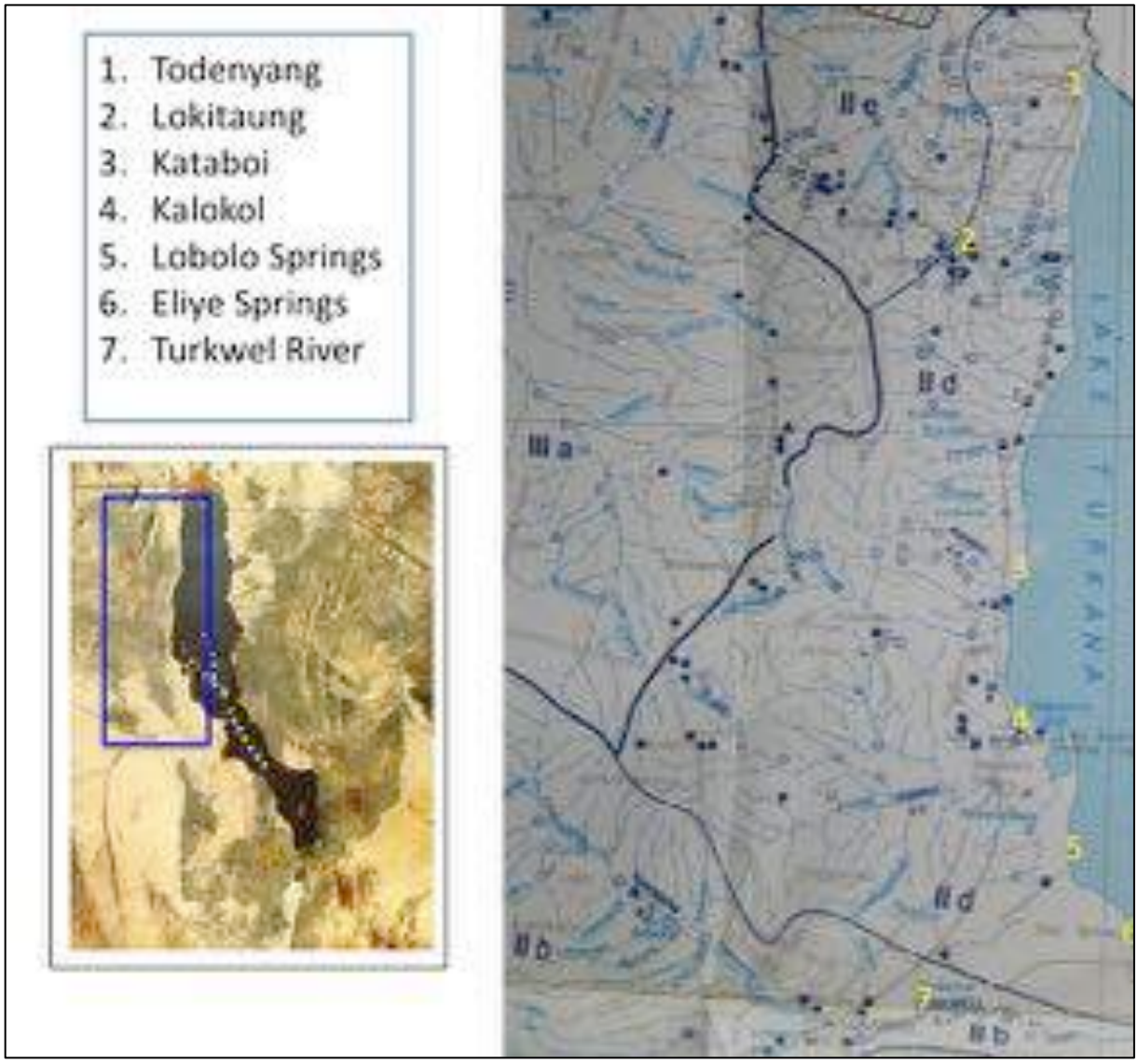


Figure 79: NW Shore (Turkwel River to Todenyang) - Water sources

Map Source: Range Management Handbook of Kenya for Turkana District (MALDM, 1994).
Map Symbol Legend:

- *Open blue dots: "Well" or "Waterhole"*
- *Solid blue dot: "Borehole"*
- *Solid blue rectangle: "Spring"*

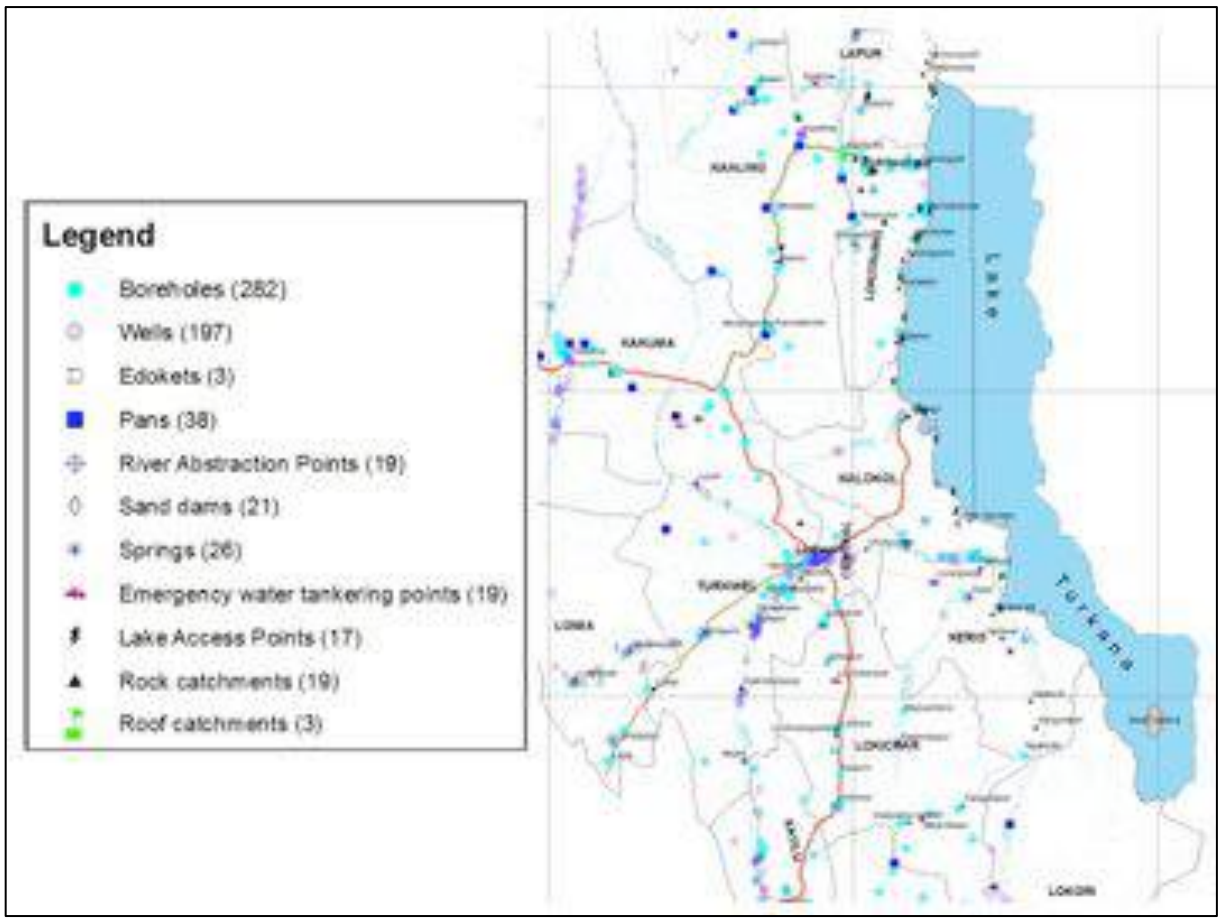


Figure 80: Distribution of water supplies in Turkana District

Source: UNICEF (2006a).

17 LAKE TURKANA FISHERIES

17.1 Previous Research

The review in this chapter has used the AFDB 2010 (Avery, 2010) literature reviews as a basis.

Lake Turkana and the Omo delta has been the subject of several extensive fisheries studies, and there have been attempts at developing commercialised fisheries along the western lakeshore.

Scientists have been studying the lake's fisheries since 1895. The following studies are notable references:

a) 1895 & 1900: Collections of fish from the Turkana Basin by Dr Donaldson Smith, during two visits.

b) 1908 - 1915: Fish collections from the Omo River and north end of Lake Turkana (Boulenger, 1909, 1911, 1915).

c) 1931 - 1932: Cambridge University Expedition (Beadle 1932; Worthington 1932; Worthington & Ricardo 1936; Trewavas 1933).

d) 1932 - 1933: Mission Scientifique de l'Omo sampled fish from the Omo River and delta (Pellegrin, 1935).

e) 1960 - 1964: Hamblyn (1960) and Mann (1964).

f) 1972 - 1975: Lake Turkana Project, UK Overseas Development Administration and Kenya Fisheries Department (Hopson et al, 1982 – report printed by University of Stirling).

g) 1985 - 1988: Norwegian Institute for Water Resources Research (NIVA) and Kenya Marine Fisheries Research Institute (KMFRI) – Lake Turkana Limnological Study (Kallqvist et al, NIVA, 1988).

h) 1987 - 1989: Department of Fisheries and Marine Biology, University of Bergen, Norway – The fish resources of Lake Turkana and their environment (Kolding, 1989).

i) 2007 - date: Lake Turkana Research Project (LTRP), KMFRI (Ojwang et al, KMFRI, 2007).

The 1972 – 1975 Lake Turkana Project's work is a remarkable detailed study. It provided a baseline for the lake. A bathymetric survey of this lake was produced for the first time, and 12 new species were added to the list of fish known in Lake Turkana at that time. A research vessel was specially manufactured in Scotland and transported to the lake through the Port of Mombasa, and thence overland from the Kenya coast, and finally through the Chalbi Desert.

Photo 7: RV Halcyon – Research Vessel, 1972 - 1975

Between 1985 and 1988, NIVA & KMFRI undertook more work on limnology and productivity of the lake for fisheries, and highlighted the challenges arising from potential changes in the Omo inflows (NIVA, 1988). In parallel, the University of Bergen studied fisheries and noted the reduction in biomass and pelagic fish population with falling lake level (Kolding).

The Lake Turkana Research Project initiated in 2007 by KMFRI commenced with two 8-day expeditions to the lake, with the following stated aim: "…to generate data on the fishery, environmental and socio-economic status in order to create interest in the exploitation and management of the resources of the lake…" (Ojwang et al, 2007). The study was declared to be part of the "preparation phase for the forthcoming Kenya Government research funded activities on Lake Turkana" (ibid, Synopsis).

17.2 Lake Turkana ichthyofauna and habitat

The following interesting facts are derived from Chapter 5 of the Lake Turkana Project reports (Hopson et al, 1982), written by A.J. & J. Hopson, 1982 (previously reported in the report to the AFDB [Avery, 2010]).

The lake ichthyofauna identified in the 1972 - 1975 fieldwork was recorded as 48 species, ten of which were endemic to the lake (Hopson et al, 1982). Thirty of the 48 species are "Soudanian", which means they are found from rivers from the Gambia in West Africa, through the Senegal, Niger, Volta, Chad and Nile Basins (Hopson 1982, citing Beadle, 1974). This is attributable to the lake's former connectivity with the Nile River system, the last connection having been about 7,500 years ago (discussed earlier in this report). The endemic species in Turkana have Soudanian or Nilotic origins. The fish population has been stable and can be traced back through fossil evidence to Pliocene times.

Of the 48 species recorded in 1982, 12 were specific to the Omo River (ibid). Of the 36 species which inhabit the lake, a few species were found to occur commonly over a wide range of habitat both inshore and offshore, for example *Engraulicypris stella, Barbus bynni, Synodontis schall, Lates niloticus.* The remainder are habitat specific, and can be separated into four generalised fish communities according to lake habitat (see also diagrammatic representation below in Figure 81 overleaf):

- *Littoral Community:* Inhabits the inshore belt, in waters from the shore to 4 metres deep (*Sarotherodon niloticus*, *Clarias lazera* occur throughout; *Barilius niloticus*, *Tilapia zillii* prefer stony/rocky shores; *Sarotherodon galilaeus*, *Alestes nurse*, *Micralestes acutidens*, *Chelaethips bibie* prefer soft substrates; *Haplochromis rudolfianus* and *Aplocheilichthys rudolfianus* favour submerged and emergent macrophytes).
- *Inshore Demersal Community:* Inshore, bottom-living between the 4 metre contour and depth 10-15 metres (Characteristic species on soft substrates are *Labeo horie, Citharinus citharus*, and *Distichodus niloticus*; There is relatively little data on rocky substrates at equivalent depths but *Bagrus docmac* probably occurs).
- *Offshore Demersal Community:* Ranges throughout deeper waters within a 3 to 4 metre band following the bed of the lake. The inshore limits vary 8 to 20 metres depending on the season. (Characteristic species *Bagrus bayad*, *Haplochromis macconneli*, *Barbus turkanae*).
- *Pelagic Community:* Found spread throughout the lake's water column from upper limits of the demersal community to the surface. Three distinct faunal layers have been recognised:
    - *Superficial layer* (from surface to midwater layer): *Hydrocynus forskalii* and *Alestes baremose* are dominant. Also post-larval *Engraulicypris stellae* and early stages of prawns *Macrobrachium niloticum* and *Caridina nilotica* are characteristic.
    - *Midwater scattering layer*: The depth of this layer is several metres and its position at depth varies from 5 metres in turbid waters to 30 metres in the southern basin.

Alestes minutus and *A. ferox* are principal species, with smaller numbers of *Lates longispinis*, and *Schilbe uranscopus*.

- *Deep pelagic layer*: Located between midwater scattering layer and demersal zone, extending over the depth range up to 60 metres. Larger fish are scarce but adult *Engraulicypris stellae* are widely dispersed. Adult prawns concentrate in this layer.

The fish community boundaries shift seasonally, and are determined chiefly by the sunlight climate (Hopson, 1982), as well as water level. The boundaries tend to break down at night when fish tend to move to the surface and inshore. Similar effects are noted when the waters become turbid during the Omo River flood season.

Hence, changes in lake level alter the littoral / inshore habitat distribution, which will alter fish community distribution and extent, and changes in flood flows and extent of turbidity affect fish movements.

Of the 48 species, 23 were classified as "important" (ibid). The 2007 Lake Turkana Project "revealed 18 species", and the "Draft Field Guide to Lake Turkana Fish Species" in the same project's Technical Report 1 illustrated 19 species, but the same Technical Report refers to "recent updates" reporting 60 species, citing Luc Devos, FISHBASE 2000 (Ojwang et al, 2007). Similar information is recorded on the KWS Tourist Map of Sibiloi National Park.

Due to its salinity and alkalinity: "…the lake contains only a few stunted gastropod species of the Genera: Bellamya, Melanoides, and Cleopatra, and no large bivalves…" (Wilkinson, 1988). Through the process of evolution, these gastropods have changed since the less saline and alkaline conditions that prevailed over 10,000 years ago (ibid).

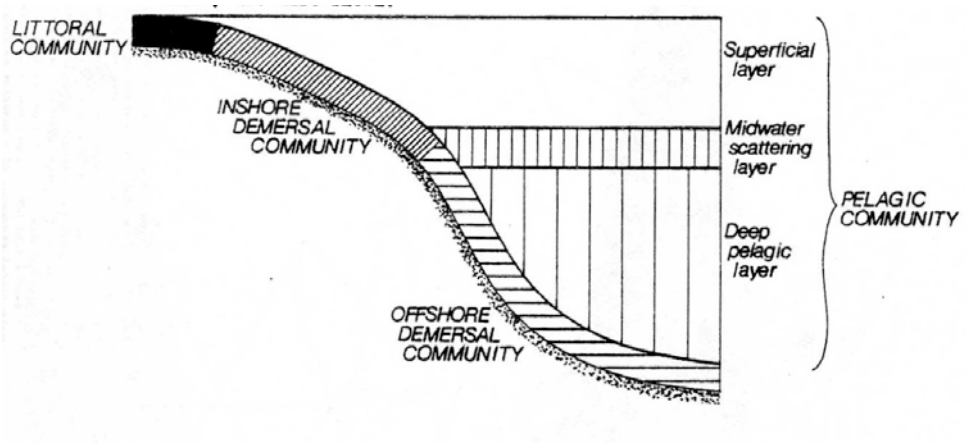


Figure 81: Diagrammatic section of fish community zones

Source: Figure 5.2, Hopson et al, 1982.

Notes on "terminology":

"Demersal Zone" = Lake bed zone.

"Littoral Zone" = Zone close to shore.

"Pelagic Zone" = Zone that is away from shore and away from the lake bed.

17.3 Fish spawning

The nature of spawning movements varies according to the species. Spawning of fish is stimulated by periods of spate of inflowing rivers, principally the Omo River. The "important" species spawn as follows (Hopson et al, 1982) (summary previously reported in Avery, 2010):

- Five species spawn only in the Omo River (*Alestes baremose, A.dentex, Citharinus citharus, Distichodus niloticus, Barbus bynni).*
- One of the above species spawns in both the Omo and Kerio deltas (*Schilbe uranoscopus).*
- Four species spawn in major river mouths, and ephemeral rivers during spate *(Alestes nurse, Labeo horie, Clarias lazera, Synodontis schall).*
- Six species spawn in littoral areas of the lake *(Barilius niloticus, Aplocheilichthys rudolfianus, Tilapia zillii, Sarotherodon niloticus, S.galilaeus, Haplochromis rudolfianus).*
- Seven species spawn in the open lake *(Alestes ferox, A.minutus, Engraulicypris stellae, Bagrus bayad, Lates niloticus, Haplochromis macconneli).*
- Two species spawn in both the Omo River and within the lake *(Hydrocynus forskalii).*

Hence the spawning of the majority of the fish is Omo river flow dependant.

17.4 Food sources for fish (after Hopson et al, 1982)

Figure 82 on p196 summarises the fish feeding habits (ibid, previously reported in Avery, 2010). The food sources are listed, and all the information is from the work of Hopson et al, 1982, reproduced as follows:

- *Phytoplankton:* These are dominated in open waters by blue-green algae characterised by low species diversity. Primary productivity and biomass show a distinct gradient along the lake, as illustrated by the following values of gross production rate in grams of Carbon/m^2/day:
  - Northern Sector: 1,315 – 6,220 gC/m^2/day
  - Central Sector: 194 – 3,936 gC/m^2/day
  - Southern Sector: 259 – 293 gC/m^2/day

  Daily rates of production varied with location and season, and rose to a peak in the post-flood season in the Northern Sector of the lake. Production rates of 4,147 gC/m^2/day were measured in Ferguson's Gulf, matching the high rates of the Northern Sector. Phytoplankton are crucially dependant on minerals carried into the lake by the Omo River.

  The open water algae were found largely uncropped by fish and crustacea, possibly because the algae's density is below optimal feeding levels. Thus, a very high portion of the organic carbon produced by the photosynthetic activity of open water algae passes through a process of decomposition before it becomes available to the zooplankton in the form of detritus, thus adding another link in the food chain.
- *Attached algae in the sub-littoral zones:* There is wide diversity, and the algae attach to a wide range of surfaces (mud, sand, rock, leaves and stems of macrophytes). Although absent from loose substrates of the high-energy shore zones, epilithic algae grow profusely on rock surfaces subject to strong wave action. In the Southern Sector where phytoplankton densities are low, attached littoral algae contribute significantly to primary production.
- *Macrophytes (aquatic plants):* The lake water's salinity levels inhibit plant growth. Plants are unable to establish on high-energy shorelines (due to wind and wave action), and hence macrophytes are generally restricted to sheltered zones of the lake and the Omo delta.
- *Seeds.*
- *Cladocera and Copepods (zooplankton).*
- *Terrestrial insects.*
- *Chironomid pupae and adults.*
- *Corixids (aquatic insects).*

- *Benthic insects.*
- *Ostracods:* These are small crustaceans, part of the 'zooplankton'.
- *Molluscs.*
- *Prawns.*
- *Fish.*

Recent inshore studies, although very much less extensive than earlier studies, concluded: "…There have been no marked changes in zooplankton composition structure in Lake Turkana…" (Ojwang et al, KMFRI, 2007).

17.5 Plant nutrients (after NIVA, Kallqvist et al, 1988)

This literature review was previously presented in a report to the AFDB (Avery, 2010).

The nutrients that usually limit algae production in lakes are phosphorus, nitrogen and silicate (NIVA, 1988). Nitrogen and phosphorus are essential for all algae, whereas silicate is essential only to algae with silicate skeletons (ibid). The NIVA & KMFRI study concluded the following on nutrients in Lake Turkana:

- Nitrate concentrations are low (< 100 μg/L): Nitrates are rapidly utilised. Nitrogen is "a potential limiting nutrient". There is a gradient in nitrogen availability along the length of the lake, reducing from north to south.
- High silicate levels (in the range 21 - 39 mg/l): Hence there is "no silicate limitation" on the growth of diatoms.
- Permanently high levels of phosphorus (1,600 - 2,870 μg/L): Hence there is "no phosphorus limitation" on algal production.

Excessive nitrate in rivers and lakes is a consequence of runoff from agricultural lands leaching fertilisers, and this leads to eutrophication, a process of choking through excessive algal growth. For instance, the UK's Environment Agency considers an "excessive" nitrate level to be 30,000 μg/l. The nitrate levels in Lake Turkana and the Omo River in the table below are a fraction of the "excessive" level.

Table 53: Nitrate measurements in Lake Turkana

Year	Source	Location	NO_3 – N μg/L
1954	Fish (1954)	Central Sector	0.15
1956 – 57	Dodson (1963)	Lake (2 locations)	Trace
1973 – 74	Hopson (1982)	Lake (several)	0 – 17.7
1987 – 88	NIVA & KMFRI (1988)	Central Sector	< 100
2007	Getabu et al (2007)	Lake	1.4 – 89.9
2007	Getabu et al (2007)	Omo River	> 20

Data Sources: Given in Second Column in the table above.
Table Source: Avery, 2010.

17.6 Commercial fisheries

This literature summary was previously presented to the AFDB (Avery, 2010).

Until 1961, Lake Turkana was unique amongst African lakes in lacking a substantial indigenous fishery (Bayley, 1982). In 1961, the Kenya Government began to encourage the lake's pastoral

nomads to take up fishing as a measure to alleviate famine and destitution (ibid). In 1975, the Kenya Government launched its Lake Turkana Research Project (LTRP) on fisheries exploitation (Ojwang et al, 2007). That study considered commercial exploitation hampered by post harvest losses and the infestation of Nile Perch by a parasite (Werimo, Malala & Orinda, 2007).

A variety of traditional fishing methods have been used. Rafts were made from doum palm logs. *Sarotherodon niloticus* and *S.galilaeus* were trapped in their scrape nests using basket traps. Basket traps were also used in rivers to trap fish migrating from the lake into rivers (*Labeo horie, Schilbe uranoscopus, Clarias lazera*). Harpoons were used on larger fish close inshore (*Lates niloticus, Clarias lazera*). Long-lines with baited hooks were also used inshore to catch *Lates niloticus, Bagrus bayad* and *Clarias lazera*. Fishing tended to be restricted to productive inshore areas up to the 15-metre depth contour (ibid). Today, the fishing extends far offshore as well.

Doum palm rafts are still seen today, but there are also modern boats as well. Nets and long lines are widely used throughout the lake. Fishing does not appear to be adequately controlled as long-lines are often encountered within Sibiloi National Park (Pers.Comm). See also the East African Wildlife Society's SWARA article in the Annexes (Patrick Avery, 2012).

It has been reported that between 2006 and 2007, the number of fishing craft increased from 650 to 6,900, and the number of fishermen increased from 2,600 to 8,160 (Mbogo, 2010, citing Ojwang et al, 2007). The same report expresses "rising concern" and states that there is "inadequate information on the potential of the lake's fishery" and that "it is difficult to establish whether current catch efforts are sustainable" (ibid). The commercial fishing sector has always been hampered by poor infrastructure to store and transport fish to market outlets, and by "a lack of comprehensive fisheries management strategy" (ibid).

Table 54 on p198 tabulates available fish catch records of the Fisheries Department, as published by Hopson up to 1976. Table 55 on p199 extends the record with available data from 1984-2010, from the various sources acknowledged. Figure 84 graphically summarises catch data between 1962 and 2010, with data gaps shown as "missing".

The Turkana catch records are put into perspective with other Kenyan lakes in Table 56 on p199 (table from Avery, 2010). Lake Turkana ranked second highest in the country for fish catch, a long way behind top-ranked Lake Victoria. Note that the area of Lake Victoria that is fished by Kenya is only 4,260 km^2, which is a little over half the total area of Lake Turkana. Lake Turkana thus provided only about 4% of Kenya's annual freshwater fish catch, a tiny proportion considering its size.

Hopson's team proposed sustainable fishery limits for each fish species based on the catch records from "inshore" fisheries. These limits are included in the final column in Table 54 on p198.

NIVA & KMFRI also jointly looked at the "offshore" fishing potential, including species that feed on zooplankton (*Alestes baremose*), predatory fish (*Lates niloticus and L.longispinus, Hydrocynus forskalii, Bagrus bayad and B.docmac*), and omnivorous catfish (*Synodontis schall*). NIVA & KMFRI assessed offshore potential using different methods, and compared with the Hopson study, as discussed below.

- Total annual yield based on annual zooplankton production = 216,000 to 540,000 tonnes (Hopson estimate was 560,000 tonnes). Note that much of this "yield" includes small fish of the *Alestes spp* that should <u>not</u> be exploited, as they are the food of predatory fish (NIVA, 1988).
- Offshore potential yield, based on predatory and prawn eating fish = 10,000 to 24,000 tonnes.
- Offshore potential, based on phytoplankton production = 22,000 tonnes (Hopson equivalent estimate = 37,000 tonnes).

The above figures were speculative, and NIVA & KMFRI noted that the Hopson data was based on a higher lake level. NIVA & KMFRI considered the figures realistic (NIVA, 1988). KMFRI have later cited a potential of 88,404 tonnes annually (Ojwang et al, KMFRI, 2007 P.v). Mbogo cited a potential of 37,000 tonnes annually (Mbogo, 2010).

Over 30 years have elapsed since the Hopson studies, and the fisheries catch recorded in recent years continued to fluctuate at similar levels until 2004 and 2007, but recorded catches were still well below the speculative "potential" computed in previous studies. A critical contributor to statistics is Ferguson's Gulf. At times, a large proportion of the lake catch was being taken in the Gulf. However, conditions within the Gulf are very susceptible to environmental change, and the Gulf ceases to exist when the lake level falls 3.1 metres below the September 1972 lake level (the zero datum for the bathymetric map in Figure 51). Earlier reports noted that the Gulf's most successful fishing season followed the removal of livestock from the area. The absence of livestock allowed the shoreline vegetation to flourish, and when inundated by rising lake level accompanying the Omo floods, the vegetation provided an ideal habitat for fish fry to flourish (*Serotherodon niloticus*, Hopson et al, p1572). This sort of shoreline degradation is a challenge throughout the lake margins.

Kolding provides a good summary of various yield estimates, and reported various independent estimates that suggested "sustainable production to be of the order of 15,000 to 30,000 tonne/yr" (Odero, 1992; NIVA, 1988). Kolding also reported the target level 15,000 tonnes set by the Kenya Government to be reached by 1988 (Kolding, 1992). Kolding concluded that there is a very low "prediction level of the fishery", and that "traditional management strategies are not applicable". The lake is dynamic and its fishing grounds have "undergone unpredictable and dramatic transformations". The adverse consequences have been "over capitalisation that could not be sustained", for instance the ill-fated fish-processing factory that still sits idle to this day.

17.7 Lake Turkana fisheries – export potential and the parasite challenge

This literature review was previously presented in a report to AFDB (Avery, 2010), and data has been brought up to date, and new imagery presented.

The lack of investment in the lake's fisheries potential was queried in Kenya's National Assembly (Question 425, 28th January 2009, National Assembly). The Kenya Government wishes to develop fisheries, either through an Authority or through "development plans". It was noted that the lake fish quality is not acceptable for export to the European Union due to parasites in the flesh (ibid; also see Werimo et al, 2007).

The widespread infestation of most fishes by a cestode parasite was earlier documented by KMFRI (Werimo et al, KMFRI, 2007, p61-62). This parasite infects the Nile perch muscle "and has thus made the fresh fillets unacceptable to consumers especially the export market" (ibid, p62). "There is need to study the parasites, with an emphasis on the endoparasites of Nile perch from this lake and their possible public health impact" (ibid, p62). In the conclusion of the same Technical Report, it is stated: "…Preliminary investigations of Nile perch suggest that the parasite has no known human health related implications. It should therefore not deter commercial exploitation of this species…" (Ojwang et al, KMFRI, 2007, p95). The parasites are also being studied by Masaryk University (Jirku et al, 2010).

In the context of commercial fisheries potential, Kolding's research findings should be borne in mind (Kolding, 1993). Some of the findings were presented above, and caution and realism was advised in commercial fisheries expectations, especially as the lake is semi-saline, and often treacherous for boats due to its high winds.

The forthcoming significant lake inflow reductions consequent upon the Lower Omo irrigation abstractions will diminish commercial fisheries prospects.

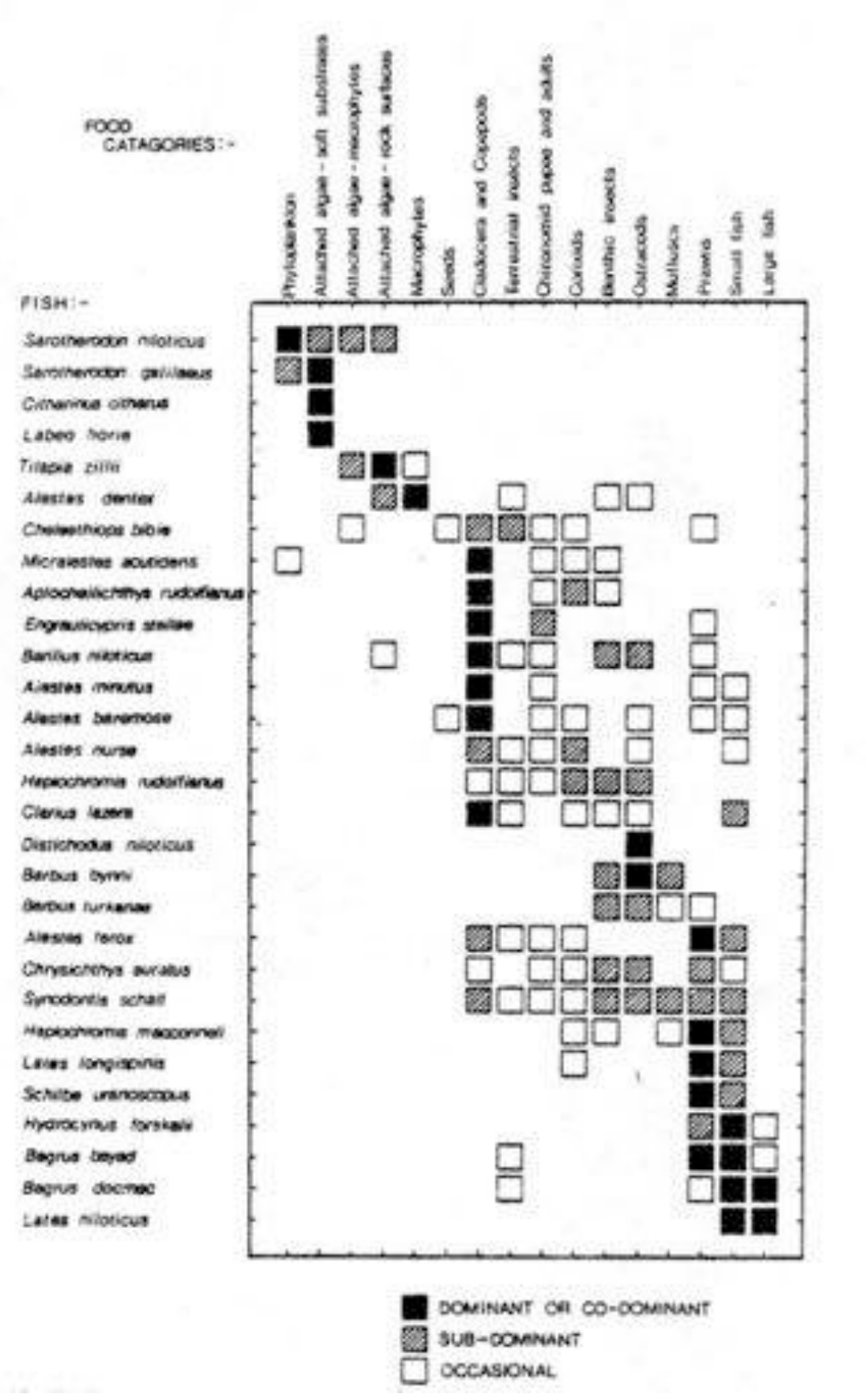


Figure 82: Food sources for fish

Source of the table of food sources: Hopson et al, 1982.

Fishermen, near Loiyangalani

Fishing net with catch

Fish drying in the sun

Sports fishermen at Allia bay

Nile Perch being weighed

Photo 8: Fishing on Lake Turkana

Source of photos: Sean Avery Photo Archive.

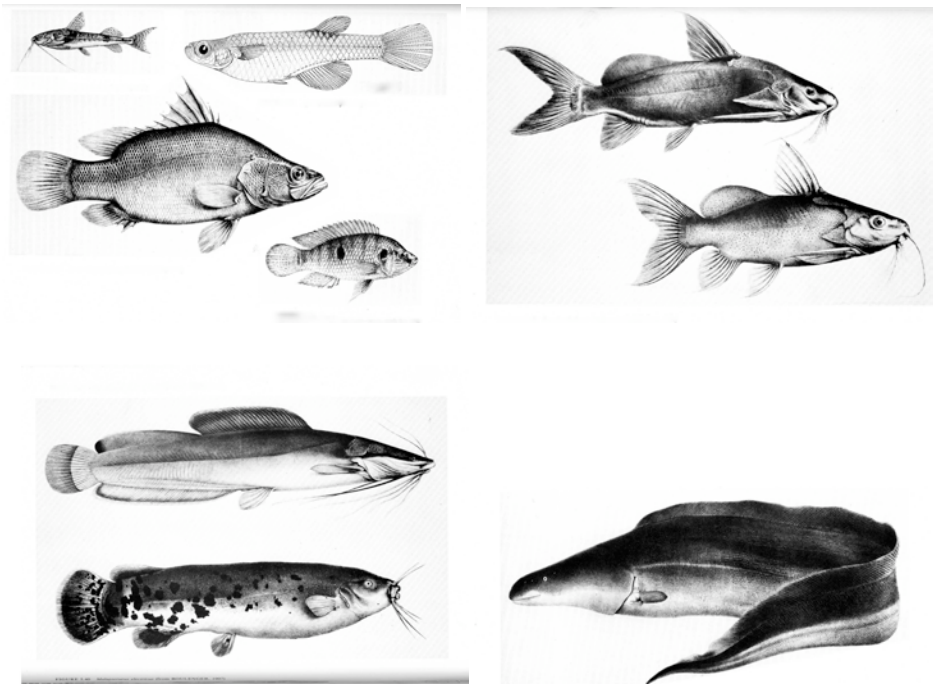


Figure 83: Some of Turkana's fish

Source of selected images of fish: Extracted from Hopson et al, 1982.

Table 54: Commercial fish catch records for Lake Turkana 1970-76 and 2000-05

1970 – 1976	[7]	1970	1971	1972 [4]	1973 [4]	1974 [4]	1975 [4]	1976 [5]	Sustainable Level [1 10]
Lates niloticus		n.d.	n.d.	382	435	508	n.d.	n.d.	2,850 [8]
Tilapia									See next row
Sarotherodon niloticus	L	n.d.	n.d.	131	217	447	1,996	16,100	500 to 22,000 [9]
Labeo horie	H	n.d.	n.d.	586	794	1,034	466	n.d.	200 to 500
Bagrus bayad		n.d.	n.d.	83	139	262	n.d.	n.d.	1,650
Barbus bynni	H	n.d.	n.d.	87	315	442	n.d.	n.d.	100 to 200
Citharinus citharus	H	3,000 [4]	n.d.	666	400	108	10	n.d.	0 to 50
Distichodus niloticus	H	n.d.	n.d.	480	287	108	84	n.d.	0 to 100
Clarias		n.d.	n.d.				n.d.	n.d.	
Synodontis schall		n.d.	n.d.	116	138	265	n.d.	n.d.	22,000
Hydrocynus forskalii	L	n.d.	n.d.	233	316	318	n.d.	n.d.	<1,000
Alestes baremose	L	n.d.	n.d.				n.d.		10,000+
Others		n.d.	n.d.				n.d.		
Total recorded catch (tonnes)		n.d.	n.d.	2,764	3,041	3,492	2,556	16,100	

2000 – 2005	[7]	2000 [2]	2001 [2]	2002 [2]	2003 [2]	2004 [2]	2005 [2]	Av.	Sustainable Level [1 10]
Lates niloticus		153	412	575	486	1,943	968	651	2,850 [8]
Tilapia		1,060	1,831	2,448	2,321	2,646	462	1,795	See next row
Sarotherodon niloticus	L							3,778	500 to 22,000 [9]
Labeo horie	H	337	630	552	930	(3,809) [3]	491	963	200 to 500
Bagrus bayad		60	71	46	54	80	44	93	1,650
Barbus bynni	H	41	58	72	41	94	74	136	100 to 200
Citharinus citharus	H	53	186	35	12	25	1	150	0 to 50
Distichodus niloticus	H	356	498	212	109	41	40	222	0 to 100
Clarias		6	6	11	24	25	6	13	
Synodontis schall				5	36	404	179	163	22,000
Hydrocynus forskalii	L	42	95	48	51		31	142	<1,000
Alestes baremose	L								10,000+
Others					20		197	109	
Total recorded catch (tonnes)		2,108	3,787	4,004	4,084	(9,067) [3] (4,180) [4]	2,493	4,458	

Table Source: Report to AFDB (Avery, 2010).

Tonnes "equivalent wet weight".

n.d. = "no data"

Table 55: Annual commercial fish catch records for Lake Turkana 1984, 1999, 2006-10

Year	Catch (tonnes)	Source of this annual catch data
1984	8,500	NIVA, 1988
1999	5,239	Mbogo, 2010
2006	4,550 (3,097 [11])	Mbogo, 2010, [11] KNBS
2007	9,000 [6] (5,122 [11])	[6]Mbogo citing Ojwang, [11]KNBS
2008	8,070 [11]	[11]Kenya National Bureau of Statistics (KNBS)
2009	9,445 [11]	[11]Kenya National Bureau of Statistics (KNBS)
2010	8,123 [11]	[11]Kenya National Bureau of Statistics (KNBS)

Table source: Report to AFDB (Avery, 2010). Updated to 2010 (this study).
Tonnes "equivalent wet weight" tabulated.

Notes on Tables:

(1) Hopson et al, 1982, Tables 13.2, 13.3, 6.19.
(2) Mbogo, 2010 (Data from MoFD statistics).
(3) Data highly suspect (too high).
(4) Alternative 2004 Catch data = 4,180 tonnes (UNEP).
(5) Hopson et al, 1982, p1577.
(6) Mbogo 2010 (citing Ojwang, 2007), Year 2007 Catch=9,000 tonnes, Sustainable yield=37,000 tonnes annually.
(7) H=Heavily exploited; L=Lightly exploited.
(8) 2,850 tonnes includes both Lates niloticus and Lates longispinis combined estimated yield (Hopson Table 13.2).
(9) Hopson Table 13.3, Yield dependant on Ferguson's Gulf conditions (22,000 tonnes applicable to Ferguson's Gulf at optimal conditions, 500 tonnes applicable to remainder of lake).
(10) Hopson et al Table 13.2, Alestes minutus and A. ferox not included (these are minute fish and are not "commercial"), yield=560,000 tonnes (approximate).
(11) Kenya National Bureau of Statistics (KNBS).

Table 56: Kenya's national fish production statistics 2003-05 (values in tonnes)

	2003	2004	2005
Lake Victoria [(1)]	105,866 [(2)]	115,747 [(2)]	133,526 [(2)]
Lake Turkana	4,004	4,180 [(3)]	2,493
Lake Naivasha	39	62	108
Lake Baringo	Closed to fishing	63	43
Lake Jipe / dams	73	40	74
Tana River dams	474	839	950
Fish farming	1,012	1,035	1,047
Other areas	1,176	843	785
Total freshwater	112,687	122,809	139,026
Marine	6,968	7,805	6,823
Grand Total	119,655	130,614	145,849

Source of original table: Avery, 2010.
Source of statistics: UNEP, Status of Environment and Natural Resources Statistics (unstats.un.org/unsd/ENVIRONMENT/envpdf/UNSD)

Notes on Table:

Note (1): Kenya's fishing area of Lake Victoria is 4,260 km^2 (National Assembly, 2009).
Note (2): The total fish yield of the entire Lake Victoria is said to be 800,000 to 1,000,000 tonnes annually – Lake Victoria Fisheries Organisation (LVFO) (www.lvfo.org).
Note (3): Other Source: MoFD data. MoFD data for 2004 (9,067 tonnes) suspect and disregarded.

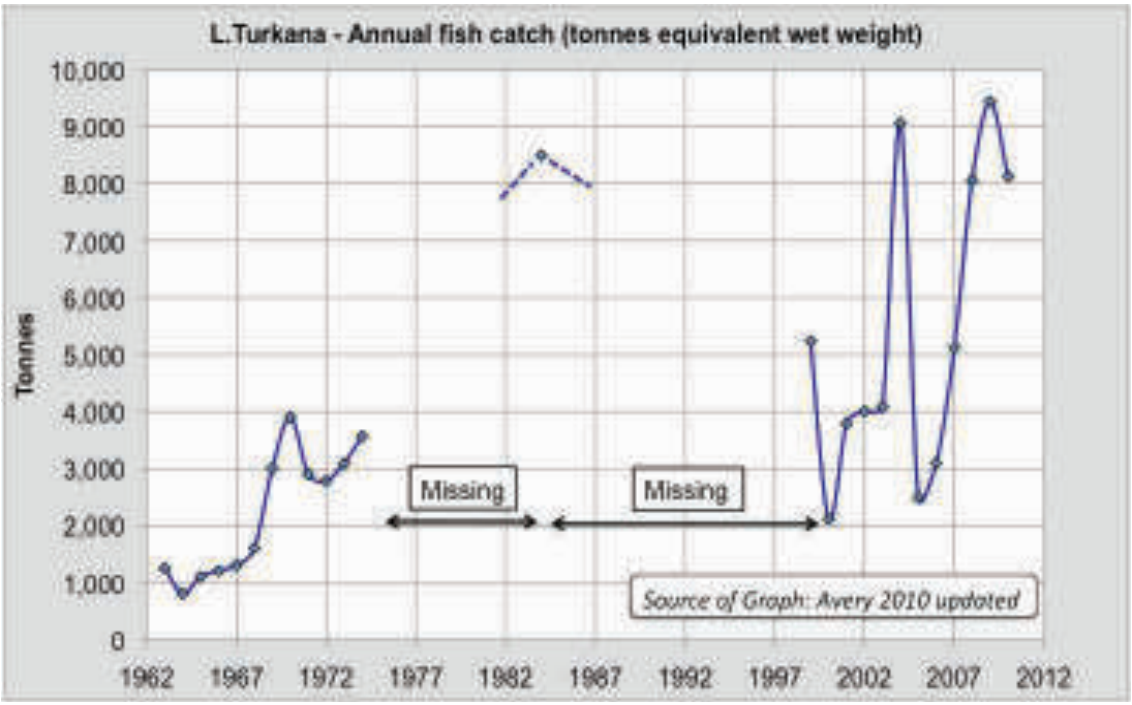


Figure 84: Lake Turkana fish catch records, 1962-2011

Data Source: Ministry of Fisheries Development records, Hopson et al, NIVA.
Data Source 2006 - 2010: http://www.knbs.or.ke/agriculture_fisheries.php.
Original Graph Source: Report to AFDB (Avery, 2010), with recent data from KNBS added.

17.8 Environmental factors affecting fisheries

The environmental factors affecting the fish were listed as follows (after Hopson et al, 1982; and NIVA, 1988; and previously presented by the Consultant to the AFDB [Avery, 2010]).

- *Salinity:* The salinity levels in the lake water are high compared to other African lakes in which some of the same fish species are to be found. The fish found in Crater Lake 'A' on Central Island within Lake Turkana include species also found in the main lake. The Crater Lake A's salinity levels exceed the main lake salinity by a factor of three times. Previous studies have stated that the fish in the main lake are "not likely to be affected by progressive naturally increasing salinity levels in the foreseeable future", assuming no change in Omo inflow volumes (Hopson et al, 1982), although more recent research should be consulted. The exception in terms of salinity tolerance is the *Mormyrids*, which are accordingly confined to fresh water rivers. Their electro-sensory systems are very likely affected by high conductivity levels.

- *Winds:* The prevailing strong south-easterly winds are a major factor in the lake environment.

  - The winds cause south-easterly surface currents in the upper layers and reverse currents occur in the lower layers. The water column is consequently well-mixed, and well-oxygenated, although there is stratification of oxygen and temperature.
  - The winds also influence the distribution of fish. The SE wind-induced surface currents carry zooplankton in the surface layers, which concentrate on the north-western shores, leading to unusual concentrations of small pelagic fish and their predators.
  - The prevailing winds also affect the distribution of littoral zone fish, which prefer the sheltered eastern shores.
  - As a consequence of the above, the southern end of the lake tends to hold less fish.

- The mixing induced by the SE winds ensures that the lake waters remain turbid, and this limits the penetration of light for photosynthetic activity to the top six metres of water.

- *Temperature*: Water temperature remains constant throughout the year in the main lake, and there is temperature stratification with cooler waters at depth. In the shallow enclosed "flood-plains" areas of the lake such as Ferguson's Gulf, heating up of the waters will occur.

- *Incoming river floods:* The most profound seasonal changes arise during the annual flooding, which peaks in the period August to October. The principal water source is the Omo River entering the lake from Ethiopia to the north.

    - The upstream flooding of the Omo River and seasonal inundation of offstream areas, and the runoff therefrom, release valuable nutrients which are carried into the lake.
    - The Omo River floods transport "allochtonous organic matter and nutrients" into the lake.
    - Nitrogen, one of the two most important factors limiting "production" in the lake (the other being light), is transported into the lake through the Omo river waters.
    - The flood influxes stimulate the migration of spawning fish into the Omo River. Within the main lake, breeding also tends to be greatest during flood periods. This is due to the sediment-rich waters, which extend south right through the Central Sector of the lake.
    - The floods dilute the lake water and lower the salinity levels in northern parts of the lake in particular.
    - The sediment plume reduces visibility and fish tend to move to the lake surface and to the shore, and the reduced light penetration can affect "production" (growth of light stimulated organisms).
    - The influx of nutrients during the flood season initiates changes in the algal population, and the margins of the lake inundate. The lake level rises are typically up to 300 millimetres per month, starting from July, and in flat areas of the lake, the inundated margins such as at Ferguson's Gulf can extend many hundreds of metres. The shoreline terrestrial vegetation provides refuge habitat for fish fry when inundated. If the shoreline areas are heavily grazed, this will reduce the refuge and potential breeding success. On the other hand, the presence of livestock adds nutrients.
    - The effect of nutrient load on chlorophyll production is very pronounced in northern parts of the lake. Chlorophyll levels are indicative of the abundance of phytoplankton.

Note that Hopson et al did not specifically list "lake level" amongst the "environmental factors" affecting fish considered at that time, although lake level was considered in regard to the inundation of littoral areas and fish breeding. Inundation of littoral zones through floods in various African lakes has been shown to result in a "boom" in fish populations, often short-lived (Kolding, 1992).

Kolding's studies demonstrated that falling lake levels between 1972 and the late 1980s reduced biomass and resulted in 70% reduction in the endemic zooplankton based open water pelagic fish communities in Lake Turkana (ibid). These fish communities are shorter lived and "unstable" (ibid). Kolding reported that the fish population had "undergone unpredictable and drastic transformation in the past decade".

17.9 Ferguson's Gulf

This literature review prepared by the Consultant was previously presented in a report to the AFDB (Avery, 2010).

Ferguson's Gulf is protected from winds by Longech Spit, which runs in a south-north direction. The algal flora in Ferguson's Gulf is "distinct". There is high primary production of algae, and fish yields are on occasion "phenomenally high" (Hopson et al, 1982). Production levels within the Gulf are amongst the highest measured (NIVA, 1988). On the other hand, the fishery is "seasonal on an annual basis" and highly variable with "boom and bust cycles" (Avery, 2010; citing Kolding, 1992).

The Gulf is vulnerable to drops in lake level, and becomes dry whenever the lake level falls below -3.1 metres relative to the September 1972 "Zero" bathymetric datum. The Gulf has been described as a "flood-plain" type environment (ibid). The Gulf water level determines its vulnerability to temperature change and dissolved oxygen change, both of which affect the fish. In 1992, a decline in median fish size had been reported. Peak production years were associated with years of peak water level rises, and "stunting" of fish was associated with "droughts in shallow lakes" (ibid).

17.10 Recent review of baseline of limnology and fisheries

This review was prepared by the Consultant and previously presented in a report to the AFDB (Avery, 2010).

The AFDB also commissioned a "baseline study of fisheries and limnology" (Mbogo, 2010). The baseline did not include new field studies and presented the following findings from other studies (ibid), which remain applicable today:

- There is "inadequate data" and there are "concerns" at the sustainability of increasing numbers of people turning to fishing as a coping mechanism for poverty.
- The "artisanal" fishing methods are "cause for concern".
- There are 11 known major fish landing sites around the lake. Eight are located on the western side of the lake (from the north: Todenyang, Lowarengak, Nachukui, Kataboi, Namadak, Kalokol, Eliye Springs, Kerio). Three are located on the eastern side (from the north: Ileret, Moite, Loiyangalani). Another report includes El Molo Bay on the eastern shore between Moite and Loiyangalani (Ojwang et al, 2007, Fig.1.1). North Island is also a major fish-landing site mentioned by Ojwang et al, and this landing beach was visited during this study.
- Fisheries Department recorded a ten-fold increase in the number of operating fishing craft between 2006 and 2007 (from 650 to 6,900 craft). 61% of the craft are traditional raft boats known locally as "ngatedei" and operated by one person. 85% of the fishing craft were on the western side of the lake. The number of fishermen during the same period increased from 2,600 to 8,160, a four-fold increase.
- The annual catch in 2007 was estimated at 9,000 tonnes (Mbogo, 2010; citing Ojwang et al, 2007), which was about one quarter of the minimum estimated potential of 37,000 tonnes annually (Mbogo, 2010; citing Rhodes, 1966).
- The major commercial fish species include: *Alestes sp, Bagrus sp, Barbus bynni, Clarias lazera* (Catfish), *Labeo holie, Lates niloticus* (Nile Perch), *Schilbe uranoscopus, Synodontis schall, Oreochromis niloticus,* several other Tilapia species, *Citharinus citharus, Hydrocynus forskalii, Distichodus niloticus.*

- The dominant commercial fish species include *Lates niloticus* (Nile Perch), the *Tilapia spp* and *Labeo* contributing 40%, 20% and 20% respectively.

The Mbogo report contains baseline information on chemistry and limnology, which was not repeated in the AFDB Report. The Mbogo Report also included data on localised research into water quality, taken from the KMFRI Lake Turkana Research Project Technical Report (citation: Ojwang et al, 2007).

17.11 "A last snapshot of natural pelagic fish assemblage in L.Turkana"

A hydroacoustic survey with supplementary gill netting was undertaken in open water in the central portion of Lake Turkana in September 2009 (Muska et al, 2012). The study was done to "explore fish distribution, abundance and biomass in Lake Turkana open water under natural conditions before the impact of the Gibe III dam manifests itself" (ibid). Hence the title of the paper "the last snapshot". Significant impacts on fisheries are widely expected as a consequence of Gibe III (ibid).

The findings were:

- Pelagic fish density was assessed at 1,381 ind./ha, which was much lower than previous surveys of the 1970s and 1980s, and one third the long-term average (long-term average 3,739 ind./ha) (ibid).
- The pelagic fish biomass was reported low compared to other African Great Lakes, being half that of Lake Malawi (ibid). The biomass was reported relatively unchanged (long-term average 25.4 kg/ha) (ibid).
- The pelagic fish density decreased from the western to the eastern shore. This is because the prevailing winds drive surface nutrients to the western shores.

17.12 Conclusions and recommendations by NIVA / KMFRI / Kolding

This review was prepared by the Consultant and previously presented in a report to the AFDB (Avery, 2010). The review has been updated.

The review repeated the findings of NIVA & KMFRI in 1988, and reported by Kolding in 1992, as they confirmed the earlier findings of Hopson, and the recommendations were very appropriate to the consequences of the regulated flow regime resulting from Gibe III, and the reductions in flow that will be a consequence of developments in the Omo Basin:

1. The two most important factors limiting production of algae in the lake are nitrogen and light penetration. The turbidity of the lake is a consequence of suspended material and algal matter, and is sustained through mixing due to strong winds. Nitrogen is brought into the lake in the Omo's river waters (NIVA, 1988).
2. "Production" potential is affected by fluctuations in river discharge. Shallow littoral areas inundated during seasonal rise of the lake may be important (NIVA, 1988; Kolding, 1992).
3. Analysis of the water entering the lake is needed for a more accurate measure of the contribution of organic material from the river (NIVA, 1988).
4. The effect of nutrient load from the River Omo on chlorophyll production is very pronounced in northern areas of the lake (NIVA, 1988).
5. There is exceptionally high photosynthetic activity in this lake (NIVA, 1988).

6. Primary production in Lake Turkana is lower than in Lake Victoria, but higher than Lake Tanganyika and similar to Lake Naivasha (at that time). Primary production rates in Ferguson's Gulf are some of the highest recorded (NIVA, 1988).
7. Variations in discharge of the River Omo will therefore most probably have a substantial effect on the potential fish production (NIVA, 1988). Kolding concluded that the lake ecology is unstable and that the lake biology "seems highly geared towards the annual flood cycles", and that there is close relationship "between biological production and the hydrological regime" (Kolding, 1989).
8. Because of the importance of fluctuation of river discharge and lake level on the ecology of the lake, continuous monitoring should be undertaken (NIVA, 1988; Kolding, 1992).
9. Developments in the catchment area, which may affect the discharge of water to the lake, may have serious effects on the lake ecosystem (NIVA, 1988).

17.13 A warning on fisheries collapse - Kenya National Water Master Plan

Kenya's National Water Master Plan published the following warning in 1992:

"For several years now, evaporation has exceeded inflows, and the lake water level and area have been reducing. If this is accelerated due to increased water consumption in the upper catchment, the concentration of dissolved matter in the lake water will be increased. If it reaches a level where the existing fauna and flora cannot survive, the existing fishery will collapse followed by the crocodile population…." (MoWD, 1992b, Vol. I, Section 3.7.3, p52).

18 LAKE TURKANA - WATER BALANCE

18.1 Introduction to the water balance

The climatic, hydrological, and bathymetric data, and physical characteristics, have earlier been presented for the Lake Turkana Basin. Unfortunately, measurement of the Omo inflows to the lake at Omorate was discontinued after data had been collected from 1977 to 1980. However, lake level measurements have been collected at 10-day intervals since 1992, thanks to satellite radar altimeter observations (see Section 13.4, p151). Hence, as long as the satellites continue to pass overhead, lake monitoring can continue since lake level is the direct consequence of inflow balancing evaporation losses.

In order to assess the impacts of developments within the Omo Basin on the lake water levels, a simple water balance model previously developed by the Consultant has been utilised for the lake based on the available data. The key parameter in this exercise is the estimation of the evaporation loss from the lake surface. The lake is in a state of equilibrium with the annual evaporative losses being replenished through the annual inflows from the Omo River. If inflows exceed evaporation losses, the lake level rises. As the lake rises, the surface area increases, and so does the evaporation loss. If the inflows are less than the evaporation loss, the lake level falls, the lake surface area reduces, hence the evaporation reduces. Once the evaporation loss matches the inflow, the lake water level stabilises. At this point, there is "equilibrium". As river inflows have varied naturally from year to year, the lake level has fluctuated "naturally" in response to the inflows, although the inter-annual range in recent years has increased with catchment change.

Hence any consumptive use of water within the Omo Basin will reduce inflows to the lake and can only result in the shrinking of Lake Turkana, with ecological consequences that have not been determined, although such effects have been forecast (MoWD, 1992b; and many others including Avery, 2010) – see Section 17.13 above (p204).

18.2 Ecological flows needed to sustain the lake

Lake Turkana is effectively an evaporation basin (Avery, 2010). Apart from some groundwater exchange, the entire River Omo inflow is returned to the atmosphere through evaporation. The lake is therefore part of the regional climatic cycle, and plays a role that has not been studied (ibid).

The lake's ecological behaviour patterns are governed by sunlight, solar radiation, wind, the lake water quality, and the currents and level changes that result from seasonal variations in the inflows to the lake. The limnology of the lake has been extensively studied (Hopson et al, 1982; NIVA, 1988), but the ecological impact of alterations to the lake inflow patterns has not been studied. The previous studies pre-date the changes that have taken place in the Omo catchment. Hence the impact of these changes is not well known. Prior to 1960, fishing was not widely practised on the lake, and both the increasing human / livestock population, and the increasing utilisation of the fisheries resource, has also caused unquantified impacts.

The Omo River has become more "flashy", inflow patterns have altered, there has been increased sediment runoff, and the delta has altered accordingly. The percentage runoff from rainfall in the Basin has increased from areas of vegetation clearance and forest reduction, and the nutrient runoff balances will have changed.

The Gibe III and Gibe IV projects will store the Omo's river waters for subsequent release through turbines that generate hydroelectric power. The Gibe projects are renewable energy projects, and although such projects are encouraged in this era of countering global warming effects due to fossil fuel burning (Avery, 2010), there are concerns expressed in the media about climate change and over dependance on hydropower.

The Gibe III Project subsequently recognised the need for ecological flows to sustain the downstream riverine environment, and considered there is need to mitigate the effects of increasing floods on the traditional cultivation practices in the lower Omo Basin. The Gibe III documents identify many of the impacts in qualitative terms, but a method of deriving the appropriate ecological flows, quantitatively and scientifically, was not presented, and the impacts on Lake Turkana were not considered at all (Avery, 2010).

The Gibe III Project has proposed an ecological flow from the dam of 25 m^3/s, to be sustained as a minimum at all times (EEPCo documents; Salini et al, 2009). The selected value appears to have been based on the lowest monthly runoff of 25.2 m^3/s in March 1973 (see the derived Gibe III inflow sequence from 1964 – 2001, Table 3.1, Agriconsulting SpA et al, 300 ENV RAG 003B) (Avery, 2010). This low flow of 25.2 m^3/s was sustained for the month of March in 1973, for one month only (ibid). A prolonged sequence of low flow at this level has not been experienced, and its ecological effect has not been assessed (ibid). The transmission losses in the river's channel have also not been assessed, so it is not known what proportion of this water will be lost (ibid). Based on experiences elsewhere, transmission losses could be appreciable, as the river travels over 600 kilometres in its passage from Gibe III dam to the lake (ibid). The Gibe III project anticipates that abstractions from the river will increase as a consequence of the regulated flow, but this abstraction effect on flows is also not quantified (ibid). The abstractions are likely to far exceed the proposed ecological flow. The increased abstractions are expected to arise because one aim is to improve food security through replacing erratic rain-fed cropping methods by more reliable irrigated methods (EEPCo: Agriconsulting SpA et al, 2009), and also to enable large-scale agriculture (Salini, 2009).

The Gibe III Project has also proposed an "ecological flood" of 1,000 m^3/s in the month of September, to be sustained for ten days (EEPCo documents; Salini et al, 2009). The basis for this 10-day flood duration has not been established (Avery, 2010). It has been assumed in the "Downstream EIA" that one flood is ecologically sufficient, but what is the basis for this assumption (ibid)? Ecologically, more than one flood pulse may be needed, for instance as anticipated in the "Building Block" approach to ecological flows developed by South Africa's Department of Water Affairs and Forestry, and various academic institutions (Avery, 2010; citing Hughes et al, 1998). The above South African methodology requires the assessment of the following flow proportions that make up the total flow volume (Avery, 2010):

- Low flows;
- Habitat maintenance floods;
- Channel maintenance / flushing floods;
- Spawning migration flows.

Hence, the single annual flood pulse as proposed in the Gibe III project design might not be appropriate, and additional criteria might need to be introduced to cater for sustaining the lake ecology (Avery, 2010). This aspect is critically important, as the flood plain fisheries are highly dependant on flood pulses (ibid; citing Kolding, 1993), as discussed elsewhere.

There are established methods, which for a project of the magnitude of Gibe III, should be implemented as a basis for guiding sustainable development of the Basin (Avery, 2010).

An example is IFIM (Instream Flow Incremental Methodology), described by HR Wallingford as follows:

> "…a conceptual framework for assessing the effect of water resources development or management activities on aquatic and riverside ecosystems, and for solving water resources management problems and conflicts that involve the definition of an ecological flow to minimise impacts on ecosystems. IFIM is a collection of analytical procedures and computer models that allows the development of a different approach for each problem and situation. The goal of this method is to relate fish and wildlife parameters to stream discharge in equivalent terms to those used to estimate other beneficial uses of water…" (Avery, 2010; citing the DFID funded Handbook for the Assessment of Catchment Water Demand and Use).

The study presented to AFDB was able to evaluate the changes in runoff into the lake, but it was pointed out that the impacts on ecology need to be the subject of separate specialist studies, although comments were made based on published research (Avery, 2010). The study of flood sequences and durations was recommended as an essential extended part of the AFDB study (Avery, 2010).

The “dampening” impact of the proposed “average year” regulation on the lake level cycle is demonstrated in Figure 85, below. The 10-day proposed controlled flood is included within the average flow for the month of September. The CESI / EEPCo / Salini flows are adjusted for rainfall and evaporation losses from the lake surface. Based on average monthly flows, the typical 1,100 millimetres lake level rise and fall cycle is dampened to 700 millimetres.

Studies of fisheries in the tropics have shown that flood-plain fisheries are the most productive (Avery, 2010; citing Welcomme, 1979; Junk et al, 1989; both cited by Kolding, 1994); that productivity increases with instability; and that level changes promote interaction between aquatic and terrestrial systems (Kolding, 1994); and that annual fluctuations in lake level are very much more significant than absolute level (Karenge and Kolding, 1993). Lake Turkana’s peak production rates have been associated with peak rises in lake level (Avery, 2010; citing Kolding, 1993).

The above is entirely as expected, as ecologists recognise that diversity is a consequence of change and variability. Hence regulation of the Omo River flows, which dampens the natural river and lake level cycles, and which dampens the speed at which the changes would otherwise occur, will be detrimental to the ecology and fisheries.

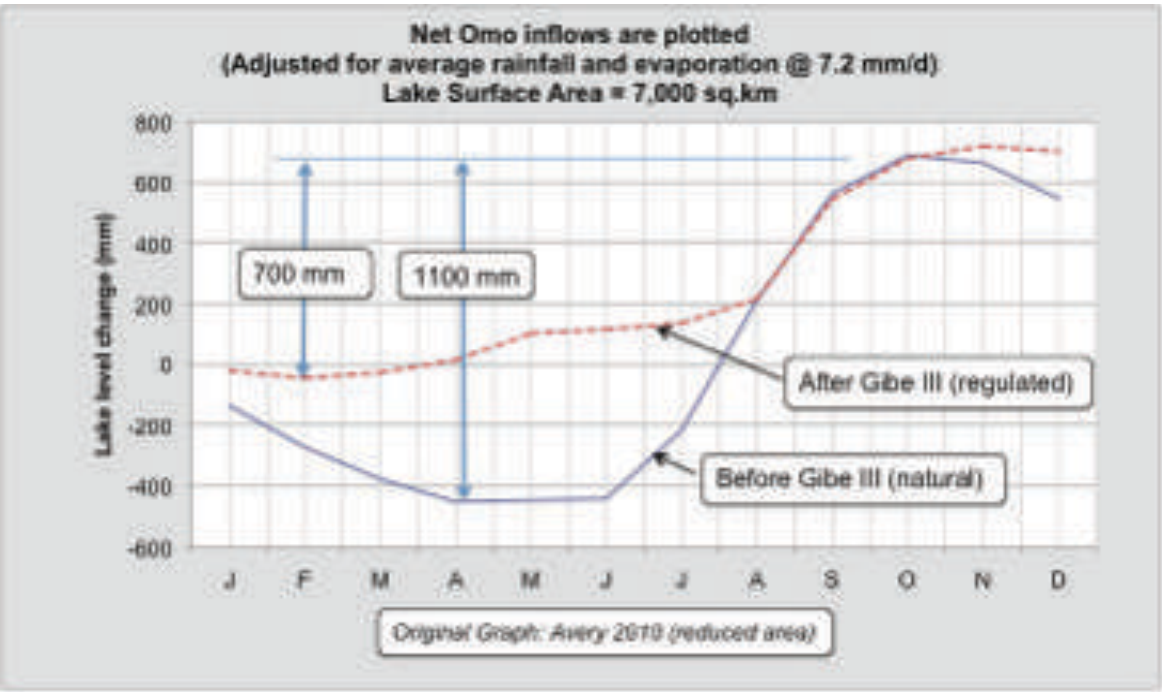
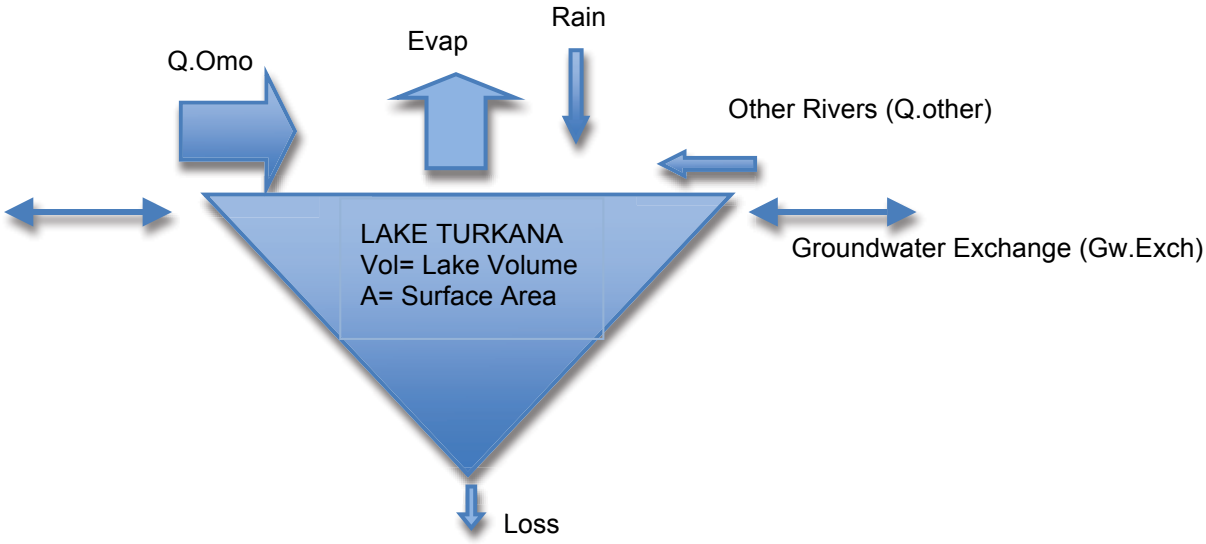


Figure 85: Impact of regulation on lake cyclical level changes

18.3 The water balance model

The water balance model was described through various equations (Avery, 2010), numbered as follows:

1. $\delta Vol / \delta T = Q.Omo + Rain + Q.other – Evap – [Loss +- Gw.Exch]$
2. $\delta T = T- (T-1)$
3. $\delta Vol = Vol_T – Vol_{T-1}$
4. $Q.Omo = Q.Omo_T – Q.Omo_{T-1}$
5. $Rain = Rain_T – Rain_{T-1}$
   where $Rain = P_{Lodwar} \times F_1$; and F_1 = Constant (see below)
6. $Evap = Evap_T – Evap_{T-1}$
   where $Evap = E \times A \times F_3$; E = Constant; F_3 = Constant (see below); A=Area (see below)
7. $A = K1.(Elev)^5+K2.(Elev)^4+K3.(Elev)^3+K4.(Elev)^2+K5.(Elev)+K6$
   where K1…K6 = Constants (see below)
8. $Q.other = Q.other_T – Q.other_{T-1}$
   where $Q_{Other} = k \times Rain \times F_2$; and F_2 = Constant;
   where k = Constant runoff coefficient (with a threshold rainfall to realise runoff defined in the model)



where:

δVol	=	Lake volume level change in time interval δT
δT	=	Time elapsed since last measurement = T- (T-1)
Q.Omo	=	Inflowing discharge volume from the Omo River during time δT
Q.other	=	Inflowing discharge volume from all other rivers during time δT
Q_T	=	Inflowing discharge volume from the Omo River at Time T
Rain	=	Rainfall volume on the lake surface during period T- (T-1)
P_{Lodwar}	=	Rainfall measured at Lodwar during period T- (T-1)
F_1	=	Factor applied to Lodwar rainfall for rainfall “over the lake surface”
F_2	=	Factor applied to Lodwar rainfall to calculate “other catchments” rainfall
F_3	=	Constant to convert daily evaporation depth to volume
k	=	Catchment runoff coefficient applied to rainfall for “other catchments”

Evap	=	Volume evaporated from the lake surface area
Loss	=	Volume of other losses (such as seepage underground)
Gw.Exch.	=	Groundwater exchange with the lake
K1, K2 etc	=	Constants derived from polynomial curve fitting
Vol_T	=	Lake volume at time T
$Elev_T$	=	Lake level (elevation) at Time T
E	=	Daily evaporation rate in mm/day (constant)
A_T	=	Lake surface area at Time T (varies with lake elevation Elev)

18.4 The water balance model calibration

18.4.1 Summary

The calibration of any water balance model requires coincident measured inflow, rainfall, and evaporation data. In the case of Lake Turkana, lake water level data is available, but there is no continuous river inflow data for either the River Omo or the other seasonal rivers, and rainfall on the lake surface can only be estimated based on data recorded at stations like the Lodwar Meteorological Station, and evaporation must also be estimated from data on potential evapotranspiration. There is also no readily available data on river abstractions with which to "naturalise" the Omo river flow. Hence assumptions must be made, and it is a priority that EWRA re-commence river flow gauging at Omorate, as this station is essential to collect and track data on the Omo Basin outflows (recommended in Avery, 2010; Sogreah, 2010). It is also recommended that a database of river abstraction licenses be compiled.

18.4.2 Omo inflow data

The only time where there was actual flow data measured by the Ethiopian Water Resources Authority (EWRA) for the Omo River at Omorate, was the 48-month period 1977-80, but unfortunately, this period coincided with a lapse in lake level readings (following the conclusion of the 1972-75 Lake Turkana Project fieldwork).

However, there is a rainfall / runoff modelled "simulated" flow sequence presented in the Omo-Gibe Basin Master Plan study that covers this period. The correlation between the Master Plan's cumulative "simulated" 1977-80 runoff and the actual EWRA measured runoff has been shown earlier in Figure 46, p138. The Master Plan over-estimated lake inflows in the early periods (Months 12 to 18) and under-estimated in later periods (Months 30 to 45), but at the end of the 48-month calibration period, the modelled and measured cumulative runoff volumes almost equalled. This verified the simulation model in terms of total volume of runoff, but showed that the simulations can differ from the actual situation within years, as would be expected.

The Master Plan's 1977-80 monthly flow sequence was analysed to derive the average annual hydrograph. This hydrograph was compared in Figure 47 (on p138) with the actual hydrograph measured by EWRA for the same time period (Avery, 2010). There was excellent correlation (comments on this comparison were included earlier in Section 12.1, on p135). Hence, on average, the Master Plan's model accurately reflected the average monthly flow variations in an average year.

Avery also compared the Master Plan's simulated inflow data with the coincident satellite recorded lake level data changes for the period 1993-94 (Avery, 2010). Using a simple spreadsheet water balance model, the daily evaporation rate was computed, and this averaged 7.2 mm/day over the 1993-94 period (ibid). This was an integrated loss rate inclusive of underground seepage / groundwater exchange.

The 1993-94 simulated monthly inflows from the Master Plan were then superimposed on the satellite measured lake level fluctuations in Figure 91 on p216. The lake's cyclical rise and fall

was very evident in this monthly data series. The river's peak flow occurred in the month of August, and the lake's level peaked in November, a time "lag" between peaks of two to three months. The time "lag" between inflow peak and lake level peak is a function of the lake balancing inflows with losses. "Lag" is a measure of the period beyond the peak for which river inflows continue to be sustained at flows exceeding the annual average. The lake level will continue to rise beyond the peak inflow month for as long as the average inflow exceeds the daily evaporative losses, which on average, equals the lake's average daily inflow. Based on Figure 89 on p215, the average lag expectation is 2.5 months (the time elapsed between the inflow hydrograph peak and the month in which the falling limb of the hydrograph reaches the average inflow 555 m^3/s). The inflow / lake level peak lags in Figure 91 are consistent with this.

For comparison, on Lake Tana in Ethiopia, the lake inflow / outflow peak "lag" is one month (Shimelis et al, 2008). Lake Tana is Ethiopia's largest lake, but with a catchment area of 15,096 km^2 and lake surface area 3,000 to 3,600 km^2, it is much smaller than Kenya's Lake Turkana, and its altitude is higher. The river inflow to Lake Tana peaks in August, the same month as the Omo peak above, and Lake Tana's water level peaks in September, one month later.

A similar inflow / lake level comparison was presented for the years 1972 to 1975 in Figure 92 on p217 (Avery, 2010). This was the period of the ODA funded Lake Turkana Project for which very reliable monthly lake levels were recorded. Unfortunately, the only inflow data are the "simulated" flows from the Omo Basin Master Plan study. The "simulated" inflow and lake level fluctuations are superimposed in Figure 92, on p217. Again, the cyclical rise and fall of the lake was very evident, with peak inflows in August / September, followed by peak lake levels two to three months later in the October / November / December period. The calculated average evaporation rate (total loss rate) over the period was 7.8 mm/day (ibid).

18.4.3 Lake level data

Puzzling differences between the fixed lake level gauge data and the satellite radar altimeter lake level readings were mentioned in Section 13.5 on p152 (Avery, 2010). Hence the fixed lake gauge data was determined unreliable over that period (ibid). Instead, the satellite radar altimeter data was adopted.

18.4.4 Other river inflows, rainfall and evaporation losses

The only available continuous daily rainfall record is for Lodwar, and this rainfall database formed the basis for assessing rainfall on the lake surface, and for estimating the contribution of other rivers based on an assumed rainfall runoff relationship – see below.

18.5 Omo River inflows "modelled" from the lake water balance model

Due to the absence of data, the following assumptions were made in the water balance model of the lake derived by the AFDB study for period to 2008 (Avery, 2010):

I. The rainfall on the lake surface was assumed to be *[1.2 x Lodwar Rainfall]*.
II. The "other rivers" were assumed to receive *[2 x Lodwar Rainfall]* with a runoff percentage 5% (applied to entire "other rivers" catchments).
III. Evaporation rate from the lake surface was assumed to be 7.2 mm/day, and this was an integrated loss figure, inclusive of percolation / seepage into groundwater.

The lake surface area for computation of evaporation loss was computed from Figure 50, p144, (the lake's "elevation / area / storage" graphs derived from the bathymetry of Hopson et al).

The water balance model was used to compute the "modelled" Omo River lake inflow from lake level for three data sets, each for a range of different evaporation rates. The "modelled" cumulative inflows were then plotted against the "simulated" cumulative inflow sequence

derived in the Master Plan study over the same period. This "double mass curve analysis" is an accepted hydrological method for checking hydrological data integrity. The Master Plan's simulated monthly flow series was included earlier in Table 36, p139. The water balance model's "modelled" cumulative flows were plotted on the vertical axis, and the Master Plan's cumulative simulated flows were plotted along the horizontal axis, the following graphs being presented (ibid):

- Figure 86, p214, 1956 – 1994: Compared to the Master Plan flows, the model predicted higher cumulative runoff volume at evaporation rates greater than 7 mm/day, and lower cumulative runoff volume at evaporation rates less than 6.8 mm/day. The calculated integrated "loss" for this period was 7.2 mm/day.
- Figure 87, p214, 1972 – 1975: The calculated integrated "loss" for this period was >8.3 mm/day.
- Figure 88, p215, 1993 – 1994: The calculated integrated "loss" for this period was 7.8 mm/day.

The AFDB study reported reasonable correlation between the modelled flows and previously published data, and an integrated "loss" of 7.2 mm/day was finally adopted (Avery, 2009, & 2010). Comparable results have been presented by other studies since reported, notably 7.9 mm/day by Salini's parallel study (Salini & Pietrangeli, 2010), and most recently UNEP's 0.22 m/mth average derived through modelling over-the-lake evapotranspiration rate "Et" (7.26 mm/day average) (UNEP, Velpuri et al, 2012). The UNEP 7.26 mm/day figure is almost identical to the original derivation of Avery, 2009. The Salini 7.9 mm/day figure is higher because the Salini model generated average lake inflows are higher. Hence the Salini figure is consistent, but higher.

The average monthly flows derived by the water balance model from the 1993 - 2008 lake level record were presented in Figure 89 (p215) and compared with the Master Plan study and Salini study averages. Strictly speaking direct comparison should only have been done with identical time periods, as it might otherwise be misleading, especially as the 1993 - 2008 period reflected by the satellite records had been one of higher lake levels that included the 1997/98 El Nino flood event. Nonetheless, the comparison of trends was of interest. The lake level derived averages from Avery's AFDB study plot are time lag-delayed by one month. This is interesting, and is a function of the different model methodologies. The Master Plan and Salini studies used rainfall / runoff models that estimated rainfall / runoff response times, which includes the time of travel of water overland, and the time of travel down the river to the lake from different parts of a huge catchment. In contrast, the lake water balance model back-calculation was assumed instantaneous. Although the lake level response to inflow will not be instantaneous, it has been ignored for this exercise. Otherwise the flow profiles of the three models are practically identical.

Hence, knowing the Lodwar rainfall and the downloaded satellite radar altimeter lake level, the Omo river inflow from Ethiopia can be calculated accurately using this simple model originally presented in a study for AFDB in 2009 (Avery, 2009).

A sensitivity analysis for the lake water balance model was presented in Table 57 (p213) for the period 1956-94 (ibid), this being the time series in the Master Plan. The effect of changing the integrated loss value was tested in the range 6.4 to 8.3 mm/day:

- In Table 57, the Master Plan study's average flow was 537 m^3/s (recomputed to be 526 m^3/s in Table 36, p139), equating to at a loss rate 7.3 mm/day.
- The average computed discharge varied from 468 to 627 m^3/s for evaporation rates 6.4 to 8.3 mm/day.
- For the selected 7.2 mm/day integrated "loss", the computed average Omo inflow for this period 1956-94 was 535 m^3/s (virtually identical to the Master Plan model's 526 m^3/s in Table 36, p139).

The annual inflow sequence from 1993-08 was previously modelled from satellite lake levels with the results presented in Table 58 on p213 (Avery, 2010). The runoff averaged 560 m^3/sec, although with some variability. In this report, three extra years of satellite level data have been added, and the mean annual inflow for the period 1993-11 reduced slightly to 555 m^3/s (also in

Table 58). In conclusion, the mean annual runoff from the lake water balance model is virtually identical to the average of the Master Plan study's flow sequences, and both are less than the 650 m^3/s computed by the Salini team's Gibe III studies.

The Omo contribution to total lake inflows in Table 57 overleaf from 1956-94 amounted to between 86% and 89% of the total (for the model assumptions adopted), the balance being rainfall on the lake surface and surface runoff from "other rivers". In the series 1993-08, the runoff was higher, and the Omo inflow proportion averaged 91%.

The monthly Omo inflow "modelled" from lake level has been compared with the Master Plan "simulated" runoff in Figure 93 (p217) for the only common period for the respective databases, namely 1993-94. To enable valid comparison, the lake level modelled flows have been lagged 1-month, for the reasons given above. In 1993, the Master Plan over-estimated runoff compared to the lake water balance model. In 1994 the Master Plan under-estimated runoff compared to the lake water balance model. This is consistent with observations made earlier in Section 18.4.2 in regard to Figure 46. Overall, from Figure 88, the Master Plan's cumulative "simulated" runoff in the period 1993-94 was 1.13 times the lake's cumulative runoff modelled at the loss rate 7.2 mm/day. Hence, overall the Master Plan over-estimated runoff in the period 1993-94 compared to the lake model.

In conclusion, the lake's modelled inflows are entirely dependant on the assumed "loss" rate, and on the lake surface area, both of which merit ongoing research. The topic of time lag also warrants further research.

Table 57: Sensitivity analysis on varying evaporation rate (1956 - 1994 data)

		O-GBMP	*Sim 01*	*Sim 02*	*Sim 03*	*Sim 04*	*Sim 05*
Evap *(mm/d)*	1	7.3	6.4	6.8	7.2	7.8	8.3
Evap *(km^3/yr)*	2	19.1	17.0	18.0	19.1	20.9	22.0
Omo *(km^3/yr)* *(% Total inflow)*	3	16.9 (88%)	14.8 (86%)	15.8 (88%)	16.9 (89%)	18.5 (89%)	19.8 (89%)
Omo *(m^3/s)*	4	537	468	502	535	585	627
Rain *(km^3/yr)*	5	1.7	1.7	1.7	1.7	1.7	1.7
Other *(km^3/yr)*	6	0.6	0.6	0.6	0.7	0.6	0.6
3+5+6-2	7	0.2	0.1	0.1	0.1	0.1	0.1
δVol *(km^3/yr)*	8	0.2	0.1	0.1	0.1	0.1	0.1

Table sourced from Avery, 2010.
Ref: A4 56-08.

Table 58: Mean annual R.Omo discharges modelled from L.Turkana's level changes from 1993 - 2011

Year	Flow m^3/s (Avery, 2010)	Flow m^3/s (This study)
1993	589	
1994	570	
1995	321	
1996	764	
1997	670	
1998	1,167	
1999	385	
2000	361	
2001	605	
2002	220	
2003	465	
2004	375	
2005	496	
2006	534	
2007	856	
2008	587	
2009		233
2010		759
2011		577
Average	560	555

Ref: A5 93-94.
Original table sourced from Avery, 2010, and updated.
New data added by this study highlighted 'yellow'.

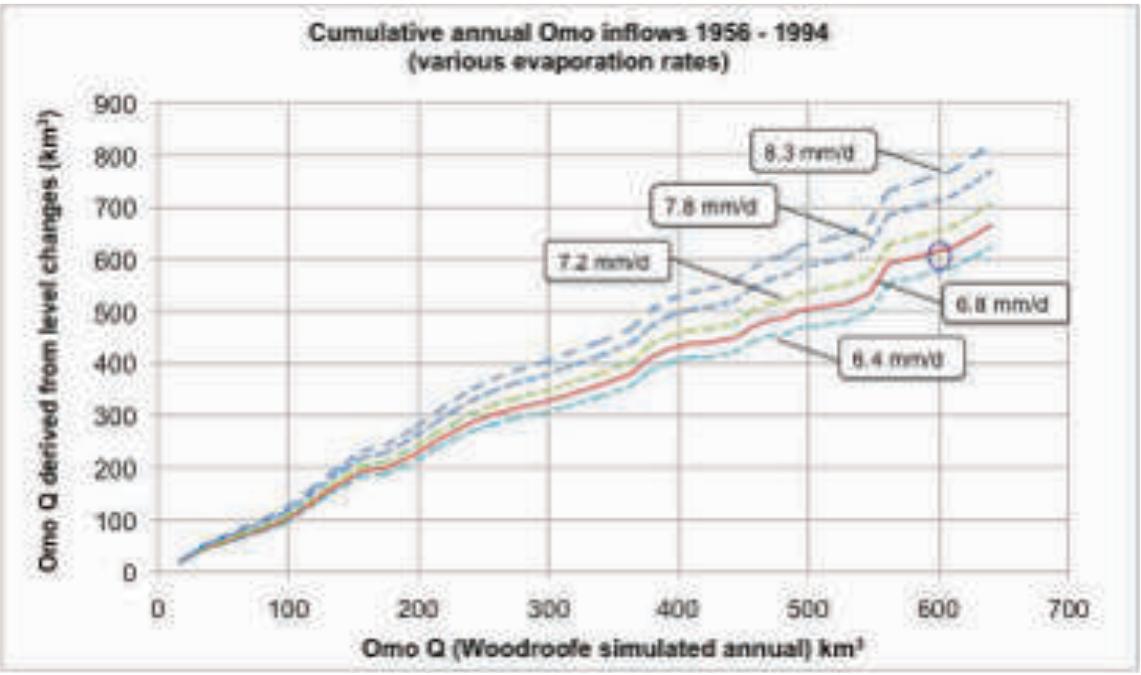


Figure 86: The Omo's cumulative "modelled" & "simulated" runoff, 1956-94, for various evaporation rates

Graph sourced from Avery (2010).

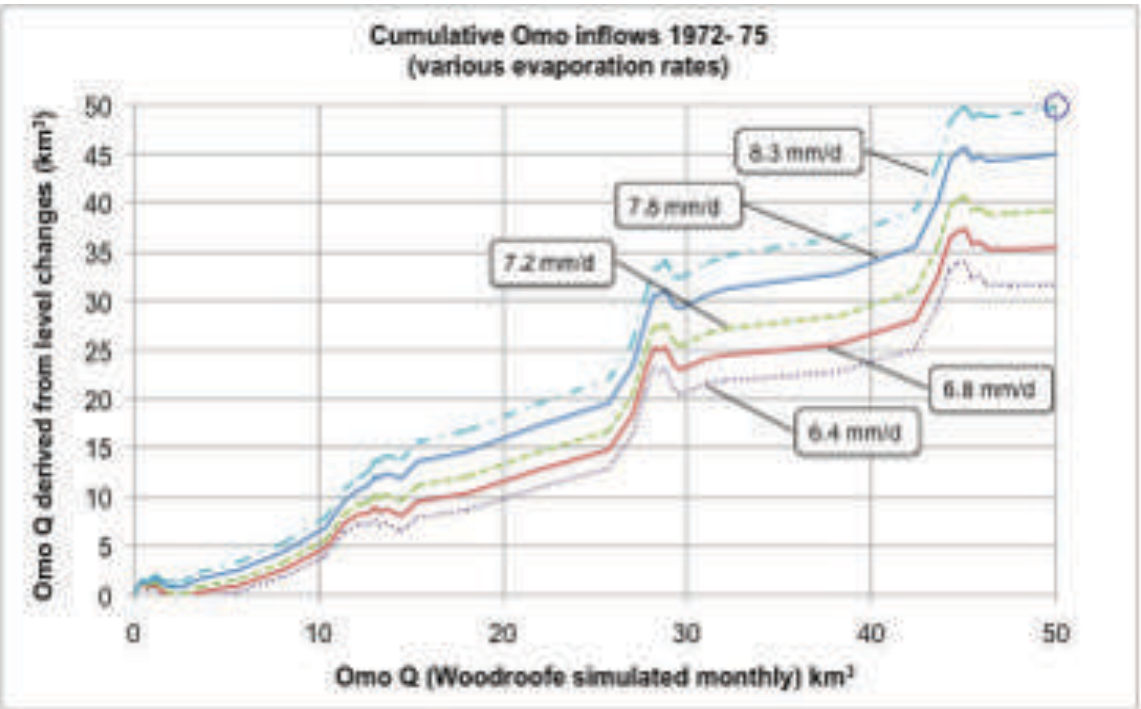


Figure 87: The Omo's cumulative "modelled" & "simulated" runoff, 1972-75, for various evaporation rates

Graph sourced from Avery (2010).

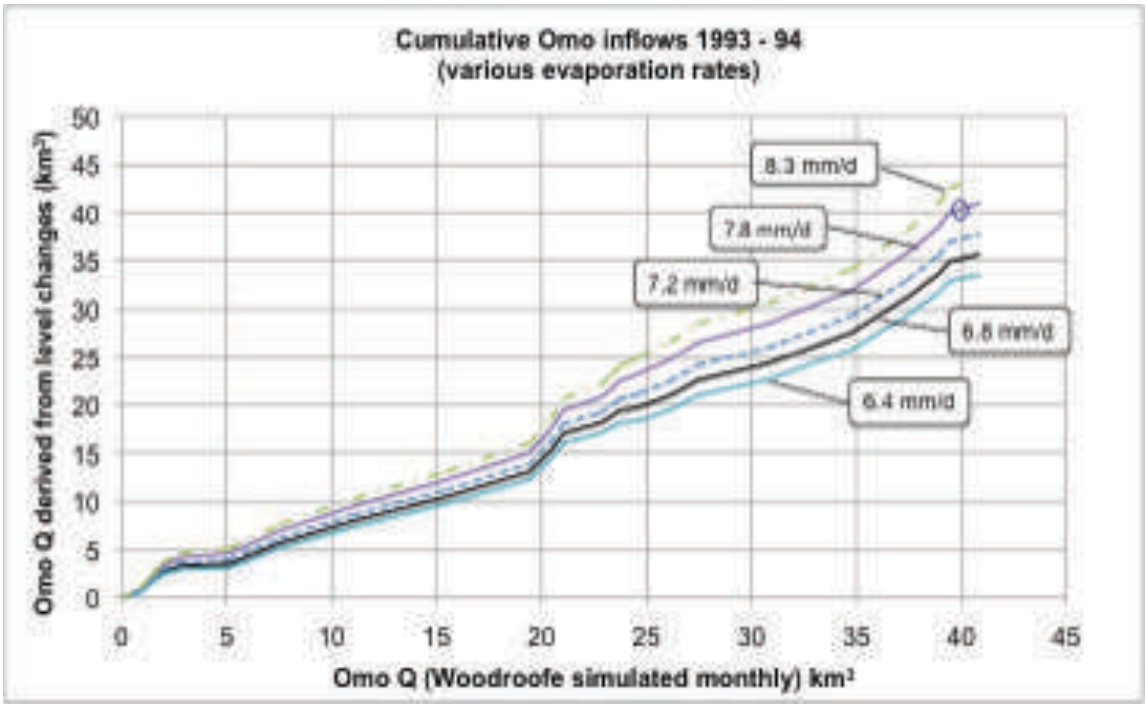


Figure 88: The Omo's cumulative "modelled" & "simulated" runoff, 1993-94, for various evaporation rates

Original graph sourced from Avery (2010).

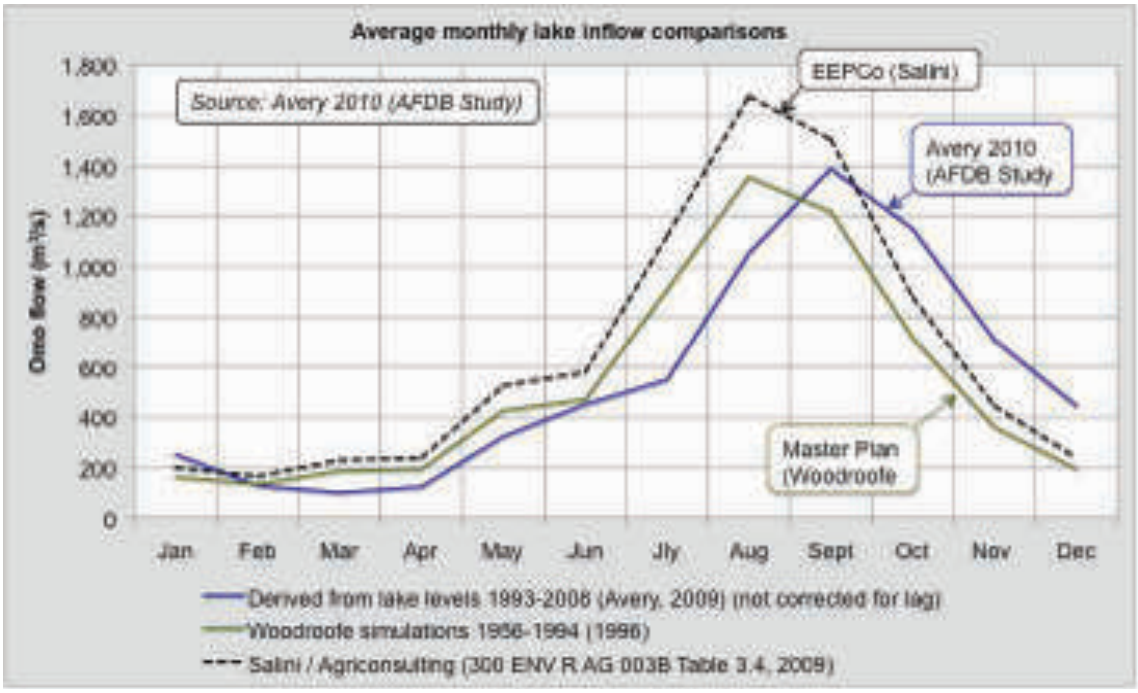


Figure 89: The Omo's average annual hydrograph – different derivations

Avery (2010) - "modelled" from lake levels (blue hydrograph).
EEPCo (Salini) and Master Plan (Woodroofe) - "simulated" using rainfall / runoff modelling.
Note the1-month time delay between "modelled" and "simulated" hydrographs.

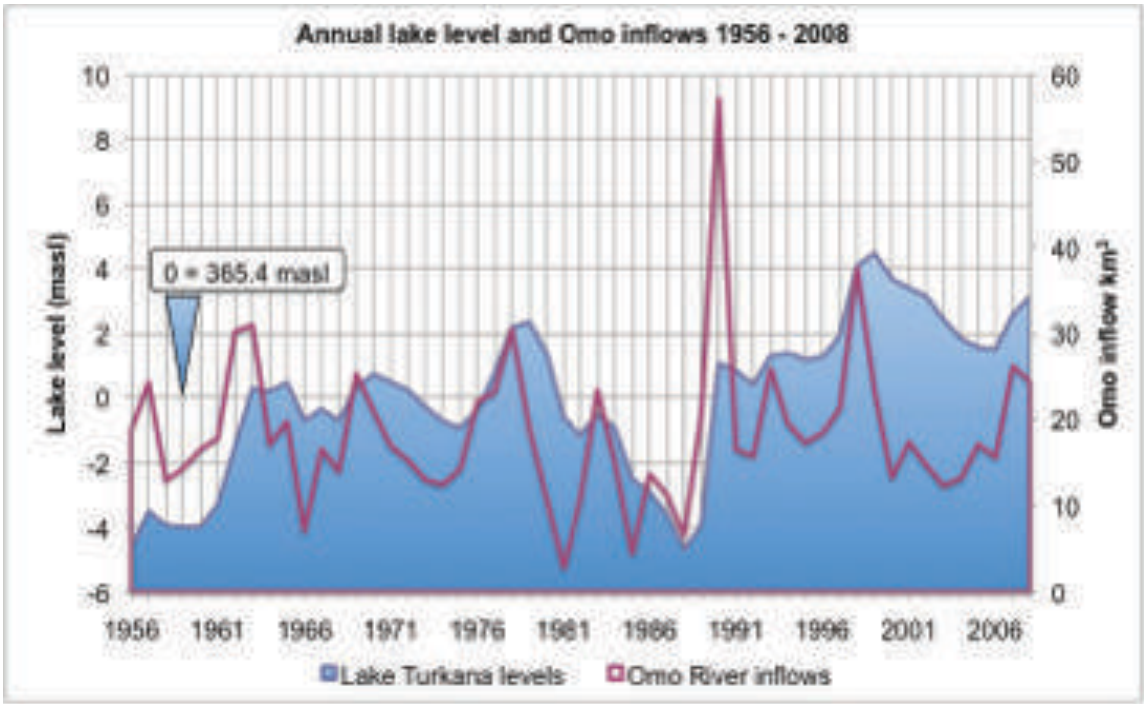


Figure 90: Lake levels & the Omo's "modelled" annual runoff, 1956-08

Graph from Avery (2010).

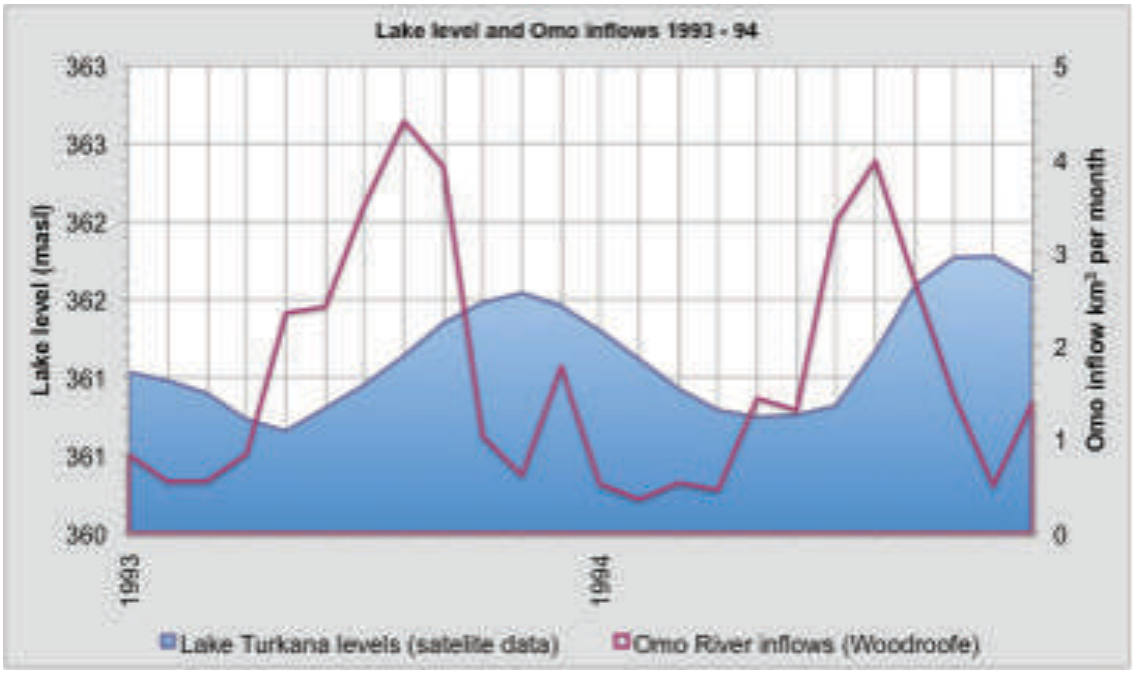


Figure 91: Lake levels & the Omo's "simulated" monthly runoff, 1993-94 (Woodroofe et al data)

Graph from Avery (2010).

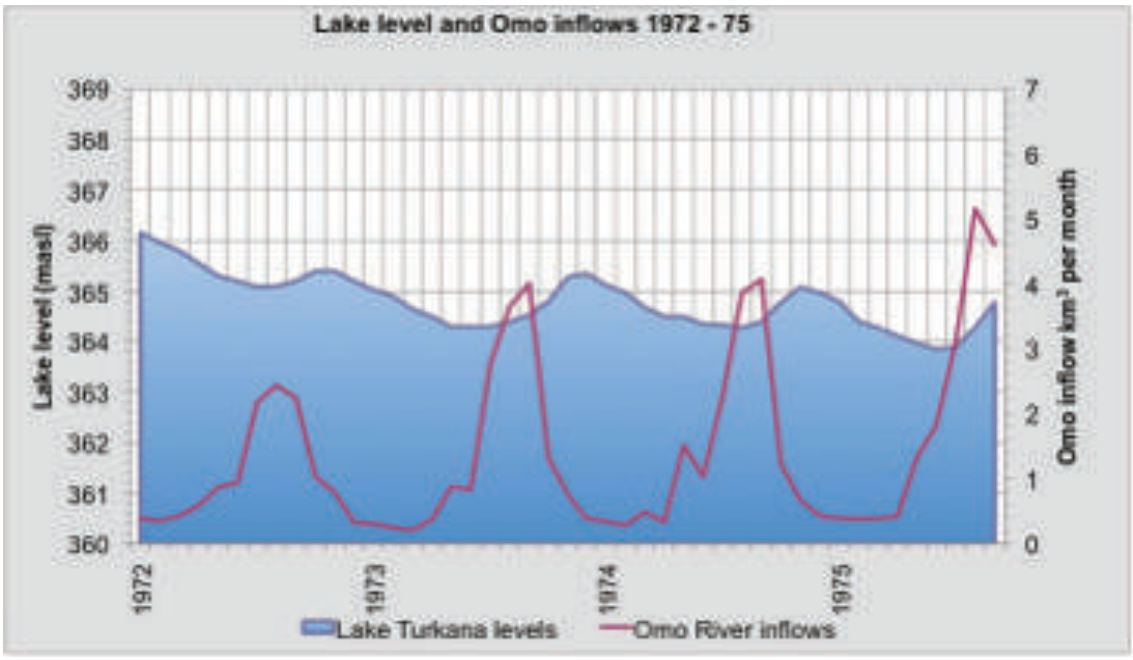


Figure 92: Lake levels & the Omo's "simulated" annual runoff, 1972-75

Graph from Avery (2010) (with amended datum).

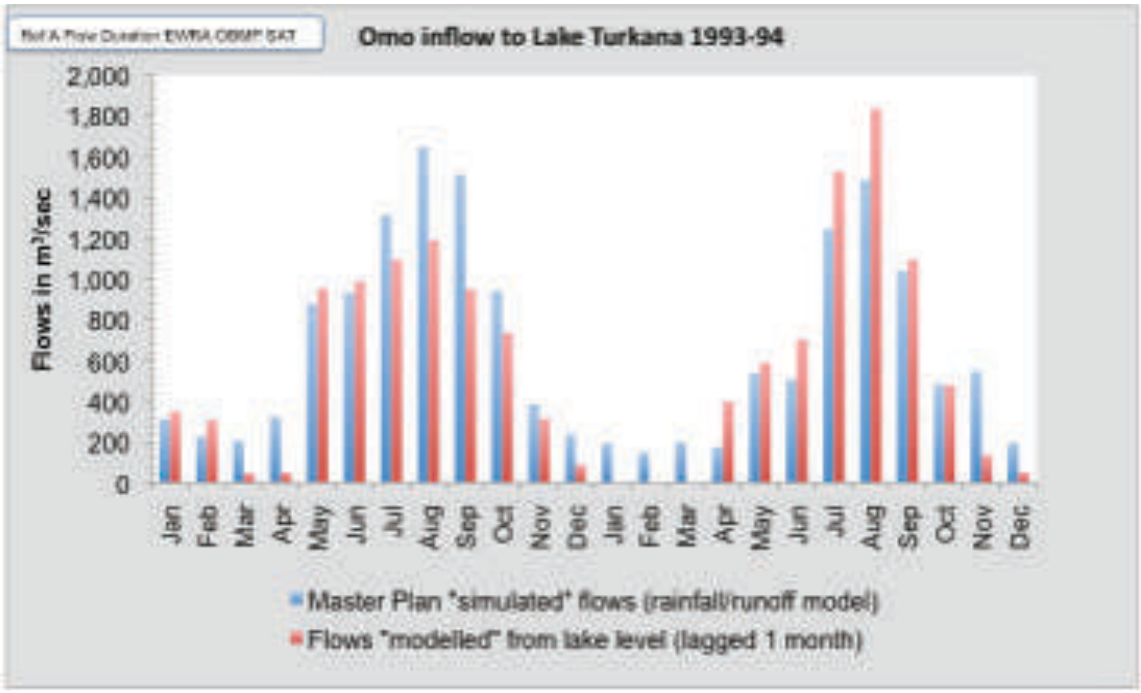


Figure 93: "Modelled" & "simulated" Omo hydrograph comparisons, 1993-94

Flows "modelled" from lake level have been "lagged" by one month in the graph (this study). Graph plotted with "simulated" flows abstracted from the Omo-Gibe Master Plan study.

18.6 The Omo River at Omorate – flow duration curves

"The flow duration curve is perhaps the most basic form of data presentation which has been used in low flow calculation. It shows the relationship between any given discharge and the percentage of time that the discharge is exceeded" (IH, 1980).

To derive the flow duration curve, the river flows are ranked in order of magnitude, with each "rank" being assigned a "percentage exceedence" value. The tabulated results can then be plotted as a graph showing the proportion of time that each flow value was exceeded. This is in effect a flow distribution analysis for a river, but with the natural variable order of events changed to a ranked order.

The flow duration analysis for the River Omo at Omorate is presented overleaf in Figure 94 overleaf. Four sets of flow sequences are compared, as follows:

- The Omo-Gibe Basin Master Plan's simulated flow series from1956-94.
- The EWRA actual measured flows at Omorate from 1977-80.
- The AFDB study's lake-modelled flows 1993-08 (Avery, 2010).
- The lake-modelled flows extended by this study from 1993-11 (this study).

As would be hoped, the various data sets display near identical flow duration curves, apart from the lowest flow regime. Beyond the 75% "exceedence" level, there is a marked flow "drop-off" with the lake-modelled results from the satellite data. These happen to be the recent flow datasets. The "drop-off" in low flows is often a result of upstream abstractions having caused diminished low flows in the later datasets, or it might be the result of diminishing low flows associated with catchment change, or it might be due to imprecision in the water level fluctuations measured by the satellite radar altimeter at these low flows. It is very likely that the "drop-off" is the combined consequence of increasing water usage in recent years for irrigation purposes upstream, and changing catchment conditions. The recent proliferation of wind pumps along the banks of the Lower Omo is indicative of increased river abstractions for irrigation, and an increase in small-scale irrigation was forecast in the Master Plan study report in 1996.

The mean annual flow at Omorate is "arrowed" in Figure 94 overleaf. Also "arrowed" is the flow equivalent to 33.5% of the Omo flow. This "arrowed" flow will only be available 65% of the time. It is thus immediately apparent from that the river cannot meet the Lower Omo irrigation demand and that the river will run dry downstream. This is consistent with what actually happened in January 2012, when diversion into the Lower Omo's Kuraz irrigation scheme commenced (see Photo 1 on p47). This alarming image is in stark contrast with what the river nearby at Omorate usually looks like (inspect the bottom image in Photo 6 on p137).

In Kenya, river abstraction licensing aims to ensure that the river flow that is exceeded 95% of the time cannot be touched, and remains at all times in the river to meet downstream needs. Based on the EWRA measured flow data in Figure 94 overleaf (the graphed black line), the 96% exceedence flow would be 100 m^3/s. This would be the amount that should remain in the river after abstractions. Hence, if the Kuraz irrigation scheme requires 183 m^3/s (33.5% of the lake inflow @ 70% irrigation efficiency in Table 14 on p48), the total flow needed in the river would be 100+183=283 m^3/s. From the flow duration curves overleaf, the river discharge falls below the required 283 m^3/s for 58% of the time. Hence, the Kuraz irrigation project can only sustain its abstraction needs once an appreciably enhanced low flow is provided from a regulating reservoir such as Gibe III.

Once Gibe III is commissioned, the average regulated low flow is expected from less than 200 m^3/s to increase to 500 m^3/s (red hydrograph in Figure 4, p16). Until this happens, no scheme should be emptying the river, as this is obviously ecologically damaging.

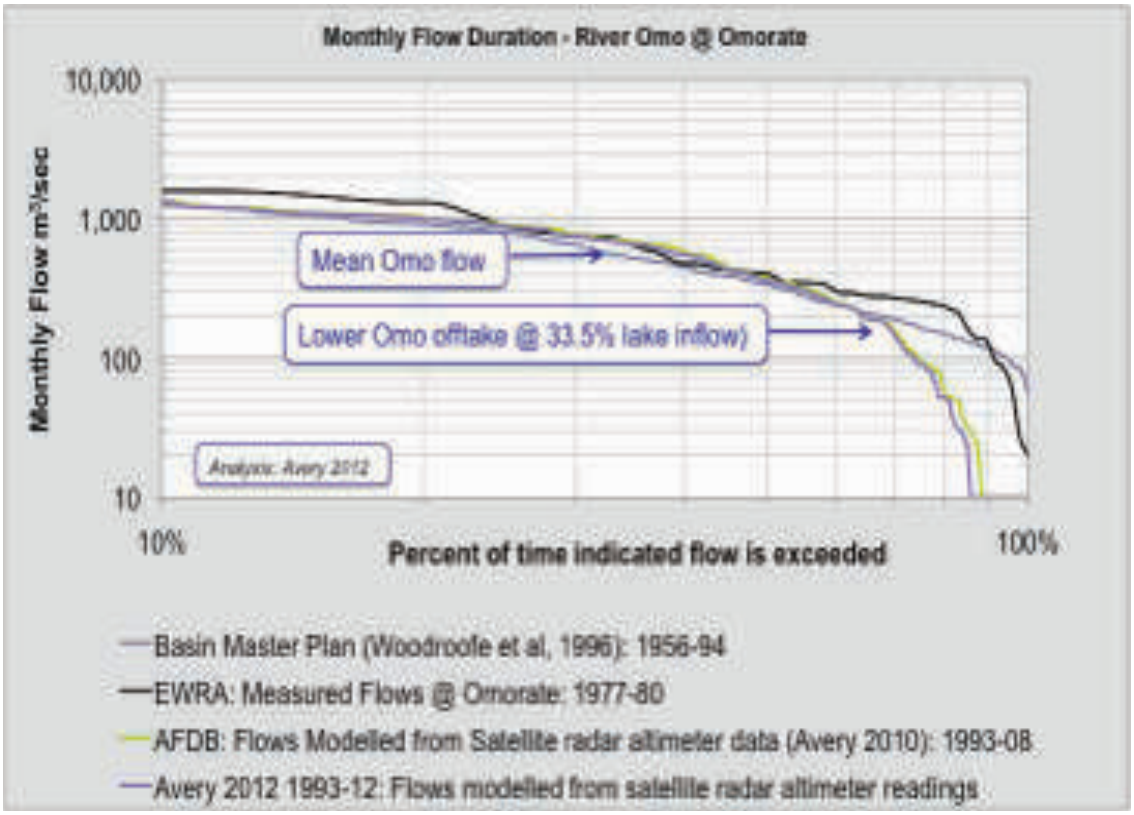


Figure 94: Flow duration curves for the Omo River at Omorate

Data Sources are indicated in the above graph's Legend.

18.7 Effect of Gibe III "filling" period and during "operation"

The filling of the Gibe III reservoir will detain flows that would otherwise pass down river to the lake (Avery, 2010). Gibe III intercepts 67% of Turkana's inflow. Hence lake level will be reduced during this filling period, which will alter the subsequent lake level cycle (ibid).

The reservoir's gross storage volume will be 14.690 km^3 (inclusive of dead storage), and seepage into the banks during filling was estimated to be up to 1.568 km^3 (Avery, 2010; citing Salini & Studio Pietrangeli, 300 GEO RSP 002A, 2007). Hence the total volume required in filling the reservoir is 16.26 km^3. This equates to almost one year's inflow volume into Lake Turkana, and is equivalent to the volume stored in over two metres on the entire Lake Turkana (Avery, 2010).

It is planned to fill the Gibe III reservoir in 3 years, but at the same time ensure an "ecological flow" of 25 m^3/s, and to release an "artificial flood" of 1,000 m^3/s from 1st to 10th September each year (EEPCo documents; Salini et al, 2009).

The impact of the specified "average year" filling rules on the lake, for the period 1993 to 2012, for instance, is as shown in Figure 95 below. The lake level would drop up to two metres below the natural lake level, and would then recover under regulated flow release conditions. For the 1993 to 2012 sequence, the lake start level would have been substantially restored after 16 years but would still be rising. The lake's "equilibrium level" is about 363.2 masl, and would take much longer to reach (the "equilibrium" level is the level at which integrated losses from the lake balance total inflows).

Hence, the filling of Gibe III alone was determined to draw the lake level down, to dampen the annual cyclical changes, with the lake level ultimately being restored as the hydropower scheme alone is not consuming water (Avery, 2010). This is the "zero abstraction downstream" scenario.

The actual changes in lake level will of course depend on the flow regime prevailing at the time, and the lake level at the time, and abstractions downstream which will compound effects. The dam construction is far from complete, hence its filling impact cannot be predicted yet with certainty. Nonetheless, it can be concluded, as expected, that cycles will change, that the lake level will be drawn down, but that long term, the lake level will be restored, albeit dampened.

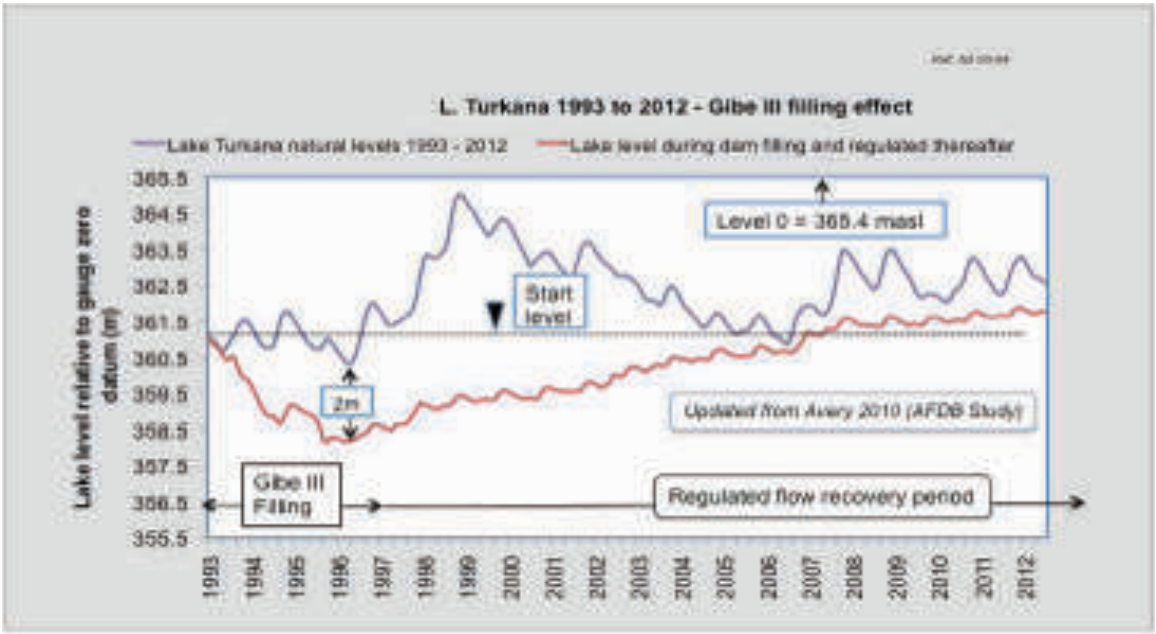


Figure 95: Effect on L.Turkana of Gibe III "filling" and regulation

18.8 Water losses due to Gibe III during operation

The AFDB reports included the following review of water losses due to Gibe III (see Avery, 2010). It had been stated that the Gibe III dam will regulate flows and that there will be a "positive" water balance for Lake Turkana (EEPCo & Salini, 2009). The AFDB study suggested that it would be realistic to include the impact of not only Gibe III, but also Gibe IV and Gibe V (Avery, 2010). Although there are no details yet released on the future plans, the term "positive" was considered misleading as no water will be added to the system, and ecologists will not agree that regulation is ecologically "positive" (ibid). Ecologists favour diversity, not uniformity, and there are numerous studies that demonstrate that flood-plain fisheries depend on water level changes from flood pulses (ibid; citing Kolding, 1993, 1994, and 2010).

A continuous flow sequence into the lake was not presented in the EEPCo reports, with only the average monthly inflow in each month being presented (Agriconsulting & Mid-Day, 2009, for EEPCo). This was presumed to be because Gibe III will regulate 67% of the Omo lake inflow, with the proportion regulated increasing when the Gibe IV reservoir is built (ibid). Hence ultimately, the flows into Lake Turkana will be virtually entirely regulated (ibid). Until Gibe IV and V are implemented, the catchment downstream of Gibe III will continue to provide variability of inflow to Lake Turkana (ibid).

The "Downstream Impacts EIA" (Agriconsulting & Mid-Day, 2009, for EEPCo) presented intended flow averages for a "dry year", and an "average year", based on an assumed mean annual inflow of 650 m^3/sec. The Consultant's studies have indicated the following lower assessments of mean annual inflow into the lake:

- 526 m^3/sec - Woodroofe et al, 1996 – see Table 36, p139.
- 555 m^3/sec - derived from lake levels – see Table 58, p213.

The Omo average inflows modelled by this study are very close to those calculated by the Master Plan study's simulations for the same period, and are lower than those presented by Salini's team for a different period (ibid). The Salini team's sequence is based on rainfall / runoff simulation and an assumed runoff factor for the catchment downstream from Gibe III dam ("Residual 2" catchment). The runoff coefficient that was derived for the downstream "Residual 2" catchment is 0.19 (ibid). This factor is quite high when compared with other dry regional catchments such as Lake Baringo (ibid) (Section 9.5 on p112). Hence, the Salini contribution of the "Residual 2" catchment may have been over-stated (ibid), which would explain why the Salini team's simulated lake inflows are higher.

In theory, a hydroelectric power scheme does not "consume" water. The scheme stores water within a reservoir created by a dam, and then releases controlled flows back downstream through the dam's turbines and sluices. However, by virtue of storing water, water losses are introduced. A large lake is created, and additional evaporation losses occur. It has been claimed that in the case of Gibe III, these losses will be offset because of reduced downstream flooding resulting from regulation. This is possible (Avery, 2010). If the inundated flood plain areas are reduced as stated, the evaporation due to such flooding will be reduced (ibid). However, with the implementation of large-scale irrigation, any such "positive hydrological balance" claimed by EEPCo will be totally reversed.

In addition, the dam will be 243 metres high. The reservoir will thus impose 243 metres hydraulic pressure, which is appreciable (Avery, 2010). It has been claimed by ARWG that losses of up to 75% could occur as a result (ARWG, 2009). These figures seem improbable and have not been substantiated (the Consultant requested substantiation from ARWG and there was no response – see Avery, 2010). However, the Contractor's team (Salini et al) engaged in further geological site investigation of both the dam site and reservoir basin. Salini's team remained of the view that there are no appreciable losses (Pers. Comm., Studio Pietrangeli, 2010). This view has not been disputed by other technical reviews, such as that of Sogreah (Sogreah, 2010), and if there are any losses, the topography dictates that the losses will feed back into the Omo River basin and will not be lost (Salini and others).

18.9 Effect of varying Omo River irrigation abstraction on lake levels

Gibe III is designed solely for hydropower generation. It is not designed as a multi-purpose reservoir, and hence is not directly supplying water for irrigation or other consumptive use purpose. The reservoir formed by the dam will store water, and it will raise water level, thereby creating "head" for power generation. This water will be released from storage, through its turbines, in a controlled fashion, thus providing its "regulated" flow sequence downstream. The scheme will not "consume" water, as all water passing through the turbines is returned direct to the river (Avery, 2010).

However, one of the stated benefits of the Gibe III project ESIA (EEPCo, Agriconsulting, 2009) is enhanced food security as a consequence of the provision of its regulated flow sequence. This means that extreme low flows will no longer occur, and it is stated that people downstream will be encouraged to move away from "risky rain-fed agriculture" to "more secure irrigated agriculture". The Report stated: "…water abstraction from the Omo River will probably increase in these low-flow years, due to both the regulated flow of the river encouraging further development of public and private permanent intake facilities for dry-season irrigated farming..." In addition, the Gibe III Environmental & Social Management Plan (ESMP; Salini et al, 2009) stated: "…Major benefits would be induced by the regulation of river flow in the downstream lower Omo valley in terms of…permanent availability of water with stable water levels allowing for development of commercial irrigated agriculture…" (Salini & Mid-Day, p61, 2009).

The AFDB study insisted that abstraction was expected as an indirect effect of Gibe III, and this would reduce downstream flows below the figures that had been published (Avery, 2009; Avery, 2010). The AFDB study noted that the amount abstracted was stated to be negligible compared to the annual flows (ibid; citing EEPCo, Agriconsulting, 2009; and Sogreah, 2010). AFDB did not agree that abstraction would be "negligible" (Avery, 2010). To the contrary, the AFDB study raised the spectre of Lake Turkana becoming Africa's "Aral Sea", an impression that has generally been ignored (ibid).

The Omo-Gibe Basin Integrated Development Plan Study (the Master Plan) was published in 1996. The Master Plan presented Year-2024 projected water demand including irrigation development of the Omo Basin requiring 32% of the water resources of the Basin (see Table 6, p54). More recent assessments of potential irrigated area were reported to be conflicting (Avery, 2010), and have been reviewed in this report. CESI suggested an irrigation area 50% larger than the Master Plan (CESI SpA, 2009 - 153,000 hectares), whereas Sogreah derived a "suitable" area of 79,000 hectares, which is very similar to the Master Plan expectations. Earlier reports by World Bank and FAO cited prospective irrigation areas 5-times the area proposed in the Master Plan (Section 2.3, p26). The AFDB studies believed there could be long-term prospect for much larger abstraction from the Omo than was considered in the Master Plan (Avery, 2010), and that belief has since been proved right.

The impact of the Omo-Gibe Basin Master Plan's projected water demand rates on the available natural lake level sequence is shown in Figure 96, p223 overleaf. This graph of lake levels is developed from the AFDB study, and a datum inconsistency in the AFDB results has been removed. This inconsistency was introduced between the 2009 and 2010 reports.

Also tested in Figure 96 on p223 overleaf is an abstraction double the Year-2024 Master Plan demand, as was done by the AFDB study (Avery, 2010). This longer-term demand is hypothetical but is included to fully demonstrate how sensitive the lake is to increasing levels of abstraction. This graph presented the monthly lake flow sequence since 1993, the period for which satellite radar altimeter lake levels are available. The recorded lake level sequence shows that the lake rises slightly over this period, boosted by exceptional inflows during the 1997/98 El Nino floods. The forecasted impact of the superimposed abstractions at both the 2009 and 2024 demand level is to reduce the lake to well below the historic low lake level.

A similar graph is included in Figure 97 overleaf, for the period 1888 – 2011. At the 32% abstraction rate, the lake level drawdown was between 12 and 20 metres below the natural lake level profile. The 32% abstraction is very similar to what is now being proposed in the Lower

Omo for the Kuraz sugar project and other commercial agriculture (see Section 4.16.3, p63). Hence this scenario is evolving now. The lake level will be drawn down far below its historic low levels. Ferguson's Gulf will be rendered permanently dry, the lake water table throughout will be drawn down, and this will in turn draw down the levels in all the lake's hydraulically linked wetlands, such as the crater lakes on Central Island, and the crater lake and ponds at the southern end of Lake Turkana.

When viewing the graphs below, it is worth bearing in mind that the lake's average depth is roughly 30 metres. This puts the lake level drops into perspective.

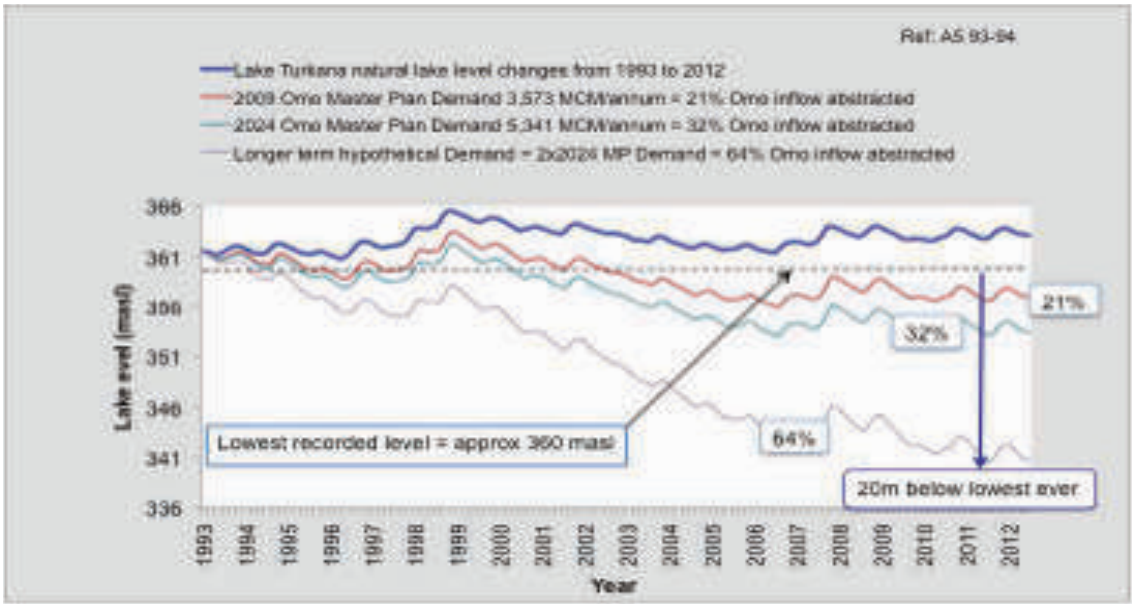


Figure 96: Lake drawdown for various abstraction rates (1993 - 2011 "modelled" flows)

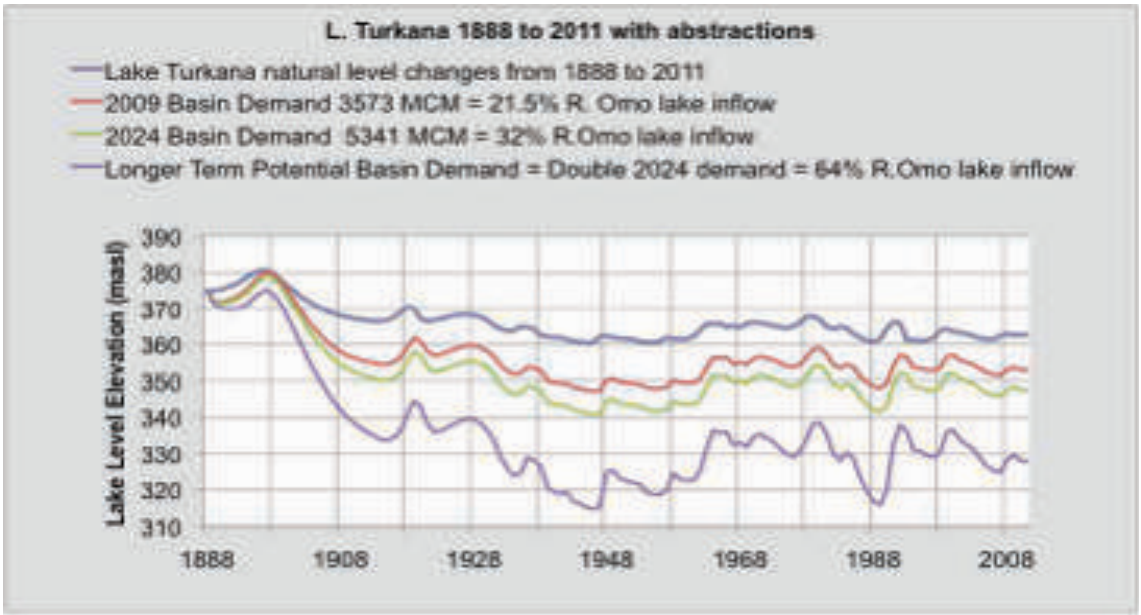


Figure 97: Lake drawdown for various abstraction rates (1888 - 2011 "modelled" flows)

18.10 Effect of varying Omo River irrigation demand on lake levels

The above analysis is hypothetical as the flow sequence 1993 - 2012 was assumed to project to the future. This sequence was unusual in regard to the huge inflow volume that resulted from the El Nino floods of 1997/98, which boosted levels in all regional lakes. For this reason, a supplementary model is introduced below which very simply calculates the relationship between lake "equilibrium level" and Omo inflow. If the Omo flow is reduced through large-scale irrigation, the consequent equilibrium lake level can be quickly derived through the following equations.

The water balance Equation 1 below was previously given as follows:

1. $\delta VOL / \delta T = \{ Q.Omo + Rain + Q.other – Evap – [Loss +- Gw.Exch] \}$

When equilibrium is reached, inflow and losses are equalised. Hence the following equations are derived:

9. $\delta VOL / \delta T = 0$, and
10. { Q.Omo + Rain + Q.Other } = { Evap + Loss +- Gw.Exch }, where
11. Evap = { Evap.Rate, E} x { A }, where
12. Evap.Rate, E = 7.2 mm/day, assumed constant, and
13. A = Lake Surface Area = fn (Elev).

Loss +- Gw.Exch is assumed negligible and integrated with evaporative loss, i.e. it is assumed: Evap = Evap + Loss +- Gw.exch.

Hence if the value "Q.Omo" is reduced, "Elev" must reduce to maintain equilibrium. It has been assumed that the Omo inflow accounts for approximately 91% of the total lake inflow balancing evaporation (this being the average computed by the water balance model for the period 1993-11). Hence the contribution for "other rivers" and "rainfall on the lake surface" was calculated to be about 9%.

Figure 98 (p225 overleaf) shows the relationship derived between annual Omo inflow reduction due to irrigation abstraction and the lake elevation level "Elev". The sensitivity to evaporation rate is demonstrated: In the range 6.4 to 7.9 mm/day, the lake level range is roughly +-5 metres.

If 39.1% of the Omo flow is removed for irrigation in the Lower Omo (60% irrigation efficiency), the lake level will fall 16 metres (Figure 99, p225 overleaf), and the lake volume will reduce to about 57% of its current sustainable volume, hence losing 43% of its biomass storage volume (Figure 100, p226), which means the lake fisheries will be similarly hugely reduced.

If 52.2% of the Omo flow is abstracted for irrigation (45% irrigation efficiency), the lake will fall 22 metres, and the lake volume will reduce to 45% of its sustainable volume, hence losing more than half of its biomass storage volume.

The long-term potential changes consequent upon abstractions from the Omo River for irrigation are considerable.

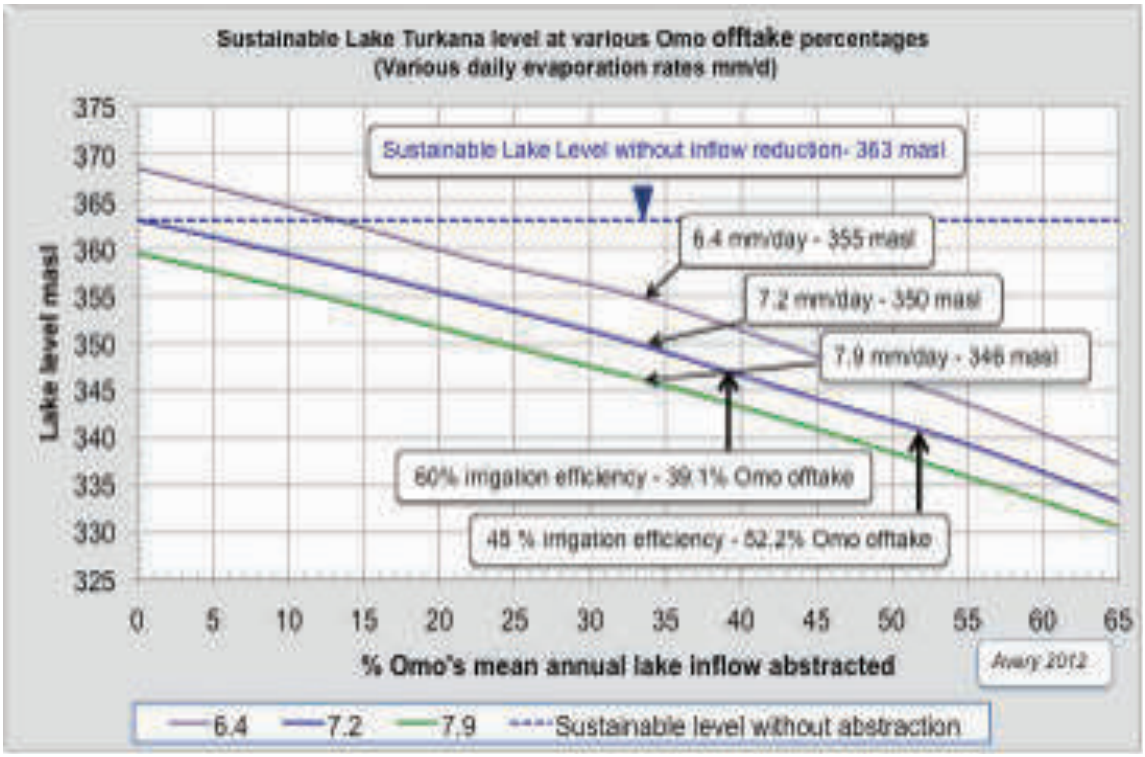


Figure 98: Lake drawdown – Sensitivity of modelled lake level to three different assumed evaporation rates

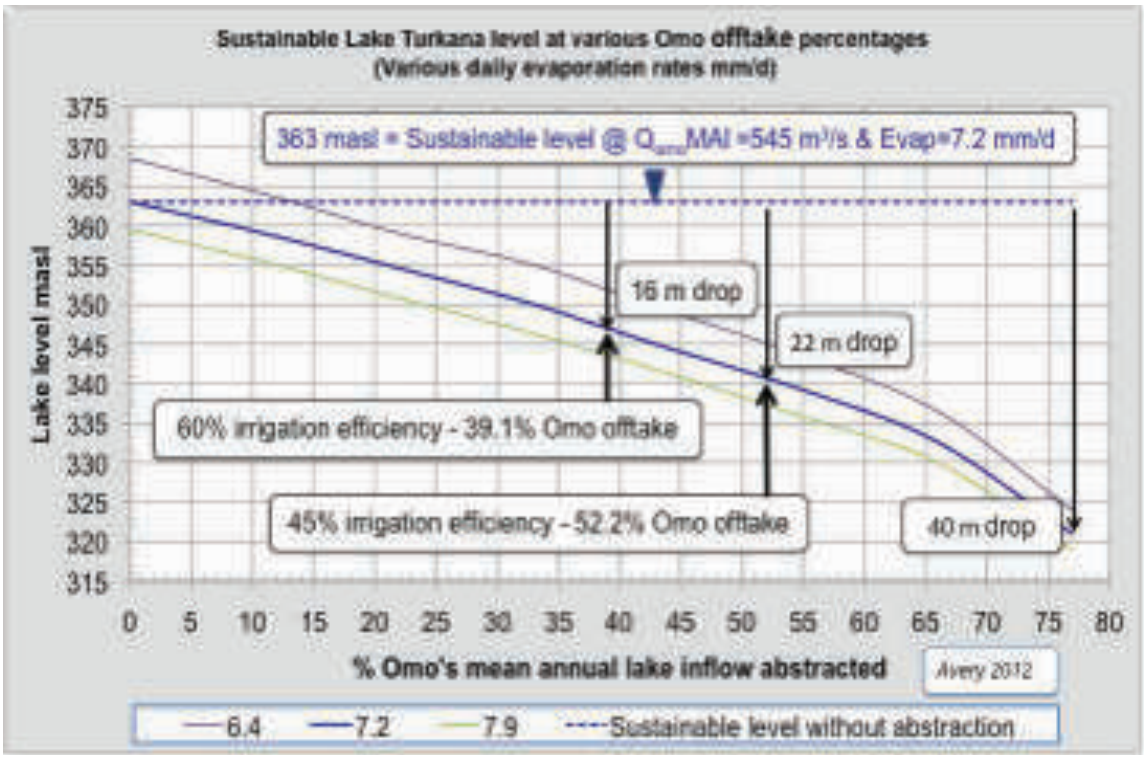


Figure 99: Lake equilibrium level reduction with increased Omo offtake (at 7.2 mm/d evaporation)

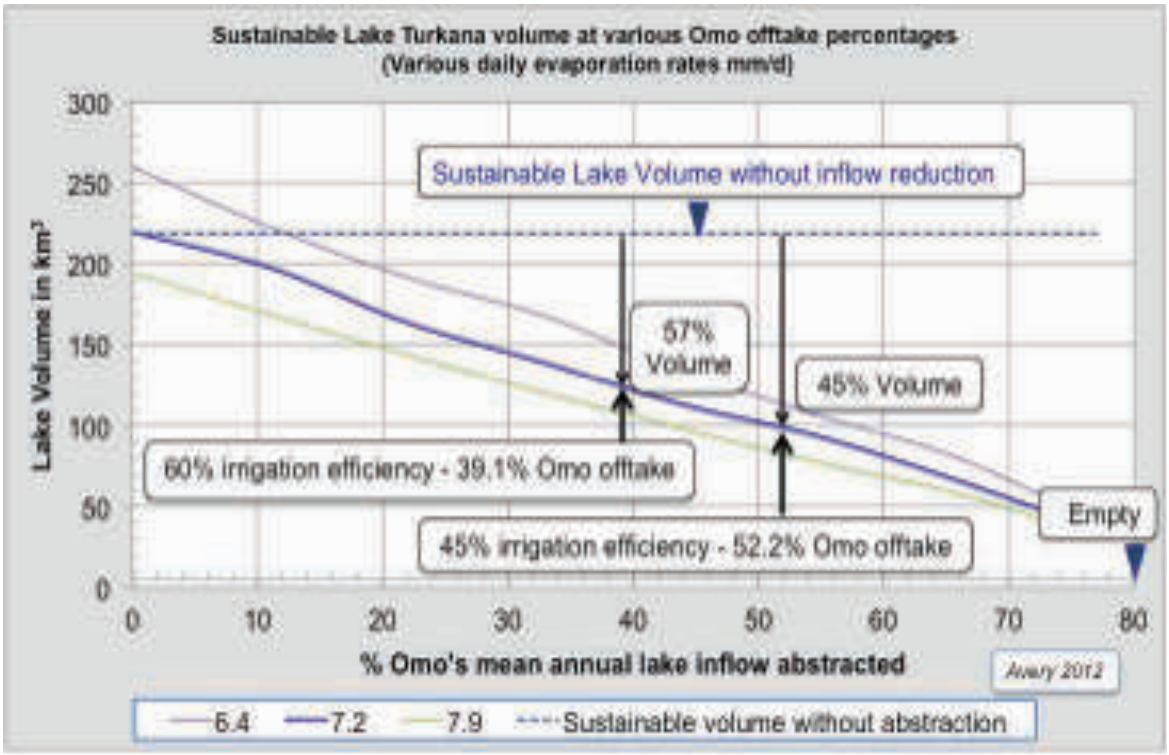


Figure 100: Lake equilibrium volume reduction with increasing Omo offtake (at 7.2 mm/d evaporation)

19 CONCLUSIONS AND RECOMMENDATIONS

19.1 Conclusions

The conclusions of the AFDB studies (Avery, 2010) are reinforced in this study:

1) Lake Turkana is located in a very arid area of northern Kenya, bordering Ethiopia, an area where fresh water resources are precious. This is Kenya's harshest climatic zone. The area has long been marginalised, security is a challenge, with ongoing border skirmishing frequent. Infrastructure is poor, and the area lacks adequate basic social services. People were traditionally nomadic pastoralists, but population has increased, and food aid has provided dietary support for 50 years, with consequent increasing dependance and sedentarisation. The people are amongst Kenya's poorest, over 90% subsisting below the poverty line, and literacy levels are low. The Turkana area is a "hot-spot" for land degradation, with studies suggesting that livestock numbers exceeded the land-holding capacity in the 1990s. As a consequence, livestock numbers suffer periodic crashes.
2) The lake area receives sporadic rainfall averaging an estimated 200 mm/yr at Lodwar, but increasing to the north. The lake's catchment extends into the Ethiopian highlands where rainfall increases an order of magnitude up to 2,000 mm/yr on average in the wettest parts of the middle and upper Omo basin. With the exception of the Omo River and the regulated flow release from Turkwel dam into the Turkwel River, rivers are seasonal, presenting flash floods and no sustained flows.
3) The lake has undergone many stages of climate change. The lake was once 100 metres higher during a more humid climate (approx 7,500 years BP). At that time the lake linked to the Nile's river system. The contemporary lake peaked in 1896, declining 20 metres to historic lows in the 1940s, 1950s and 1988. The lake level today is two to three metres above the historic low levels of the last 60 years.
4) The lake is a closed basin, and the water is gradually but progressively becoming more saline through relentless evaporation, although the process of increasing salinity is slowed down due to chemical processes and deposition that rapidly remove salts, but the rate slows with increasing salinity.
5) The water quality is not suitable for agriculture. The water is not suitable for human consumption either. The lake water is however within potable limits for livestock, apart from the fluoride levels, which exceed allowable limits. Nonetheless, due to the scarcity of water, people and livestock drink the water out of necessity. The excessive fluoride levels are evident from the mottled teeth seen amongst the local people, and also in the incidences of the disease crippling fluorosis. The poor water quality is improved where lake water is diluted by the Omo fresh water inflows in the north of the lake. This effect is seasonal.
6) Apart from some small springs, the only significant perennial fresh water resource reaching the lake is the Omo River, whose catchment is entirely within Ethiopia. Kenya's Kerio / Turkwel Basins contribute less than ten percent to the lake inflows. The Turkwel Dam regulates the Turkwel River, and existing irrigation schemes utilise water. As flows reaching the lake are in any case low, the impact on the lake water balance is insignificant.
7) Although slightly saline, studies published in 1982 reported that the lake has a flourishing varied fish population comprising 48 species known at that time, 10 of which were endemic, 23 of which were important for human utilisation. The fish were not expected to be affected by naturally increasing salinity in this lake, and some of the lake species are known to exist in very much more saline conditions. More recent research has increased the species list in the main lake to 60 species. Research is needed to ascertain the effect of more rapidly induced increasing salinity. A doubling of salt levels would lead to changes in fauna and flora.
8) The fish breeding process is controlled almost entirely by the effects on the lake of seasonal fresh floodwater pulses from the Omo River.

9) The lake experiences massive evaporation at a rate equal to the annual inflow of the Omo River. A basin of water placed on the lakeshore will evaporate 5.9 metres of water in a year. The lake sustainability depends entirely on what happens within the Omo Basin, which provides about 90% of the lake's water inflow.

10) Fishing is a valuable alternative livelihood and food source in this harsh environment. The lake's Omo delta zone, with its soils and fresh water, has sustained a population of agro-pastoralists who also engage in fishing. Fisheries are therefore very important to local people.

11) The Ethiopian Government is developing the water resources of the Omo Basin independently, and with the encouragement of its partners and donors. The impacts of the Omo Basin schemes on Lake Turkana have not been previously been assessed. The AFDB study published in 2010 remains the only work to have assessed the impacts of large-scale abstraction to meet forecast basin demands.

12) Developments within the Omo Basin will impact the fisheries resources of Lake Turkana. The fish resources are known to decline with river inflow reductions and declining lake levels. The fish resources are also known to depend on seasonal flood-plain inundations that result from natural flood inflows. The proposed regulated Omo flows will alter the flood inflow patterns upon which the lake fish depend, and will alter the transport of nutrients. The impacts of the proposed regulated flows have not been fully and scientifically quantified. The fisheries resource of the lake has not been comprehensively updated, apart from some small studies. An update study should look at the present fisheries resource and its utilisation, and impacts on the resource as a consequence of human activities, and should evaluate the effects of prospective changes in the Omo Basin (Avery, 2010).

13) Developments within the Omo Basin, which remove water for consumptive use, especially through irrigation abstraction, will impact the lake through reduced inflows and a reduction in lake levels, and associated with this, there will be a reduction in the water table and water quality. The extent and effects of the reduced flows have not been fully assessed, and they are to a very small extent offset by increasing runoff due to catchment change. Note that irrigation abstraction is not a project component of the Gibe III project, as the dam is developed solely to generate power, but indirectly, the regulated flow sequence from the dam is intended and stated to stimulate downstream irrigation.

14) The filling of the Gibe III reservoir will cause a two-metre drop in Lake Turkana's level. Thereafter, the dam alone will not alter the annual water volume inflow volume, except insofar as losses that occur within the Gibe III reservoir. Hence, as long as reservoir losses are proved minimal, once filled, Gibe III alone will not cause lake levels to fall. The real challenge to lake levels lies with other consumptive use projects within the Omo Basin, namely extensive irrigation development in the Lower Omo in particular, a process which will be stimulated by Gibe III's enhanced regulated low flows (Avery, 2010). If the lake level falls, lake biomass reduces, and the fish population falls (ibid).

15) Reduced levels in the lake due to irrigation abstraction schemes would result in recession of the lake shoreline, and the Omo River would deeply incise below its present delta channel bed levels. The water table would drop, and this would impact existing agricultural practices near the lake. The delta's exposed lands would extend further into Kenya.

16) The Lower Omo irrigation developments have been calculated in this report to require an amount equal to 33.5% of the Omo's annual inflow to the lake. Abstraction of this amount of water will reduce the lake level by 13 metres, which will reduce the lake volume to 59% of its current sustainable volume, which will in turn proportionally reduce the lake biomass and fisheries. Lake water quality will be affected, salinity levels will change, and inflowing water quality is expected to deteriorate. In the event that irrigation water management is inefficient or wasteful, the lake level drop could increase to 22 metres. As the average lake depth is only 30 metres, the potential impacts are considerable.

17) The population in the Omo Basin in Ethiopia was estimated to reach 13.429 million in 2009 (Woodroofe et al, 1996), distributed as follows:

    a. 900,000 people (out of 13,429,000) within South Omo (ibid).

    b. 175,000 (out of 900,000) people were within Lower Omo (Sogreah, 2010) (only 1.3% of the total basin population).

c. 82,000 (out of 175,000) people were estimated to be “directly dependant on the Omo River” (ibid).

18) The 2009 population in the three districts adjoining Lake Turkana in Kenya is:

a. Turkana District: 650,000 people
b. Marsabit District: 160,000 people
c. Samburu District: 210,000 people

Of the above combined population, only about 200,000 people are within census sub-locations abutting Lake Turkana, with 90,000 people estimated within the immediate lakeshore zone.

19) Hence the directly affected populations in the Lower Omo and around the lake amount to about 170,000 people. Note that population is doubling every 20 years. The indirectly affected population, through the inevitable “domino effect”, will be very much larger. Estimates in the literature mention 500,000 people being affected by Gibe III.

19.2 Recommendations

1) The hydrological study presented in the AFDB report has been reviewed, but can be further reviewed to validate the assumptions made on rainfall and evaporation.
2) A river gauging station should be re-established immediately on the Omo River at Omorate as recommended by AFDB and Sogreah in 2010. In addition, a gauging station should be established upstream of the offtake weir that is today feeding the Kuraz project irrigation canals.
3) River abstraction amounts throughout the Omo Basin need to be recorded. This will enable the gauged river flows to be naturalised, in order to monitor hydrological change.
4) Rainfall measurements throughout the Basin should continue, as recommended by the AFDB report in 2010. Evaporation measurements should be taken in the Lower Omo, together with other climate data needed to accurately assess crop water requirements in this hot environment.
5) The lake level gauge at Ferguson’s Gulf has been restored (Pers.Comm., MoWI, Nairobi, 2010). The USDA-FAS satellite radar altimeter readings should continue to be processed and compared with the lake gauge data in order to calibrate / validate the satellite data.
6) The flood patterns of the Omo River need to be studied in terms of flow volumes and durations. The impact of changes due to catchment degradation need to be addressed as the presence of dams can assist by regulating the flashy runoff that results from catchment degradation. This recommendation was made by AFDB in 2010 (Avery, 2010).
7) When available, the plans for Gibe IV and Gibe V dams need to be evaluated, to determine the revised flow sequence that will reach Lake Turkana, including reviewing mitigation plans for the designs.
8) The potential water utilisation within the Basin for irrigation needs to be constantly reviewed, with the impact on Lake Turkana’s levels being monitored.
9) The impacts of the Gibe III, IV and V hydropower schemes, and the irrigation developments, and the impact of a regulated flow sequence, on water quality and nutrient / sediment transport to the lake, need to be assessed, as recommended by AFDB in 2010 (ibid).
10) A scientifically proven and appropriate method of assessing ecological flows in the River Omo needs to be chosen and utilised, and a similar methodology should be derived for the lake, as recommended by AFDB in 2010 (ibid).
11) The status of Lake Turkana’s fisheries resource needs to be updated to determine changes that have taken place since the detailed baseline studies that were done over 30 years

ago, and taking account of research since that time, as recommended by AFDB in 2010. The fisheries resource will have been impacted by catchment degradation over that time, by changes in runoff and sediment runoff patterns, and by population pressure and associated increased fishing, and the effectiveness of fisheries regulation, as well as livestock grazing of littoral zones. A start with a fisheries review was made by the Lake Turkana Research Project (LTRP), launched by KMFRI in 2007 (referenced in the AFDB funded baseline study of Mbogo, dated 2010).

12) The bathymetric survey undertaken by Tullow Oil in 2011/12 needs to be obtained and contrasted with the existing bathymetric map. In particular, the northern sector of the lake should be examined to identify changes that may have taken place in the last 30 years. Revisions to the lake model may be necessary based on this new survey data.

13) The impact on fisheries of all proposed developments in the Omo Basin, in terms of flow and nutrient flow, needs to be studied and mitigation measures identified, as recommended by AFDB in 2010 (ibid). In addition, the effect of agricultural chemical inputs needs to be evaluated.

14) A full evaluation of the economic value of the lake as a "resource" should be produced, as recommended by AFDB in 2010 (ibid). The economic value of the fisheries resource needs to be quantified, so that its destruction / damage can be appropriately compensated.

15) A thorough socio-economic and livelihood evaluation survey of the lake-dependant communities should be undertaken, as recommended by AFDB in 2010. Steps to achieve this have included the useful AFDB funded study of Kaijage & Nyagah (2010). There are also many useful studies done by Oxfam, and others. The "affected" population needs to be properly quantified, both those directly affected, and those indirectly affected.

16) The impact of present proposed and planned developments in the Omo Basin needs to be evaluated, and agreement reached on the way forward for the Basin and the Lake, including agreement on appropriate compensation for affected communities. An integrated basin development ESIA is required, as recommended by AFDB in 2010. UNEP has taken steps to do this, but the process is too slow, and being overtaken by events.

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    b. Volume II (Part 1): The Master Plan
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    d. Volume III: Development zones and areas
    e. Volume IV: Project profiles
    f. Volume V: Pre-feasibility studies
    g. Volume VI: Water Resource Surveys and Inventories (A)
    h. Volume VII: Land Resource Surveys (B)
    i. Volume VIII: Natural Resource Surveys and Inventories (C)
    j. Volume IX: Socio-economic Surveys and Inventories (D)
    k. Volume X: Socio-economic studies (E)
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ANNEXES

See Volume II of this Report.