AFRICAN DEVELOPMENT BANK GROUP

HYDROLOGICAL IMPACTS OF ETHIOPIA'S OMO BASIN ON KENYA'S LAKE TURKANA WATER LEVELS & FISHERIES

FINAL REPORT



Prepared for the African Development Bank, Tunis

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LIST OF ACRONYMS

AFDB	African Development Bank
ADB	Asian Development Bank
ALRMP	Arid Lands Resource Management Project, Kenya
ASAL	Arid and semi-arid lands
ARWG	Africa Resources Working Group
BGS	British Geological Survey
BP	Before Present (Present = 1950)
DFID	Department for International Development, UK (formerly ODA)
EEPCO	Ethiopian Electric Power Company
EA	Environmental Audit
EIA	Environmental Impact Assessment
EIB	European Investment Bank
EPA	Environmental Protection Authority, Ethiopia
ESIA	Environmental and Social Impact Assessment
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
GoE	Government of Ethiopia
GoK	Government of Kenya
IUCN	International Union for Conservation of Nature
JICA	Japan International Cooperation Agency
KMD	Kenya Meteorological Department
KMFRI	Kenya Marine Fisheries Research Institute
KPLC	Kenya Power & Lighting Co. Ltd
KWS	Kenya Wildlife Service
LVFO	Lake Victoria Fisheries Organization
MoA	Ministry of Agriculture, Kenya
MoE	Ministry of Energy, Kenya
MoFD	Ministry of Fisheries Development, Kenya
MoLD&F	Ministry of Livestock Development and Fisheries, Kenya
MoWD	Ministry of Water Development, Kenya
MoWI	Ministry of Water & Irrigation, Kenya
MWR	Ministry of Water Resources, Ethiopia
NASA	National Aeronautics Space Administration, USA
NEMA	National Environmental Management Authority, Kenya
NIVA	Norwegian Institute for Water Research
NMK	National Museums of Kenya
NMSA	National Meteorological Services Agency, Ethiopia
OBMP	Omo Basin Master Plan
ODA	Overseas Development Administration, UK
TLU	Tropical Livestock Unit
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
WDD	Water Development Department, Kenya
WFP	World Food Programme
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 metres
km^2	square kilometres
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

Weight and concentration

g	gram
mg	milligram
kg	kilogram (1 kg = 1,000 gram)
t	metric ton (US) or tonne (1,000 kg)
ppm	part per million (milligram per litre)
mg/L	milligram per litre
meq/L	milli-equivalents per litre
μg/L	microgram per litre

Time

sec	second
min	minute
hr	hour
d	day
mth	month
yr	year

Misc

μS	micro Siemens (electrical conductivity)
^oC	degree Centigrade (temperature)

EXECUTIVE SUMMARY

1. This report was undertaken for the African Development Bank, and presents a thoroughly researched review of all the data previously published in connection with Lake Turkana's hydrology and fisheries.

2. Lake Turkana is located within Kenya's northern arid and semi-arid lands, which comprise 80% of Kenya's land area. The Turkana area borders Uganda, Sudan and Ethiopia. The region's people subsist largely through pastoralism. In recent years, the human and livestock population has increased appreciably, perhaps beyond sustainable limits. The area is prone to frequent droughts during which livestock perish in large numbers. These droughts lead to destitution, and since the 1970s the area has been a regular recipient of humanitarian relief food. Food aid is practically an "institutionalised drought coping mechanism" in the area (Snyder, 2006), and the consequences include exacerbating tension through in-migration of people attracted by the food relief.

3. The northern areas are often reported as "marginalised", with a history of tension caused by colonial border constraints, insecurity and livestock losses through drought and rustling. The Kenya Government has 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).

4. The Lake Turkana catchment area is 130,860 km^2 in both Ethiopia and Kenya. The lake is Africa's fourth largest lake, and the world's largest desert lake. The lake is located in Kenya within an area inhabited by interesting and predominantly pastoralist people.

5. The lake is sustained by the inflows of Ethiopia's Omo River, which alone provides 90% of the lake inflow. 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 runoff volume. Lake Turkana is a closed basin, hence the inflows are totally evaporated over time, and hence the lake waters are almost saline, unfit for consumption, and unsuitable for agriculture. However the lake has a thriving and diverse fish population.

6. Since the 1960s, the Kenya Government has encouraged people living around the lake to diversify livelihoods in order to reduce dependance 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 around the lake. There are challenges to fishermen as the lake experiences fierce winds that create dangerous conditions for boats, and there are reports of conflict with wildlife. The commercialisation of fishing has been hampered by very poor road infrastructure and a lack of fish storage facilities. The fisheries resource has today become an increasingly important alternative livelihood providing a valuable source of protein to people in the Turkana area.

7. Various major studies on the lake fisheries have been undertaken:

   a) 1895-00: The first visits to the Lake with fish records (by Donaldson-Smith).
   b) 1909-15: British Museum Catalogues (Boulenger, 1909-15).
   c) 1930-31: Cambridge University Expedition on East African lakes (Beadle, 1932).
   d) 1930-32: The Omo Expedition (Mission Scientifique de l'Omo, Pellegrin, 1935).
   e) 1972-75: Lake Turkana Project, Overseas Development Administration, UK, with Kenya's Fisheries Department. Lake Turkana was at that time the last of the world's major lakes whose bathymetry had not been measured. A research vessel built in UK was launched in 1971 specifically for the study (Hopson et al, 1982).
   f) 1985-88: 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 (Kallqvist et al, NIVA, 1988).

g) 1987-89: Turkana Fisheries Study – University of Bergen, Norway (Kolding, 1989).

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

The critical dependance of the lake's fisheries on the Omo River fluctuations and nutrient supply were clearly established by the above studies.

8. 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 1988–92, and the project area included the Lake Turkana region (BGS, 1993).

9. The above studies provide a wealth of information on the lake, its chemistry and interesting aquatic ecology, but there is very little on the hydrology of inflowing rivers. Apart from the Omo River, the inflowing rivers are seasonal, typical of arid areas, and difficult to monitor.

10. Studies published in 1982 (Hopson et al) reported that Lake Turkana was inhabited by 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 to be found in rivers extending from West Africa to the Nile. More recent studies increased the number of known species of fish to 60 species.

11. The key environmental factors governing fish in Lake Turkana were previously reported to be (ibid.):

a) Salinity of the water. This lake is one of the most saline in the Rift Valley with abundant and distributed fisheries.

b) The lake's prevailing NW winds control the lake currents, which drift the zooplankton to western shores, and the wind-driven currents sustain the lake in its well-mixed and well-oxygenated condition.

c) The lake's water temperature is stable, with stratification at depth.

d) And, most important, the annual flooding influx of the Omo River, which stimulates fish spawning, and whose effects govern the lake's ecology.

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

12. Naturally occurring increasing water salinity levels are believed not critical. However, any changes to the flood regime of the Omo River will directly impact the breeding of 70% of the lakes "more important" species. The Omo floods inundate areas upstream within the Omo catchment from which nutrients are derived. These inundations replenish wetlands favoured by birds and other creatures. The floods cause the lake to rise and inundate littoral zones. These inundations submerge terrestrial vegetation that provides necessary 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 (ibid.).

13. Twenty-three of the fish species known in 1975 were considered "more important" (ibid.). Of these, 10 species spawn in the Omo River or in major river mouths, 6 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 16 of the lake's "more important" species is dependent on the Omo flood volumes and periods, as well as the cyclical lake rises which inundate the littoral areas of the lake (ibid.). The value of the littoral zone to fisheries is dependant on the levels of stock

grazing of these zones, as the vegetation provides necessary refuge when inundated. 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 a source of nutrients.

14. Lake level was not listed amongst the "key environmental factors" by the 1972 studies edited by Hopson et al (ibid.). At that time, the levels were expected to continue to fluctuate within two to three metres of the levels in 1972, which reflects the natural cycle experienced up to that time. However, if the lake level were to drop 10 metres, this would represent 28% of the lake volume, a large reduction in volume. Any volume reduction reduces the fisheries habitat volume and hence available biomass, and also causes an increase in salinity through concentration of salts. The reduction in lake levels between 1975 and 1988 were reported to have resulted in 70% reduction in open-water pelagic endemic fish (Kolding, 1993), a direct consequence of reduced biomass. On the other hand, lake levels have risen in recent years in response perhaps to increasing runoff associated with human-induced catchment change.

15. When lake levels fall more than 3.1 metres below the 1972 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 "production" measurements in 1988 were reported as being amongst the highest recorded. In recent years, the Gulf has been impacted by sedimentation, and the shore is being invaded by *Prosopis juliflora*, an alien shrub. Hence, the Gulf's current bathymetry is uncertain. The filling of the Gibe III reservoir will drop the lake level by two metres and would render the Gulf dry again. Hence, the importance of Ferguson's Gulf needs to be carefully considered, along with other areas negatively impacted by enforced lake level reductions.

16. 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 riverbank cultivation practices along the Omo River banks would be illegal in Kenya, and 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, to the detriment of the water resources as a whole. Lake Turkana is no exception.

17. The lake 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 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 an increasing trend level, also shared by other regional lakes. The lake level changes are today monitored on a 10-day cycle by satellite.

18. 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). 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, which filled and overflowed into the Nile (this link occurred NW of the contemporary lake through the Lotagipi Swamp in Sudan).

19. In the last 9,500 years, the lake has risen and fallen in response to major climate changes. The sedimentary history shows that the lake was once 80 metres higher than it was in 1972, with a very much larger surface area, with the delta 100 km further north, and with links to the Nile river system. A link last occurred with the Nile between 9,500 and 7,500 years ago (Butzer et al, 1971). Sedimentary records show that during the

Holocene, the lake fell to within 15 metres of today's level 6,200 years ago (Butzer et al, 1971, summarised by Hopson et al, 1982).

20. The contemporary lake today sits about 363 metres above mean sea level. This is below the 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. As stated earlier, the Soudanian fish species found in the lake today originate from former times when the lake was linked to the Nile River. The fish species in Lake Turkana are found across rivers to West Africa, although the lake has endemic species as well, but these are derived from the Soudanian species.

21. In recent history, the contemporary lake peaked in the 1896, as did other regional lakes (Butzer et al, 1971). The lowest level for this "contemporary" period was reached in the 1940s, and again in the 1950s when the lake fell 20 metres below its 1896 peak. A similar low was reached in 1988. The lake today is 17 metres below its 1896 peak, but above its historic low points.

22. Hence the lake has experienced a very wide range of "natural" level fluctuation. It might be concluded from this that further change is acceptable.

23. 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 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 waters are slowed on entering Lake Turkana, and this controls the development of the delta.

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

25. The flood pulses of the Omo river have many positive effects. The floods flush the river, they replenish off-stream depressions and swampy areas; they 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 body of the lake. Flood pulses promote the beneficial interaction of aquatic and terrestrial ecosystems, and peak fisheries production rates are 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).

26. As Lake Turkana is dependant on the Omo River for almost 90% of its inflow, this river is the lake's "umbilical cord". If the Omo River inflow is reduced, the lake level and associated biomass will fall. 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 presents trans-boundary challenges.

27. This study collates all the readily available climatic, hydrological and fisheries data. The purpose was to assess the impact of the Gibe III hydropower reservoir on Lake Turkana's levels, and to identify the consequences. In performing this study, other current developments within the Omo Basin have become evident, and these have impact not only on the lake, but also on the Gibe III proposed river flow mitigation measures. 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.

28. This study has confirmed that Lake Turkana is almost entirely dependant on the Omo River, as stated by previous studies. The Gibe III hydropower project is under construction and this project alone will need an equivalent of over two metres on Lake Turkana in order to fill its large reservoir. Thereafter, the scheme will "process" 67% of the water that 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 be altered according to the power scheme's operating rules.

29. Plus, the regulated flow is expected to stimulate irrigated agriculture downstream of the Gibe III dam to replace traditional rain-fed agriculture (EEPCO, Agriconsulting studies). This is an indirect effect of the dam, which will inevitably cause flows to the lake to diminish. This effect has not been quantified. The dam will create a 200 km^2 reservoir with gross storage 15 km^3, which is roughly the mean annual flow needed to sustain Lake Turkana. 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. The removal of bed load sediments will stimulate erosion of the river downstream. None of these impacts have been quantified.

30. The geological study of the Gibe III reservoir basin was still in progress in 2009 when the draft of this report was submitted (Salini studies). Until the findings are agreed, it will not be possible to conclude debate regarding the losses that might occur due to the high water pressures resulting from the 243 metre high dam, and the potential seepage losses underground, and potential impact on water available downstream. Recent studies suggest that the concerns about underground seepage losses were unfounded (Sogreah, 2010). Concerns had also been expressed about seismic impacts that can result from the huge superimposed load that comprises the stored water volume.

31. An ecological flow and an annual ecological flood release of ten-day duration have been proposed from Gibe III (EEPCO, Agriconsulting studies). Although the "flood-pulse" intention is correct for this lake's flood plain fisheries, the proposals were not supported by any quantified scientific evaluation, and there are many questions arising. For instance, what is the significance of the selected ten-day flood pulse duration? 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? As the "fertility" of the lake is entirely due to the continuity of nutrient inflows, what are the nutrient inflow levels at the moment, and how will they be affected by upstream storage / flow regulation? What assurance is there that the compensation flow releases will be sustained given the conflict of interest with power generation interests?

32. The impacts of Gibe IV and Gibe V have been mentioned in the EEPCO reports, but the mitigation measures thereafter are not addressed. These schemes are under study and are downstream of Gibe III, and are part of a planned cascade of projects on the Omo river that will interfere with the proposed ecological flow releases from 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. 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 (Karenge and Kolding, 1994).

33. The various previous reports do not address the long-term plans for water abstraction within the Omo Basin in terms of the impact on Lake Turkana. This hydrological study has demonstrated that with the potential abstractions that might be implemented, the lake could drop up to 20 metres. This is not attributable to Gibe III, but the data is presented as it reinforces the need for an integrated trans-boundary Basin impact assessment in order to put Gibe III into a proper and correct perspective.

34. The ecological flow proposals for release from Gibe III imply that Lake Turkana's sustainability is important. However, no scientific quantitative studies have actually been presented to decide whether the lake should or should not be sustained, and if so, at

what water level should that be? What is the economic value of the lake to Kenya and the environment? This needs to be evaluated.

35. A World Bank Concept Note has described the importance of development within the Omo Basin, and has stated in regard to Lake Turkana that there is "no significant use of the lake's waters" (World Bank, 2004). The same "Note" considers that it would be relatively easy to obtain a "no objection" from the Kenya Government, and that if there is donor funding involved, Kenya "can benefit from the Project". The Gibe III Project process is consistent with the World Bank Concept Paper proposals. In 2009, the Kenya Government signed a MoU with Ethiopia to buy power from Gibe III, hence the Kenya Government is supportive of the Project, and an inter-governmental environmental monitoring committee was being established. The consequences of the Project cannot be ignored.

36. The Gibe III Project commenced construction without benefit of an environmental and social impact assessment (ARWG). Studies have since been carried out, but within Ethiopia only. Positive impacts on the lake's hydrology have been claimed, but there was no basis for these claims. The challenging trans-boundary issues were clearly anticipated and reported in the 1996 Omo-Gibe Basin Integrated Development Master Plan, but were beyond the scope of that report, and hence were not addressed further at that time.

37. There are concerns that there is past global experience that ecological flow rules may be disregarded / amended to suit other more pressing national needs. 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, as stated earlier.

38. This study has overcome the absence of river flow data for the hydrological assessment of Lake Turkana by computing river discharges from lake level fluctuations. This study has successfully utilised satellite radar altimeter readings of the lake level, which are observed at 10-day intervals. Hence the Consultant has demonstrated a very useful tool for ongoing lake inflow monitoring, and the assumptions should be refined by additional ongoing study.

39. This study confirms the vulnerability of the lake to catchment degradation and especially the proposed water developments within the Omo Basin. If irrigation development proceeds as planned in the Omo Basin, the lake will diminish, as will biomass and fisheries. Whether this is of consequence should be the subject of a separate study and consultations with the Kenya Government and stakeholders, and should be based on a proper economic valuation of Lake Turkana and its resources. The consequences on people that depend on the lake cannot be ignored.

40. 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 that can be expected from Gibe III, also indirect impacts are presented to put Gibe III into a proper perspective. This study thus also looks at the hydrological impacts of the other Omo Basin developments. Although independent of Gibe III, other Basin developments fall within the Basin's development framework, and it is important to assess these impacts and to integrate the mitigation measures. The hydrological assessments in this report can be refined, to validate the assumptions made on rainfall and evaporation.

b) A river gauging station should be re-established immediately on the Omo River at Omorate.

c) The lake level gauge at Ferguson's Gulf should be restored to routine monitoring status, with an immovable permanent reference datum, and measurements should be linked to the satellite monitoring which has been undertaken at 10-day intervals since 1992.

d) 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.

e) The proposed flow sequence from Gibe III needs to be reviewed taking into account river channel transmission losses, and the abstractions arising from the proposed changed agricultural practices being promoted downstream to improve food security.

f) The impact of the downstream proposed Gibe IV and V schemes on the Gibe III ecological flow sequences need to be determined as the Gibe III ecological flows and flood will be intercepted.

g) The potential water utilisation within the Omo Basin needs to be 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.

h) A scientifically proven and appropriate method of assessing ecological flows in the Omo River needs to be chosen and utilised, particularly taking into account the importance of flood plain fisheries in the tropics.

i) The status of Lake Turkana's fisheries resource today needs to be reviewed, as changes will have taken place since the detailed studies were done over 30 years ago. The fisheries resources 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.

j) The full impact of changes within the Omo Basin on fisheries should be evaluated.

k) A full evaluation of the economic value of the lake as a "resource", and its contribution to microclimate, should be produced, and a decision reached on the lake's future.

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

m) An updated integrated basin-wide environmental & social impact assessment is needed.

n) It would sensible for the EIA studies to evaluate the consequence of a dam-break situation, especially as the 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.

1 INTRODUCTION

1.1 Acknowledgements

This report was produced in stages thanks entirely to the African Development Bank, Tunis (AFDB). The Consultant is very grateful for the opportunity to undertake this interesting study, and has valued the interaction with a range of AFDB professional staff, in particular Emmanuel Nzabanita, Noel Kulemeka, Amadou Diallo, and Yogesh Vyas. This study was first reported in draft form in November 2009 (Avery, 2009).

The assistance of staff of the Kenya Marine Fisheries Research Institute (KMFRI) is gratefully acknowledged, through provision of the invaluable ODA funded Hopson Report, and the lake gauge's level data. In particular, thanks are due to Dr William Ojwang. The Kenya Meteorological Department (KMD) is also to be thanked for the efficient delivery of the rainfall data requested.

The Consultant acknowledges the co-operation of Friends of Lake Turkana (FoLT), with whom useful meetings were held, and for their comments on the draft report.

The extremely prompt co-operation extended by the Gibe III dam contractor, Salini, is especially appreciated. Salini have assisted readily with requests for data, and provision of the Master Plan reports was invaluable. Thanks are also extended to UK Consultants Mott McDonald, who kindly assisted where they could with the data acquisition.

In Ethiopia, thanks are due to the Ethiopian Electric Power Company (EEPCO), the Ethiopian Water Resources Authority (EWRA), and the Ethiopian National Meteorological Services Agency (NMSA), for kindly assisting with data extension requests.

In Norway, thanks are due to the Norwegian Water Research Centre (NIVA), who kindly responded to requests for data with a copy of their 1988 Limnological Study, and more recently Jeppe Kolding kindly provided his University of Bergen fisheries project thesis from the same period, and various papers.

In the USA, Dr Birkett of the University of Maryland (UMD) kindly assisted with queries relating to the invaluable radar satellite altimeter lake level measurements. The USDA-FAS website is gratefully acknowledged for provision of current lake level data through satellite radar altimetry.

The Consultant acknowledges the professional support provided through the various East African consultants engaged by AFDB in the follow-up to the 2009 Draft Report, namely Ms Anna Stella Kaijage and Ms Niceta Nyagah from Tanzania, and Messrs Ngece, Mbogo and Maina from Kenya, and Ms Elizabeth Ndinya, also from Kenya.

1.2 Introduction to this report and the further studies undertaken

This report presents Lake Turkana's baseline including fisheries, and presents an assessment of the climatic and hydrological characteristics of the lake based on available data. It also includes a modelling exercise to extend records of water inflow to the lake. The purpose of this report was specifically to provide AFDB with an assessment of the potential impact on Lake Turkana's water levels arising from the construction and operation of the Gibe III hydroelectric power project in Ethiopia.

This report has thoroughly reviewed the literature on all aspects of the lake that are related to hydrology. A key aspect is the lake's fisheries resource, and the inter-dependance of fisheries on the lake's hydrology, which have been thoroughly researched. This report has also considered the impacts in the broader context of development within the Omo Basin, as the Gibe III project is not an isolated development affecting Lake Turkana, and the various developments proposed downstream will interfere with and possibly invalidate the proposed mitigation measures for Gibe III. In addition, irrigation development within the Omo Basin is reviewed with regard to potential reductions in the Omo River flows, and the impacts of developments in the Omo Basin on the lake's hydrology have been forecast.

The terms of reference, as agreed with AFDB, were based on data available to the Consultant in June 2009, and are attached in Annex 4. The Draft Report was submitted in November 2009 (Avery, 2009).

In parallel with this study, AFDB commissioned a socio-economic study of the Lake Turkana area, which also undertook consultations in selected villages on the western side of the lake (Kaijage and Nyagah, 2009).

In a follow-up to the above two studies in 2009, AFDB commissioned supplementary studies during 2010 arising out of the above original two studies. These supplementary reports sought to extend the previous studies to address baseline conditions in Turkana within Kenya, with the aim of contributing to an Environmental and Social Impact Assessment (ESIA) of the effects of Gibe III dam on Lake Turkana. These supplementary studies included:

- Socio-economic analysis and public consultation of Lake Turkana communities (Kaijage and Nyagah, 2009). The work was done 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).
- Fisheries and limnology (Mbogo, 2010). This report reviewed studies done locally since 1988, and the report included more recent fish catch statistics, which are also discussed in this Final Report.
- Physical and biophysical environment (Ngece, 2010*)*. This study included satellite image interpretation to assess changes in vegetation in recent years around Lake Turkana. Key findings are included in this Final Report.
- Irrigation within the Turkana basin (Maina, 2010*)*. This study summarised Government irrigation statistics within the Kerio and Turkwel basins, which are summarised in this Final Report.

The geographical location of the Gibe III project within Ethiopia is shown in the figure below. Note that Lake Turkana is located to the south-west of the map, within Kenya, but with its northern shore on the international border.

Figure 1: Ethiopia and the Gibe III Catchment
Reproduced from Salini & SP Report 500 HYD RSP 001A, Jan 2009

1.3 Gibe III Hydro Project – Objections to the Project

The Ethiopian Government's Gibe III Hydro Power Project has been under construction on the Omo River in Ethiopia since 2006. It is the third in a cascade of hydro projects along the Omo River, and fourth and fifth projects further downstream (Gibe IV and V) are being studied.

The following is extracted from an EEPCO Report (Salini 300 POW R SP001 B, 2008):

The complete development of the Omo River hydropower schemes includes the following hydro power plants (see Figure 2):

- Gibe I upstream of Gibe III - operating
- Gibe II upstream of Gibe II - under repair due to tunnel collapse
- Gibe III - under construction since 2006
- Gojeb and Halele / Werabesa - foreseen upstream
- Gibe IV and V - foreseen downstream

The Gibe III dam will be 243 metres high, and the hydropower station will generate 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).

Hence the Omo Basin has already undergone 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.

There has been criticism voiced in the international media that an EIA had not been submitted for Gibe III prior to commencing construction. Subsequent studies were done, but there has been criticism about the quality of the EIA studies undertaken for Gibe III, and it has been suggested that the new dam will have catastrophic effects downstream, which have not properly been considered.

For example, the key issues targeted in a report available on the international media, are as follows (ARWG):

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

"…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…"

(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..."

"…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)..."

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

(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…"

(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…"

The terms of reference in the Appendix were prepared in order to determine the impacts of the Gibe III Project on Lake Turkana's water levels, and the possible consequences. The African Development Bank (AFDB) requested this study, because there was no substantiating data submitted in any of the reports with which to check the claims that the lake levels will decline.

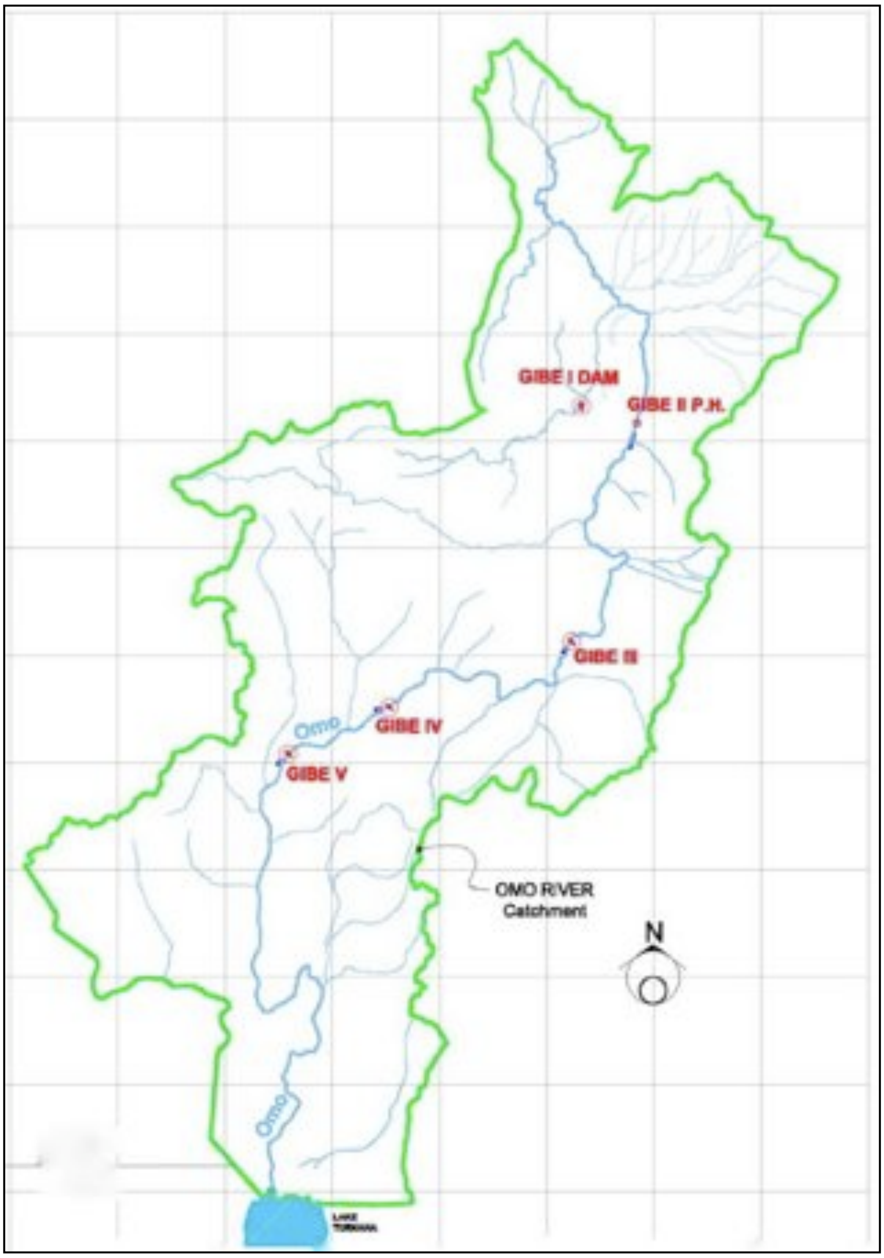


Figure 2: Planned cascade of Gibe hydropower schemes along the Omo River

(Source: CESI (2009). Note that Gojeb and Halele / Werabesa Hydropower schemes are not shown. They are located upstream of Gibe III).

1.4 The Omo Basin and irrigation – "An early candidate for development"

The Omo Basin is seen as an "early candidate for development" in regard to irrigation potential, for the following reasons reported in a World Bank Concept Note available on the internet (World Bank, 2004 - extracts are quoted verbatim from the document):

- "…Ethiopia is poor with an increasing population, with over 80% of the country's population 'mired in a declining subsistence agriculture economy'…"
- "…The basic problem is that irrigation is an extremely rare and neglected sector..."
- "…The Ethiopian 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. Due to the high soil losses, many areas have been rendered useless for farming and this could lead to a collapse of farming systems..."
- "…From several perspectives, it is stated that 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..."
- "…The Omo Basin has an irrigation potential of 348,000 ha and could be an early candidate for development because there is no significant use of the Omo River by any other country and the river enters Lake Turkana within the boundaries of Ethiopia, and 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 dam/dams on the Omo, Kenya could also benefit from it…"

The Omo-Gibe Basin carries 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 carries larger flows. Hence the Omo Basin is a very significant resource within Ethiopia.

Hence it is not surprising that the Omo Basin is perceived to be "an early candidate for development". Water is without doubt one of Ethiopia's key resources. The country is the main water tower for the River Nile, and development of the water resources is an inevitable response to the country's needs.

1.5 Omo-Gibe River Basin Integrated Development Master Plan Study, December 1996 – potential irrigation areas

In 1990, a desk study identified 445,320 ha of prospective irrigation area within the Omo-Gibe River Basin (WAPCOS, 1990). This is similar to the areas quoted in World Bank and FAO documents. For instance, FAO identified an annual water requirement for irrigation of 4.01 km^3 out of an annual runoff on the Omo-Gibe Basin of 16.10 km^3. This irrigation requirement would account for 25% of the Basin's annual runoff (FAO, 1997, Table 31).

The water demand projections of the Omo-Gibe Basin Integrated Development Master Plan Study (the Master Plan) are re-presented in Table 2 (after Woodroofe et al, 1996). Irrigation forms by far the major component within the estimated water demand. The Master Plan narrowed down the WAPCOS 445,320 ha to a shortlist of 74,300 ha. Recent communication between AFDB and MWR (Ministry of Water Resources) gives the area to be in the region of

100,000 ha (Pers.Comm AFDB / MWR, 2009). The MWR figure is possibly the source of the figure of 99,716 ha "Land suitability for irrigated agriculture" listed by a recent review (Sogreah 2010, Table 7).

Sogreah conclude after review with "remedial measures", that out of the above 99,716 ha, 5,000 ha is "highly suitable", 60,000 is "moderately suitable", and 14,000 ha is "marginally suitable". Sogreah's revised total "suitable" area is therefore 79,000 ha (Sogreah, 2010).

The recent CESI study for the Gibe III Project (CESI, 2009) presented the irrigation area information in Table 1 derived from "respective Wereda Agricultural and Rural Development Offices". The potential area reported is 153,000 ha (10,100 + 142,900), which is double the figures given in the Master Plan, and double the Sogreah figures above. Hence, according to the CESI study, the potential water demand from irrigation assessed today might be double the figure presented in the 1996 Master Plan. There is need to reconcile the various figures.

The potential Year-2024 Basin water demand assessed by Woodroofe et al in the Master Plan (Table 2) amounts to 16% of the Omo Basin runoff calculated later in this report (see Figure 56).

The irrigation benefit arising from the Gibe III Project alone has been assessed to require only 0.4% of the Omo Basin annual runoff (based on 80 MCM/annum from 9,500 ha - Sogreah Review, 2010). Another recent assessment is 1.4% of the Omo Basin annual runoff (7,300 ha @ 2 L/sec/ha/12hrs = 14.6 m^3/sec for 12 hrs/day = 230 MCM/annum (Maina, 2010). These Gibe III consequent irrigation amounts are negligible. It will be other major irrigation project prospects within the Omo Basin that have the potential to reduce inflows into Lake Turkana.

Table 1: Irrigation schemes in the Omo Basin
(Source: CESI SpA et al, Table 5.47, 300 ENV R CS 002C, 2009)

Small scale irrigation schemes		Large scale irrigation schemes	
Existing ha	Potential Ha	Existing Ha	Potential ha
667	10,100	-	142,900

Table 2: Water demand in the Omo Basin (million cubic metres per annum)
(*Source: Woodroofe et al, Vol XI, F1, 1996)*

Year	Domestic MCM/yr	Commercial & Industrial MCM/yr	Livestock MCM/yr	Small-scale irrigation MCM/yr	Medium-scale irrigation MCM/yr	Total 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	3,523	5,341

Notes:
1. Woodroofe et al assumed 1.5 L/s/ha for irrigation purposes
2. 2024 Total = 16% of annual Omo River discharge (see Figure 56*)*

1.6 Omo-Gibe River Basin Integrated Development Master Plan Study, December 1996 – the impacts on Lake Turkana

It is pertinent to refer to the following extracts from the 1996 "Master Plan":

- "…The main potential use of the basin's resource is for the irrigation..." (Woodroofe et al, Vol XI, 83).
- "…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, 84)".
- "…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).
- "…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…" (ibid., Vol XI, 85).

The average annual inflow to Lake Turkana was assessed in the 1996 Master Plan to be 526 m^3/sec = 16.6 km^3/annum (ibid, Vol VI, A1, C35 – see later in this report). Hence the potential irrigation developments identified in the Master Plan in 1996 would remove 16% of the lake's Omo River inflow. If the latest potential irrigation areas are correct (Table 1 above), then 16% might be an under-estimate.

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.

The cascade of current planned projects in the Omo Basin was illustrated earlier in Figure 2. Gibe I and II are operating/built, Gibe III is under construction, and Gibe IV and V are under study, and irrigation development is also being planned.

1.7 Lake Turkana – Background Information

1.7.1 Lake Turkana's protected areas

Within the lake, there are three volcanic islands respectively named North, Central and South Island. 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 ha 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 wild game animals, birdlife and reptiles characteristic of these northern arid lands (KWS*)*. This is the only archaeological conservation area in Kenya that has been gazetted as a National Park (ibid.) Section 2.2 provides more details.

- 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 ha 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, 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 ha National Park was established. With its three volcanic crater lakes, this Park protects a prime breeding area for the Nile Crocodile (UNEP/UNESCO/IUCN, 2005).

- 1983/85: South Island's 3,900 ha 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 waterbirds, 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", providing habitat and a corridor for migration. The threats to the protected areas described above are consistent with the Consultant's long experience of the area.

1.7.2 Lake Turkana - background

Lake Turkana (the lake) is 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, to an ever-increasing degree with increasing population.

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 arid region. There is no cultivation along the lake except within the Omo delta to the north. Further from the lake, there is cultivation on the top of the nearby extinct volcano (Mt Kulal, south-east of the lake), and also within the Horr Valley to the south, and along the Turkwel and Kerio river courses south-west of the lake.

80 - 90% of the lake surface water inflow derives from the Omo River in Ethiopia. Hence the lake is almost solely dependant on this one river basin, and any developments within this basin will 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 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. Some development is anticipated, for instance a wind energy generating farm between the Horr Valley and the lake, which will require new roads, but few opportunities for local people will arise.

In recent years, population dynamics have changed. Population has increased and the Turkana area receives food aid, both sides of the international border, a situation, which 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, and undermines self-sufficiency and the sustainability of traditional skills. Hence the area has many challenges already, and it is important to separate these from the impacts arising from other developments in the 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.

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

Key hydrological characteristics for Lake Turkana as regards Gibe III are as follows:

- 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. The Gibe III fill volume is almost 7% of the volume of water presently stored in Lake Turkana, which is significant.

If as has been claimed, there is 50-75% 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).

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 are improbable and have not been substantiated.

The ESIA study (EEPCO, Agriconsulting S.p.A, 2009 et al) gives monthly discharge graphs for the "before" and "after" Gibe III scenarios – see Figure 3. 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 (higher low flows and lower high flows), whilst the annual volume is reported to be much the same. About 67% of the lake inflow will be controlled by discharges from Gibe III.

In response to adverse media publicity, EEPCO has issued the proposed mitigation measures reproduced in the Annexes (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…"

Amongst the various benefits listed, EEPCO stated that "…there will be "sustainable flow and positive hydrological balance to Lake Turkana…"

This Final Report will try to address the hydrological concerns raised, and the accuracy of information.

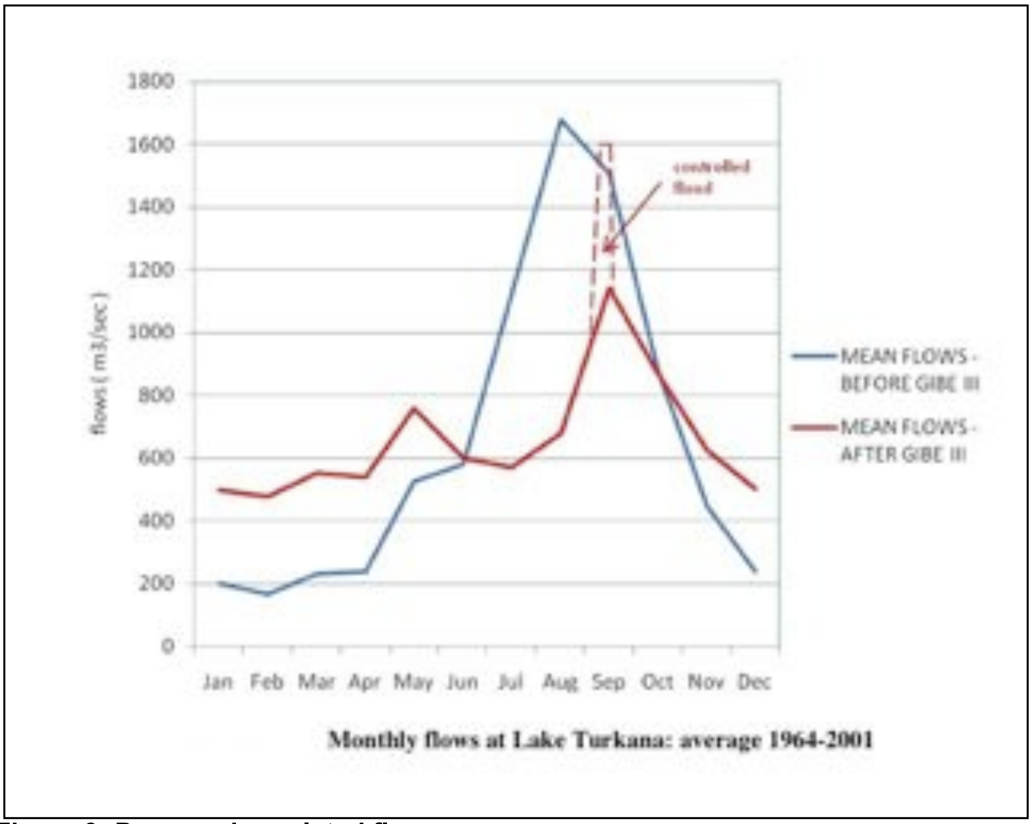


Figure 3: Proposed regulated flow sequence
(Source: EEPCO, Agriconsulting et al, 2009)

2 LAKE TURKANA

2.1 Lake Turkana

Lake Turkana, formerly named Lake Rudolf, is the largest lake in the eastern portion of the Rift Valley. In response to the Government's measures to develop commercial fisheries, the lake was studied extensively between 1972-75 by the UK's Overseas Development Administration and Kenya's Fisheries Department. That study completed the bathymetric and biological surveying of the world's great lakes, and the comprehensive documentation produced is an essential reference today (Hopson et al, 1982).

A 3-dimensional satellite image is reproduced in Figure 4, 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.

The Route Map for the Lake Turkana area is reproduced in Figure 6 (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 Loyangalani, 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.

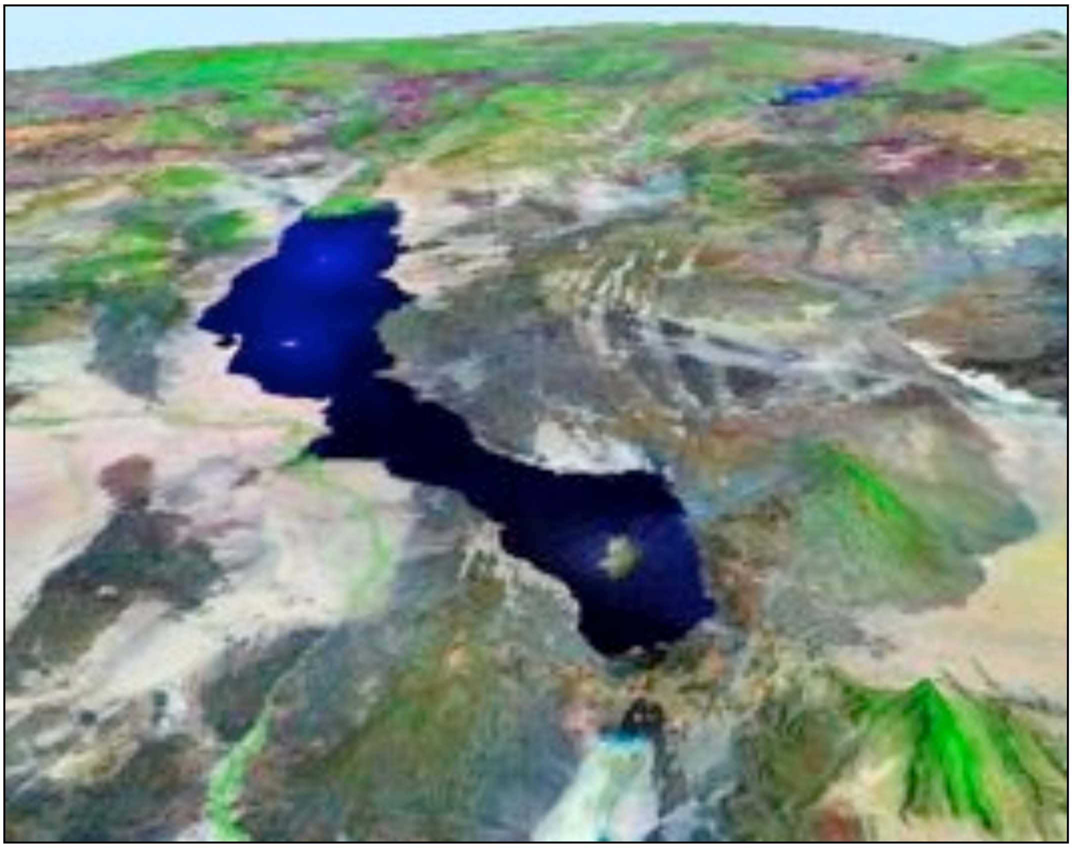


Figure 4: 3-D Satellite Image of Lake Turkana
(Source: USDA-FAS website)

2.2 Lake Turkana since 5 million years ago

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 fossil are included below*:*

Fossil beds at Sibiloi National Park

Fossil at Sibiloi National Park

Petrified logs at Allia Bay

Sibiloi NP – Karsa Gate

Photo 1: Sibiloi National Park
(Source: Sean Avery Photo Archive)

The lake's "palaeo" history can be charted as follows:

- 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 12.

- 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 – see Figure 5 (reproduced from EEPCO, Agriconsulting S.p.A & Mid-Day International, 2009). "…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 80m 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 +55m.
- 3,250 BP: A third "transgression" occurred in the late Holocene, with high lake level +35 to +40m. This was the last time that the lake was connected to the Nile system (Wilkinson, 1988).

"…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 80m above 1988 lake levels, provide strong evidence of hydrographic connection (ibid.). It is believed that the Lake Turkana / Nile connection was established on a number of occasions during the late Tertiary / Quaternary (Wilkinson, 1988), and that connections are 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 is more likely to have been when the lake was higher (+80m), between 9,500 and 7,500 years BP (Wilkinson, 1988, citing Butzer et al 1971). A rise of 70m 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 via the Lotagipi Swamp, and the size of the lake 10,000 years ago is shown as "Mega-Turkana" in Figure 7. The lake surface area was 5 times what it is today, and the Omo delta was 100 km to the north.

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).

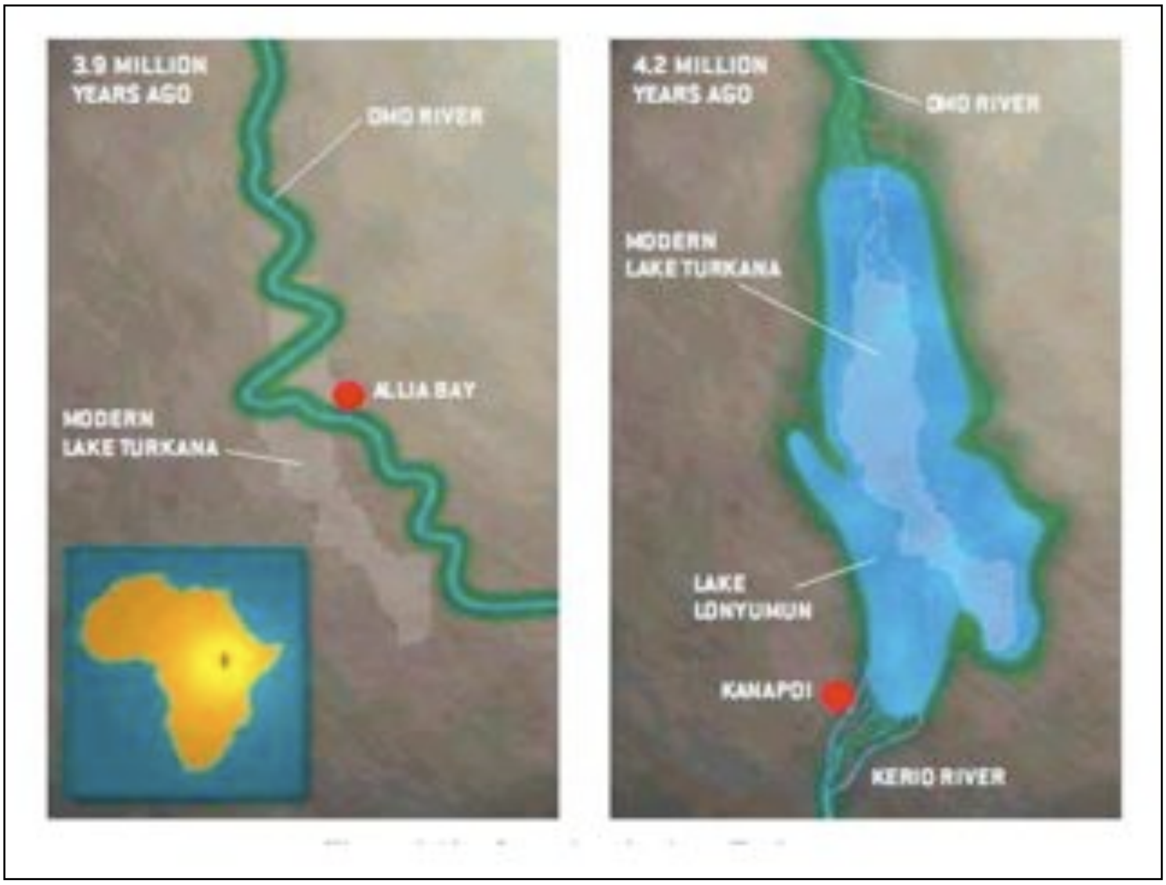


Figure 5: Turkana millions of years ago
(Source: Agriconsulting S.p.A & Mid-Day International, 2009)

Figure 6: Lake Turkana
(Source: Survey of Kenya 1:1,000,000 Route Map dated 1978)

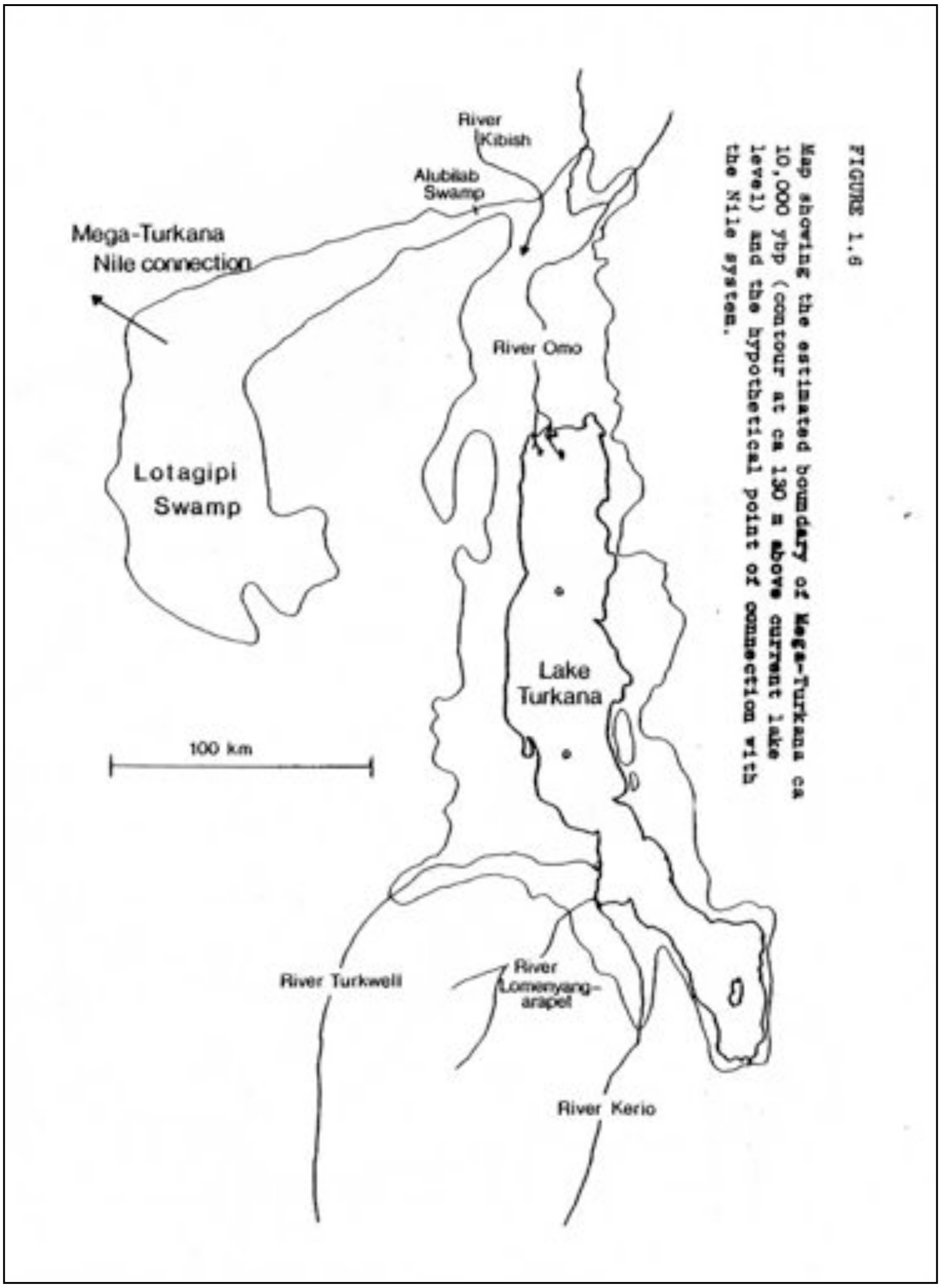


Figure 7: "Mega-Turkana"
(Source: Hopson et al, 1982)

2.3 Lake Turkana's demography

A detailed report on the sociology of the project area commissioned by AFDB is the subject of a separate report (Kaijage & Nyagah, 2010). Consultations were also conducted in various villages, and the socio-economic profile was described (ibid). A separate general profile is presented below, derived from various data sources not necessarily cited in the Kaijage & Nyagah study.

Population has grown in Kenya from 2.5 million people in the 1930s, to 39 million people today. The results of the recent national census had not yet been released when this report was drafted.

Lake Turkana formerly fell within the Turkana, Samburu and Marsabit administrative Districts of Kenya, with borders shown in Figure 11. 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 in other reports commissioned by AFDB for this project - 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 – see Figure 11.

Population statistics have been assembled in Table 3 below. For a harsh environment such as Lake Turkana, the population increases are challenging. For Turkana District, the increase is four-fold in 40 years. Population growth rates of 3.3% per annum have been used for Turkana, which means that population would double in 20 years (Watson et al). 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 lands alone occupy 56% of Kenya, and host 8% of the country's population (ibid). Hence the ASAL areas are significant in terms of national planning and responsibility.

Table 3: 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)	127,000 (3)
2006	469,713 (4)		
2009	652,455 (2)	205,774 (2)	159,059 (2)

Sources:
(1) PriceWaterhouseCoopers, 2005; (2) Vision 2030, GoK, 2009; (3) Snyder, 2006; (4) Watson & van Binsbergen, 2008; (5) Rutten (1988).

Figure 8 and Figure 9 present traditional generalised ethnic groupings in East Africa and the Horn of Africa. The peoples of Northern Kenya are Nilotic and Cushitic. 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 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 (El Molo, Dassenech and Gabbra occupying the area east of the lake, shown on the map as "Galla" and "Somali").

Figure 10 illustrates the distribution of culturally very 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 Porr and Moite.

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 Turkwell Rvers, and fishing on Lake Turkana. The Samburu are Maa-speaking pastoralists. The livestock principally include cattle, sheep, goats and donkeys.

The Cushitic peoples include the Dassenech and El Molo, traditional "hunter gatherers" who fish the eastern and north-eastern shores of the lake up to the Omo delta. The Dassenech are also called Shangila, Merille and Galeba, and live in the Omo delta, extending south into the Ileret area of Kenya. They also cultivate. The El Molo is a remnant community living on El Molo Bay north of Loyangalani, and is the only traditional fishing community on Lake Turkana. 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 (Kaijagi and Nyagah, 2010).

Provision of social services in the area is challenging due to lack of investment, poor infrastructure and the mobility of pastoral communities, and most such services are found on the western side of the lake (Kaijage & Nyagah, 2010). The average distance to a health facility in Northern Kenya is 52 km, compared to the "national norm" of 5 km (ibid). 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 Government's "Vision 2030" recognises "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). Hence the Government formed a separate Ministry of State for Northern Kenya within the Office of the President.

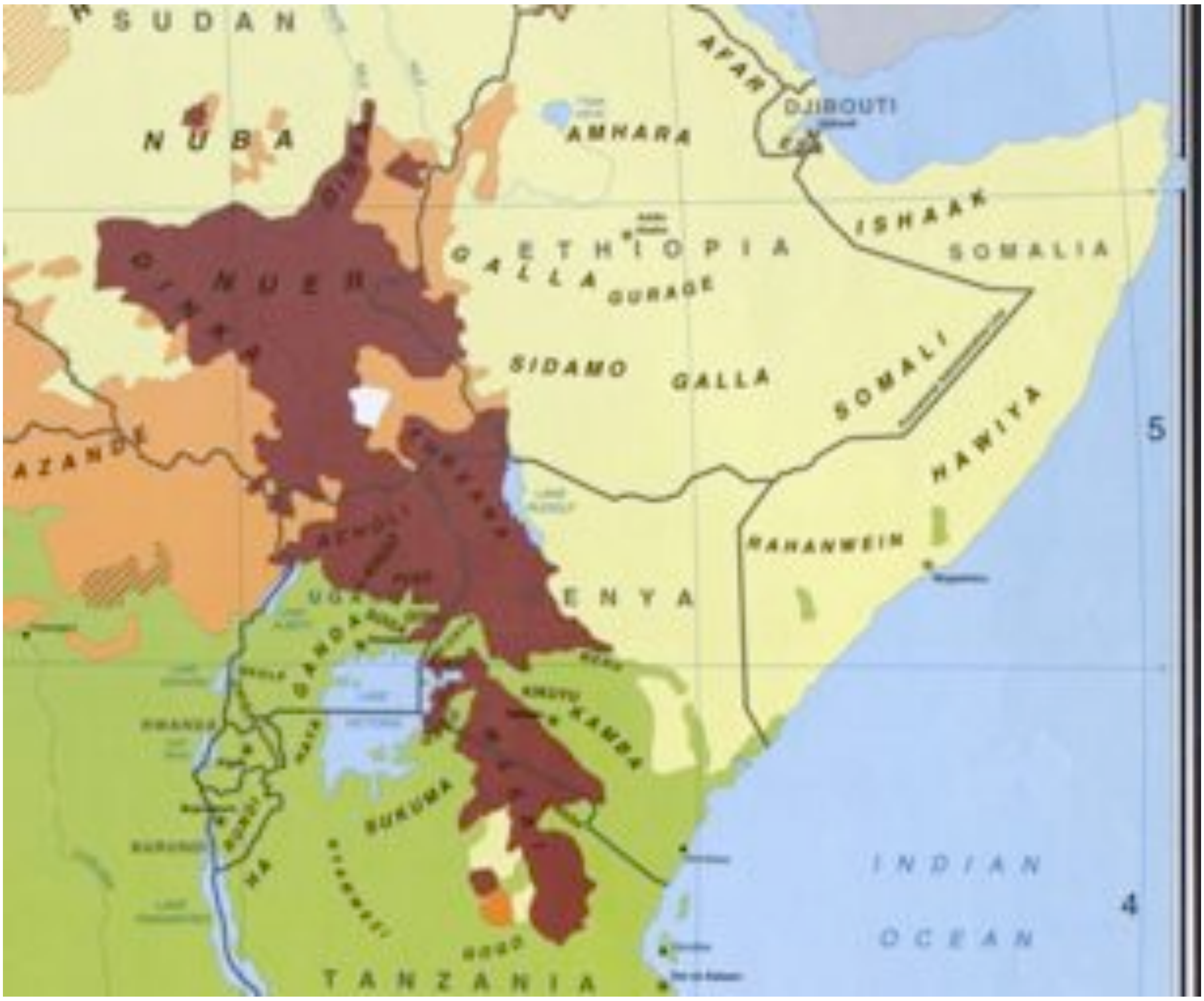


Figure 8: Ethnic groups in the Horn of Africa
(*Source: Central Intelligence Agency, USA, 1974)*

Figure 9: Ethnic groups within Kenya
(*Source: Central Intelligence Agency, USA)*

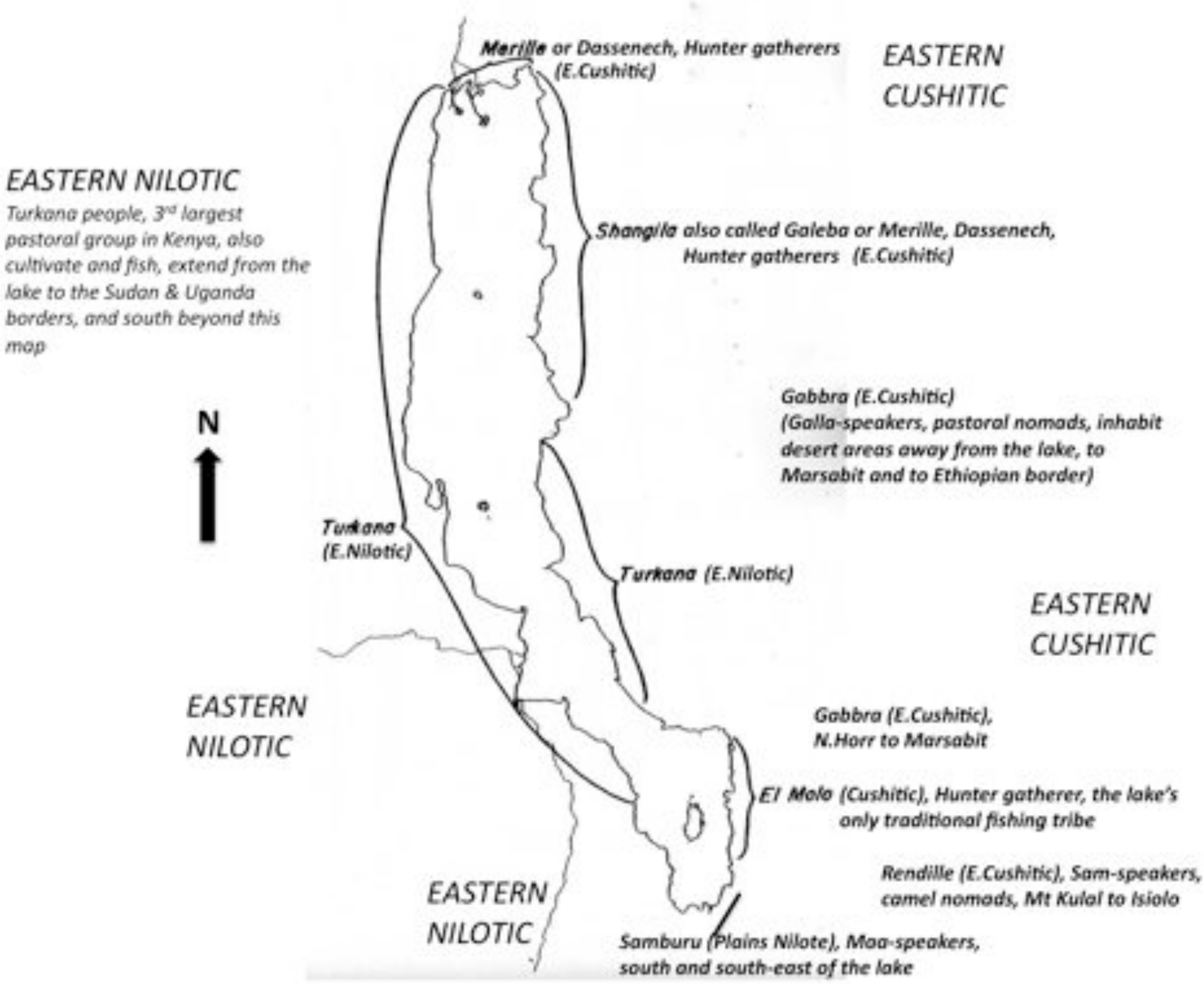


Figure 10: Tribal distribution around Lake Turkana's shores
(*Source of lake base map with shoreline tribal distribution - Hopson et al, 1982 (modified)*
Source of linguistic groups (Nilotic and Eastern Cushitic) - Feddes & Salvadori, 1979)

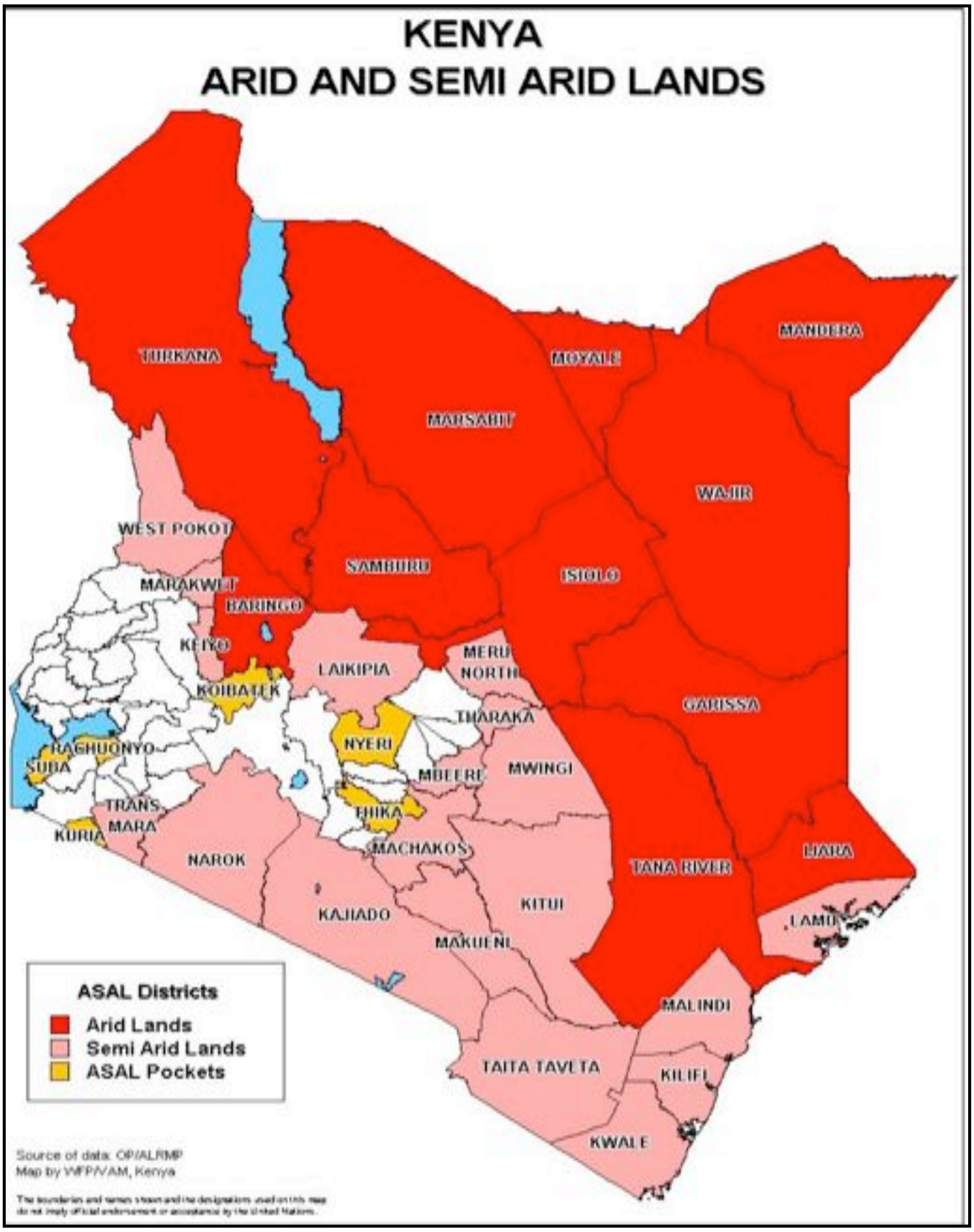


Figure 11: Kenya's arid and semi-arid lands (ASAL) demarcated

(Source: 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))

2.4 Bio-physical environment

The information on the lake's bio-physical environment was previously presented in the Draft Report (Avery, 2009), and has been updated. Similar information is presented in other reports that can be referred to separately (Ngece, Maina, Mbogo, Kaijage & Nyagah, all 2010).

2.4.1 Agro-climate and temperature

Lake Turkana falls within the 80% of Kenya made up of "arid" and "semi-arid" lands (ASAL) demarcated in Figure 11. Of these ASAL areas, 70% are arid zones affecting 56% of Kenya (GoK Vision 2030).

Turkana is within Agro-climatic Zone Zone VII-1, the most severe combination of moisture and temperature classifications in Kenya, with the characteristics listed in Table 4 (Sombroek et al, Kenya Soil Survey):

Table 4: Agro-climatic and temperature zones

Moisture Availability Zone:

• *Classification:*	Very arid
• *Average annual rainfall:*	150 - 350mm
• *Average annual potential evaporation:*	2100 - 2500mm
• *Vegetation:*	Desert scrub
• *Potential for plant growth:*	Very low
• *Risk of failure of an adapted maize crop*	95 – 100%

Temperature Zone:

• *Mean annual temperature:*	24 - 30^{O}C
• *Classification:*	Fairly hot to very hot
• *Mean maximum temperature:*	30 - 36^{O}C
• *Mean minimum temperature:*	18 - 24^{O}C
• *Absolute minimum temperature:*	10 - 16 ^{O}C

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).

2.4.2 Flora

The Lake Turkana area is sparsely vegetated with characteristic bush and scrub, and scattered stunted trees. Sandy / bouldery luggas drain the higher ground, 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). More recent studies talk of 30% of Kenya's forests and 10% of Kenya's grasslands being subject to degradation (Muchena, 2008).

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

As an extension of this study, the flora of the area was described, and changes in vegetation cover were mapped from satellite imagery between 1973 and 2008 (Ngece, 2010). Five zones were selected – see Figure 57 in Annex 1. The imagery was used to differentiate areas covered with lake water, swamps, woodland, bush and grasslands. The study shows 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. The desolate southern end of the lake, where there are no settlements, shows very little change, which is also anticipated. There is even supposedly an "increase" in woodland in this southern area.

It is of interest to note the appearance within the Turkwel / Kerio irrigated areas of the invasive alien tree *Prosopis juliflora*, some time between 2001 and 2008. *P. 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 (ibid). 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….

Commercialising *Prosopis juliflora* is however reported 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 *P.Julifora* seeds!

2.4.3 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 hosts 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, topi, greater kudu, hippo, lion, cheetah, leopard, striped hyaena, silver-backed jackal, crocodile, and more than 350 species of birds. The Tourist Map list is incomplete, as other species have been seen, for instance wildcat and baboon (the Consultant's visit in July 2010). Due to conflicts with increasing numbers of pastoralists, the wildlife population has diminished outside national parks, reserves and conservation areas, and bush-meat poaching and livestock encroachment threaten populations within the parks as well. 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 and supported through Kenya's Northern Rangelands Trust.

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 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 1.7.1.

The arid lands host a remarkable diversity of interesting birdlife, and the Omo delta and its 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 Loyangalani* *North-eastern shore near Allia Bay*

Photo 2: Shores of Lake Turkana
(Source: Sean Avery Photo Archive)

2.4.4 Domestic livestock

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 mainly by livestock. 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 5. 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 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 45.

Table 5: 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 6 below compares livestock numbers in Turkana District with estimates of land carrying capacity of the rangelands. It has been concluded that the sum of all livestock numbers exceeded the "carrying capacity" of the rangelands in the early 1900s, and that that Turkana "today" (in 2008) "must be heavily over-stocked (Watson & van Binsbergen, 2008)". This is consistent with the remote sensing observation that the 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, 86% of which own livestock (ibid. p8). A similar detailed study of livestock challenges was not found for Marsabit and Samburu Districts, which also border the lake, but the patterns of change are likely to be similar. In the 20-year period 1982-2003, the livestock population increased three-fold. The challenges in regard to competition for available forage are clear, and increasing human population is reducing the opportunities for mobility. The livestock crash during the 2009 drought will have reversed the trend, perhaps temporarily. In some parts of Kenya, 80 to 90% of livestock perished.

Table 6: Livestock population in Turkana District

	Shoats (No of animals)	Cattle (No of animals)	Camels (No of animals)
1982 (1)	1,065,920	103,290	82,780
1993 (2)	1,267,880	153,550	63,153
2003 (2)	2,926,800	193,600	140,760
Holding capacity (3)	2,439,003	146,898	79,801

Sources of statistics:

(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).

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

Table 7 below includes comparable livestock data for Marsabit District (Marsabit District extends from the eastern shore of the lake). The year 2003 was chosen for convenience 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.

Samburu District to the south of the lake is also relevant to any study of the project area, as it includes the southern lake shore. This smaller 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 2009 drought. Whilst cattle numbers halved, over the same period the hardier shoats and camels remained numerically much the same.

Table 7: Livestock population in Marsabit District compared with other Districts

	Area (km^2)	Shoats (No. of animals)	Cattle (No. of animals)	Camels (No. of animals)
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)

Sources:

(3) Maina, 2007; (4) Table 6 *above;*

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

2.4.5 Geology and physiography

Lake Turkana was formed within the Kenya Rift, an integral part of the East African Rift System extending over 3,000 km from the Red Sea and Gulf of Aden, through Ethiopia, Kenya and Tanzania, to Southern Mozambique – see Figure 12 (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, followed by Lake Bogoria, Lake Nakuru, Lake Elementeita, Lake Naivasha, Lake Magadi, before running into Tanzania's 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.

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)".

Lake Turkana's chemistry is dominated by the Omo River inflows that are largely responsible for replenishing the lake. The Omo catchment is said to comprise 68% volcanic deposits, and 25% alluvial deposits (Yuretich et al, 1976, and British Geological Survey, 1993).

2.4.6 Topography and Soils

A soil map is included in Figure 13 (Kenya Soil Survey, Sombroek et al), and descriptive notes of the soil types are included in the Annexes.

The terrain is a 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 hills, and is dominated by the inflowing Omo River delta. This will be the most densely populated area of the lake on account of the perennial fresh water inflow, and the opportunities for settled agro-pastoralism and fishing. The northern end of the lake is consequently the most important from the point of view of fisheries. The flat areas to the north of the lake, with their meandering channels and oxbow lakes, were the bed of the former larger palaeo lake that existed 10,000 years BP (Butzer et al, 1971).

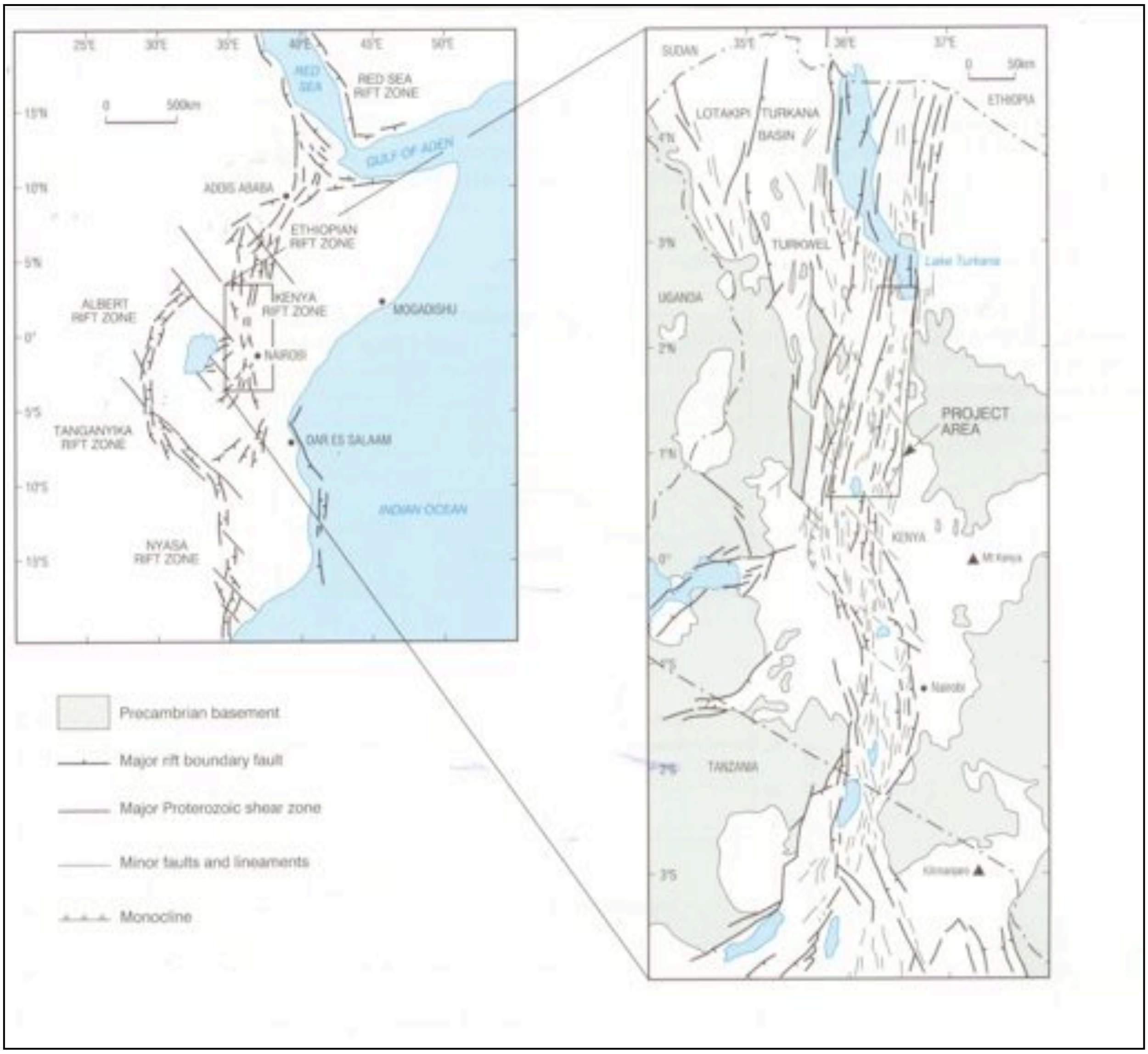
The lake shoreline is generally barren with stunted vegetation, offering no opportunities for cultivation. There is very little aquatic vegetation on account of the high lake water salinity. Due to the strong winds, much of the shoreline is a "high-energy" shoreline with vigorous wave action. People subsist through nomadic pastoralism, and some 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. To the south-east of the Park, lies the Chalbi Desert with its dunes and desert hills and flats.

The eastern lake shoreline to the south is predominantly strewn with lava boulders, with lava scarps overlooking the lake, and with lava scarps also jutting into the lake. Looming 2,000 metres 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 below and beyond to the south. Hence the lake was once a very much larger lake, and once extended south of the "Barrier".

The western lakeshores are flat and monotonous compared to the rugged terrain of the lake's southern end. However, there are interesting dunes at Eliye Springs south of Lodwar. The beaches at Eliye Springs are not unlike the Kenya coast, with sandy beaches and palms, another interesting contrast in this rugged terrain. 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.



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)

Figure 12: Rift Valley, and Lake Turkana within the Rift Valley
(Source: Dunkley et al, British Geological Survey, 1993, abstracted from Figure 2.1)

Notes: See descriptive notes on soil types and topography in Annexes.

Figure 13: Soil Map of the Lake Turkana area within Kenya
(Source: Soil Map of Kenya, Kenya Soil Survey, Sombroek et al)

2.5 Lake Turkana drainage basin

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 losses (predominantly due to the very high evaporation characteristic of arid areas).

The possibility of "minor sub-surface flow" from the lake into the lower elevation Suguta Valley to the south has been investigated (Dunkley et al, British Geological Survey [BGS], 1993). The Suguta Valley is located 60 metres below Lake Turkana's water level, and there are no significant emergent springs, thus suggesting an impermeable barrier (ibid). 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".

The Turkana drainage basin area has been delineated by previous studies, and a drainage map is included in Figure 14 (after Vetel et al, 2004).

The following drainage areas were delineated:

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

Table 8: Catchment areas
(Source: Ferguson & Harbott, 1982)

Drainage Area	Area km^2	% Total
Omo Basin	74,000	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

Although its catchment is 56.6% of the total, the Omo River contributes over 90% of the lake inflow (Ferguson & Harbott, 1982). This river rises in the Ethiopian highlands where rainfall increases with altitude, and annual rainfall is overall very much higher – see Figure 15.

The Kerio and Turkwel Rivers contribute less than 10% of the total water discharge into the lake, although they comprise 30% of the Turkana drainage area (Ferguson & Harbott, 1982). 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 to less than the estimate made by Ferguson & Harbott in 1982.

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

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.

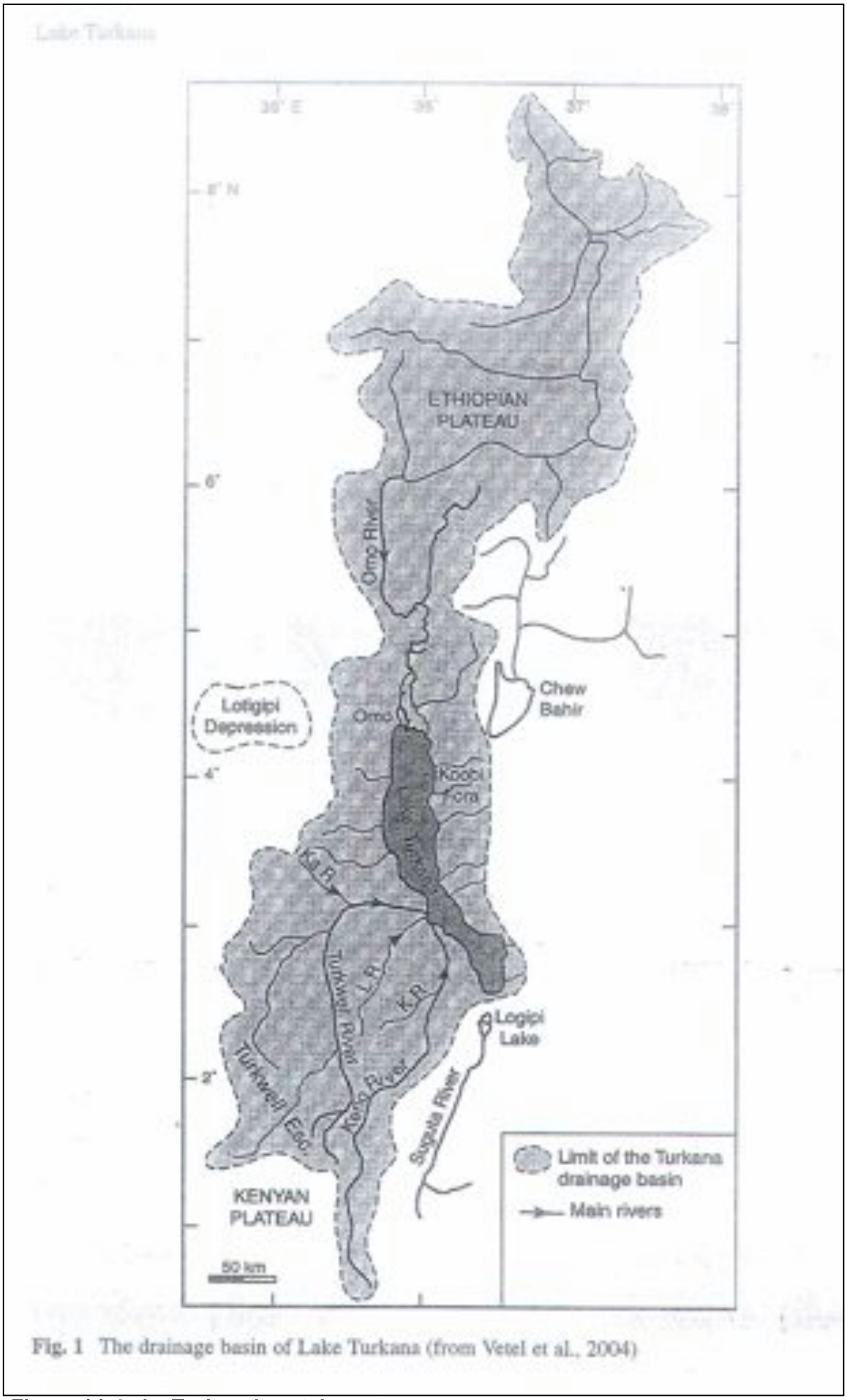


Figure 14: Lake Turkana's catchment area
(Source: Vetel et al, 2004)

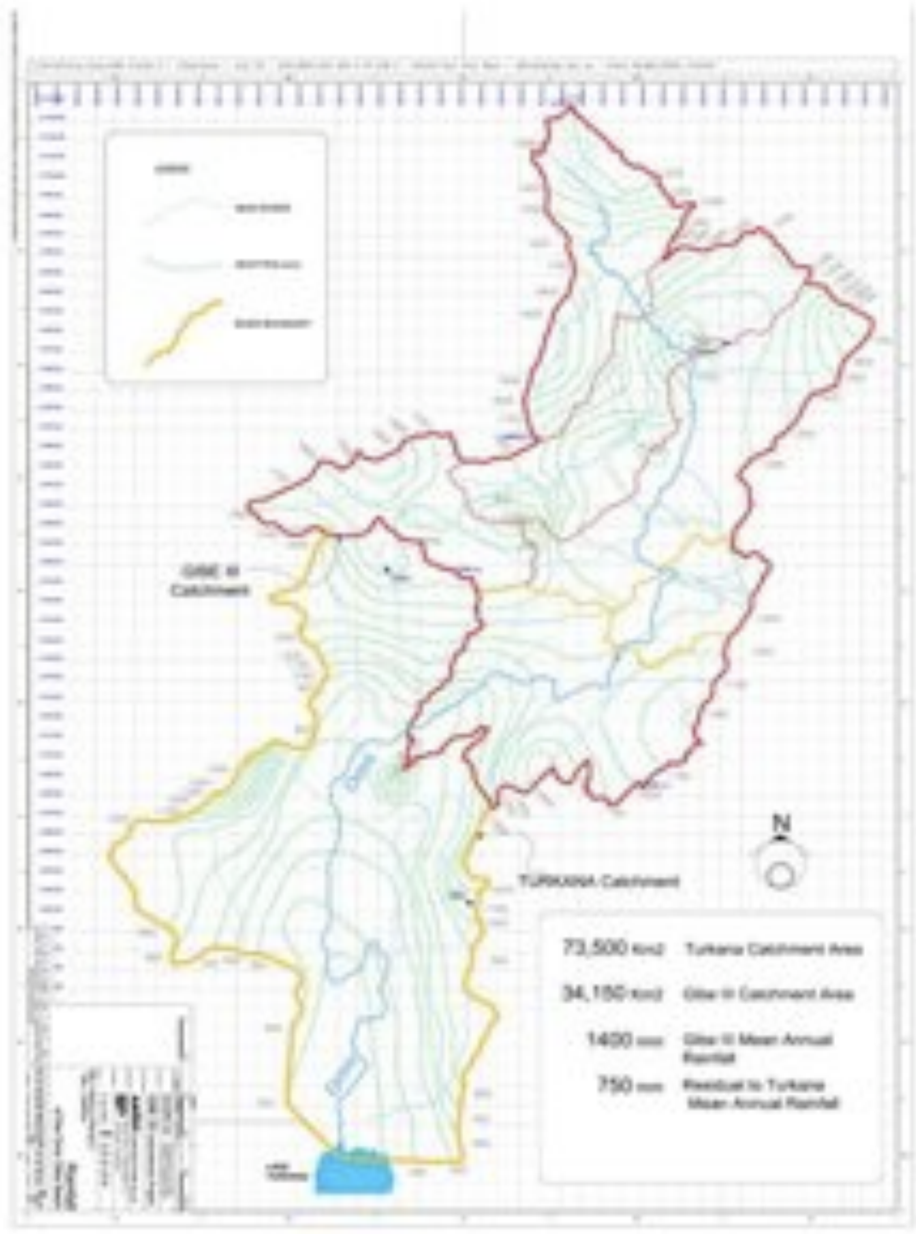


Figure 15: Omo River catchment area, with rainfall isohyets, and with Gibe III catchment delineated (in red).

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

2.5.1 Kerio River Basin and Delta

The Kerio River enters the lake south of the Turkwel river delta, in the south-west of the lake. The Kerio delta is similar to the Turkwel delta, but of "constructive-elongate" type (Wilkinson, 1988, citing Elliot in Reading, 1978).

The Kerio River Basin in Kenya covers a total of 17,800 km^2 extending over 350 km distance, with an average basin width of only 50 km (Sogreah, 1982). The upper basin rises in high altitude forest to the north-east of Timboroa (altitude 2,750 m). 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 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/sec (Sogreah, 1982). Much of this flow can be expected to dissipate between Lokori and Lake Turkana, although some flash floods can be expected to reach the lake.

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

The Kerio river channel to the lake is clearly marked on Figure 13 and in the 3-D satellite image as green lines in Figure 4.

2.5.2 Turkwel River Basin and Delta

The Turkwel River also enters the lake south of Lodwar. The Turkwel delta is a "fluvial-dominated, high constructive lobate" type (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 8 above (after Ferguson & Harbott, 1982).

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

The Turkwel River runs a course of length 340 km, 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.
- The semi-arid plain of the Turkwel River forms the third part of the basin extending from Kaputir to Lake Turkana. The only flow is in the form of 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.

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

The Kerio river channel to the lake is clearly marked on Figure 13 and in the 3-D satellite image in Figure 4.

2.5.3 Combined Turkwel / Kerio runoff into Lake Turkana

With the Turkwel dam, the effective Turkwel / Kerio catchment area draining to the lake is 41,700-5,900=35,800 km^2. Annual runoff in the Lake Baringo catchment was found to be only 5% of rainfall *(Sogreah, 1982)*, and this is a useful basis for estimating "other catchments" runoff in the water balance model developed for Lake Turkana.

2.5.4 Irrigation in the Turkwel and Kerio Basins

A separate study was commissioned by AFDB to assess the irrigation potential within the Lake Turkana drainage basin (Maina, 2010). The findings for the catchment within Kenya are tabulated below. These Kenyan irrigation schemes are similar to the scale of irrigation schemes envisaged as a consequence of Gibe III (see Table 1), and hence have similar minimal impact on the lake. The "potential irrigation" in Table 9 below is low compared to the potential irrigated area in the Omo Basin (see Table 2).

Table 9: Irrigation in the Turkwel / Kerio basins

	Area (ha)	Water requirement (m^3/sec)
Present irrigation	2,187	2
Potential irrigation	10,000	10

Source of data: Maina, Draft Report, 2010

2.5.5 Water resources of the Lake Turkana area

Traditionally, people derive potable water from springs and wells sunk into the sandy beds of seasonal river channels entering the lake. A brief review of notable water resources based on published geological surveys is included as follows. This is presented in a clockwise direction around the lake, starting at the north end of the lake:

1. *Northern end of Lake Turkana:* People here have access to the perennial fresh waters of the Omo River.
2. *North-Eastern end of Lake Turkana:* "…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. There are a number of seasonal river channels entering the lake.
3. *Eastern side of Lake Turkana, Koobi Fora, Allia Bay through to Moiti:* There are a number of seasonal river channels entering the lake. The perennial Jarigole spring near Allia Bay within Sibiloi National Park serves as a protected potable water source for KWS and visitors. "…Away from the lake established waterholes and springs occur between the volcanic units on most of the large hill masses…(Wilkinson, 1988)".
4. *South-eastern shore from Moiti south through Loyangalani:* From Moiti south to Loyangalani, numerous seasonal river channels reach the lake. Loyangalani Trading Centre itself is an "oasis" by the lake with piped water from perennial alkaline hot springs (Ochieng et al, 1988). The spring conductivity of 554 μS/cm is 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).
5. *South end of lake Turkana:* This is the most barren part of the lake. Seasonal river channels enter the lake. The nearest perennial water sources arise from the Ng'iro Range to the south-east of the lake, and the streams are to be seen in the Horr Valley. Elsewhere, people resort to springs, for instance at Parkati, or wells in seasonal river channels.

6. *South-western side of Lake Turkana*: This is the area of the Kerio and Turkwel River delta, and the well-known Eliye Springs. "…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)".
7. *North-western side of Lake Turkana:* "…Springs occur on most of the large hill masses, notably at Lokitaung and elsewhere in the Labur and northern Lokitdok Hills… (Walsh & Dodson, 1969)".

2.6 Omo River flow data

The Omo River flow at the point of entry to Lake Turkana is no longer gauged or measured.

All available historic flow data was requested in 2009 from the Ethiopian Water Resources Authority in Addis Ababa (EWRA). The only data availed was a table of monthly discharges for Station 93002 measured from 1977-80. The station was located shortly before the Omo delta, with details as follows:

Table 10: River gauging station at Omorate

Station No:	93002
River Name:	Omo
Station Location:	Omorate (sometimes referred to as Omo Rate
UTM Co-ordinates:	172733 531223
Catchment area (km^2):	*73,738*

The Omo River Basin hydrology has been studied in detail in the Omo-Gibe Integrated Development Master Plan Study submitted in December 1996 – referred to throughout this report as the "Master Plan" (Richard Woodroofe & Associates). In view of the absence of data, a flow series was simulated for the Omo River at Omorate by means of a rainfall / runoff model (ibid, Vol. VI, A1).

The Omo flow data for Lake Turkana is reproduced in Table 11. The annual totals and monthly averages have been re-computed as there are inconsistencies in the original tabulation.

The simulated flows for the period 1977-80 have been contrasted with the measured EWRA data in Figure 16 and Figure 17. The cumulative runoff curves of the EWRA measurements and the Master Plan simulated data are similar, but the monthly average values show that the Master Plan model has not reflected the bi-modal flow peaks shown by the EWRA measured data. This means that the model was influenced most by the upper catchment rainfall, which is uni-modal, and less by the lower catchment, whose rainfall is bi-modal (see later sections of this report for catchment rainfall pattern variations).

The Omo River simulated annual flow series from 1956-1994 has been extended in this study to 2008 by back-calculation from satellite radar altimeter lake level measurements (described later in this report). The results are submitted in Figure 18.

It has been 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 Figure 18 which shows that in the later years, the inter-annual variations are much more variable.

A photograph of typical terraced hillside cultivation within the Omo Basin is included below. Also included is a photograph of severe soil erosion seen near Arba Minch. Finally, a photograph of the Omo River at Omorate is included, photographed not far from the delta.

Ethiopian highland cultivation

Soil erosion near Arba Minch

River Omo at Omorate

Photo 3: Omo Basin and Ethiopian highlands
(Source: Sean Avery Photo Archive)

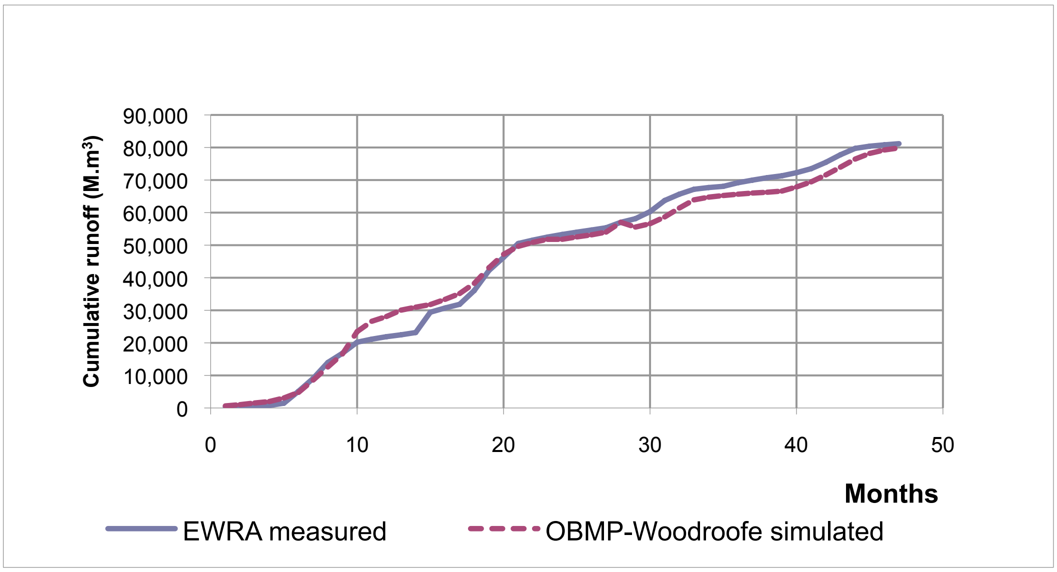


Figure 16: Omo cumulative runoff, 1977-80

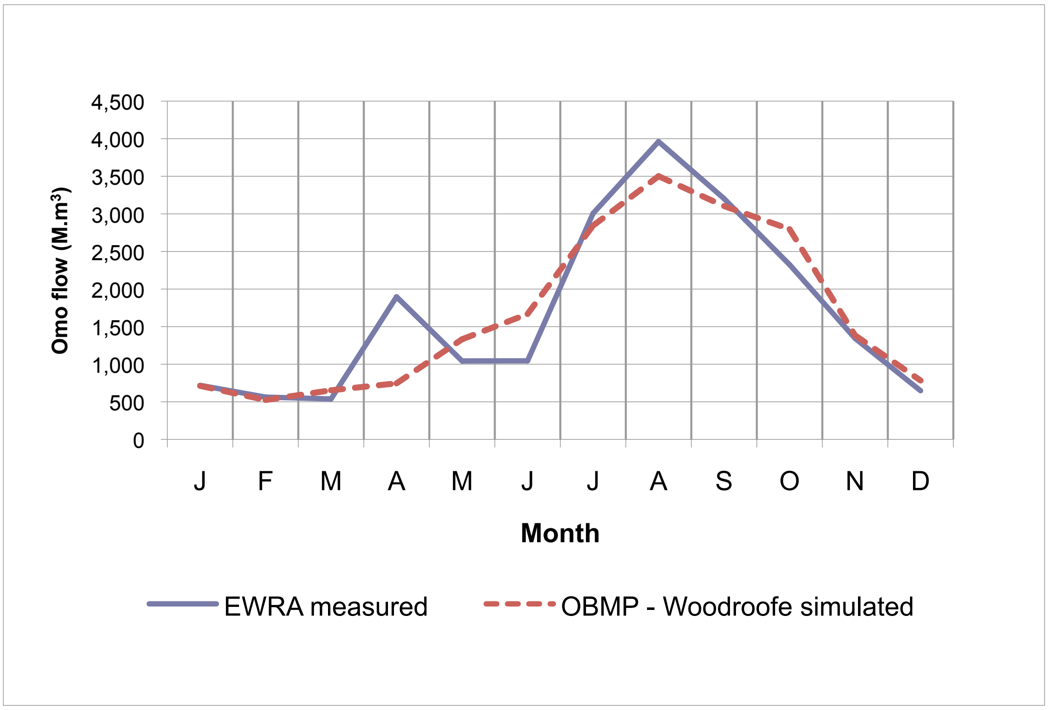


Figure 17: Comparison of EWRA measured and Master Plan simulated flows, 1977-80

Table 11: Simulated Omo River flows at 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: Monthly flows reproduced from Table C7, Vol VI, A1, Richard Woodroofe et al, 1996, with totals and averages re-computed.

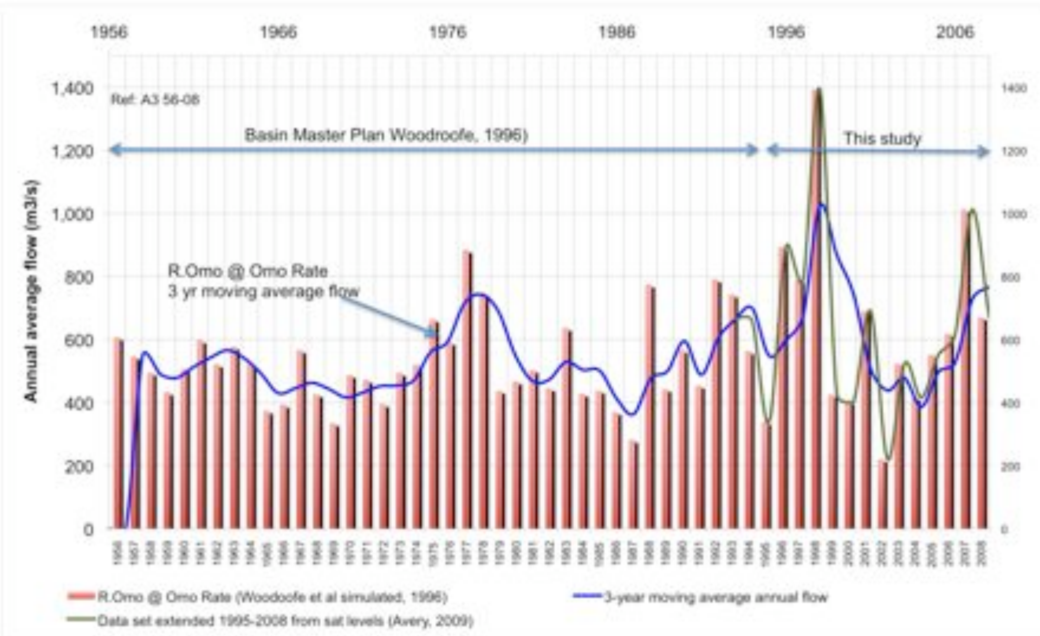


Figure 18: R.Omo at Omorate, Ethiopia (just before entering the lake)

2.7 Lake Turkana bathymetry

2.7.1 Historic bathymetric data

The bathymetric survey of Lake Turkana was undertaken during the 1972-75 Lake Turkana Project (Hopson et al, Ferguson & Harbott, 1982) – see Figure 19. The datum was taken to be the lake level in September 1972 (Zero = 365.4 masl).

The following lake characteristics are extracted from the above work, applicable to the 1972 level (ibid):

- The lake is 257 km long;
- The lake width varies from 44 to 13 km, and averages 31 km.
- The mean depth is 31 m, and the maximum depth is 114 m.
- The surface area of the lake measures approximately 7,560 km^2
- The volume of water stored is 237 km^3, 28% being stored within the top 10 m.

NIVA & KMFRI amended the Hopson bathymetric map. The NIVA / KMFRI study was undertaken in 1988, and the lake had dropped 5 metres in level since the time of the Hopson study. NIVA & KMFRI added the lower 1988 shoreline to the original Hopson bathymetric map. NIVA & KMFRI adopted the lower level prevailing at the time of their study as their zero datum (Zero = 360.4 masl), and they adjusted the contours relative to this lower datum – see Figure 20. Hence their datum is 5 metres lower.

The original hypsometric data datum used by Hopson (Datum Zero = 365.4 masl) has been retained in this study, and this datum has been used to create elevation / area / storage curves for the lake – see Figure 21 and Table 12. The Hopson Zero lake datum was adopted as the level of the lake on 10th September 1972. This level was determined to be equivalent to a surface elevation 365.4 m above mean sea level, based on survey done by the UK's Ministry of Defence on 22 June 1972 (Ferguson & Harbott, 1982).

It is evident from the bathymetric contour map that a reduction of lake levels will result from a reduction in volume of water, resulting in the shrinking of the shallower northern end of the lake in particular. This will cause the River Omo to deeply incise through the existing delta, and there will be an extension of the delta south into Kenya. A reduction in level greater than 3.1m below the 1972 Zero datum would leave Ferguson's Gulf dry. This is discussed further below in Section 2.7.3.

Table 12: Lake Turkana 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: Zero level = 365.4 metres above sea level (Hopson et al, 1982)

2.7.2 Omo delta historic imagery

Some interesting images of the delta are included in Figure 22, which show changes over time (Source: USGS website). Figure 23 is a 2009 image, and Figure 24 is a historic image from the period 1972-75 (Hopson et al, 1982).

2.7.3 Effect of falling lake levels on shoreline

Figure 21 shows that at Zero datum 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.

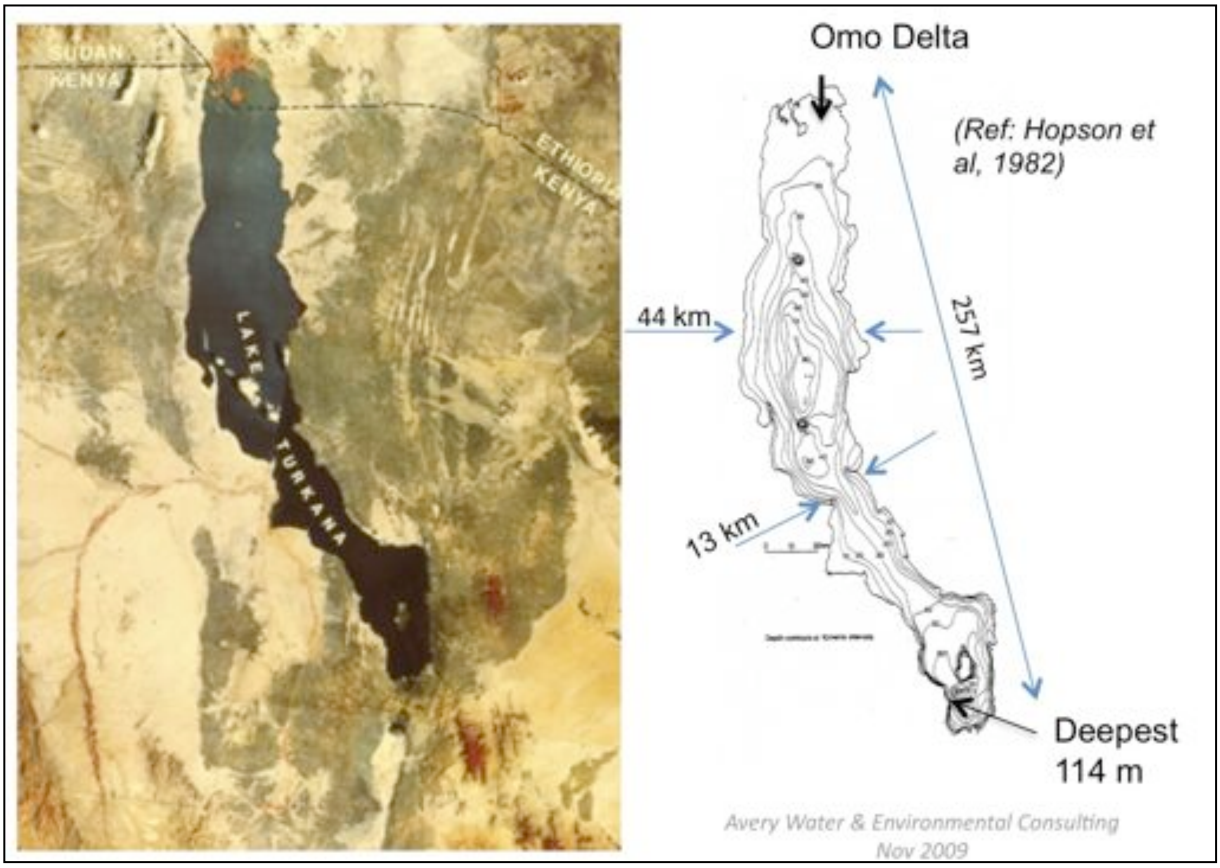
The volume required to fill the Gibe III dam is equivalent to a little over two metres depth on the Lake.

Figure 25 is the Hopson datum bathymetric map with depth zones highlighted. The following is apparent:

1. *Depth Zone 0-20 metres:* Twenty metres below the 1972 level, the volume stored will halve, and the northern end of the lake will shrink south within Kenya by about 40 km. 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 km.

2. *Depth Zone 20-40 metres:* Forty metres below the 1972 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 located in the middle, and the other at the south end 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 lake-shore will shrink 60 km south, and the Omo River length will increase by this distance.

Reduced lake water levels will lead to down-cutting of inflowing river channels in response to the increased hydraulic gradient resulting from the drop in water table. These possibilities were mentioned in the Omo Gibe Basin Master Plan (Woodroofe et al, 1996).



Notes:

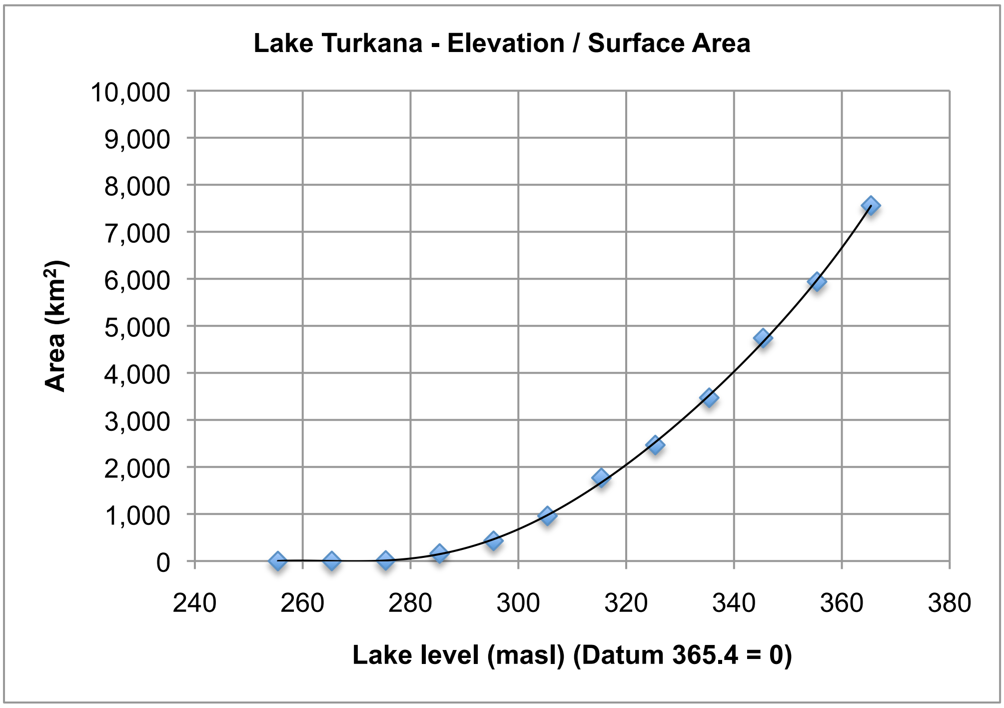
The “shoreline” is the 1972 lake water level, i.e. Zero level datum adopted at that time = 365.4 metres above sea level (masl).

The lake level in late 2010 was slightly lower than 1972 (about 363 masl)

Figure 19: Lake Turkana Bathymetric Contour Map
(Source: Ferguson & Harbott, 1982)

Figure 20: Lake Turkana – Bathymetric Contour Plot and Shore Zone Map

(Sources: Bathymetry taken from NIVA / KMFRI, 1988, Zero Datum = 360.4 masl. Imagery superimposition on Survey of Kenya 1:250,000 base mapping provided by Ramani, Nairobi. Note: The level in late 2010 was 363 masl, hence higher than 1988.)



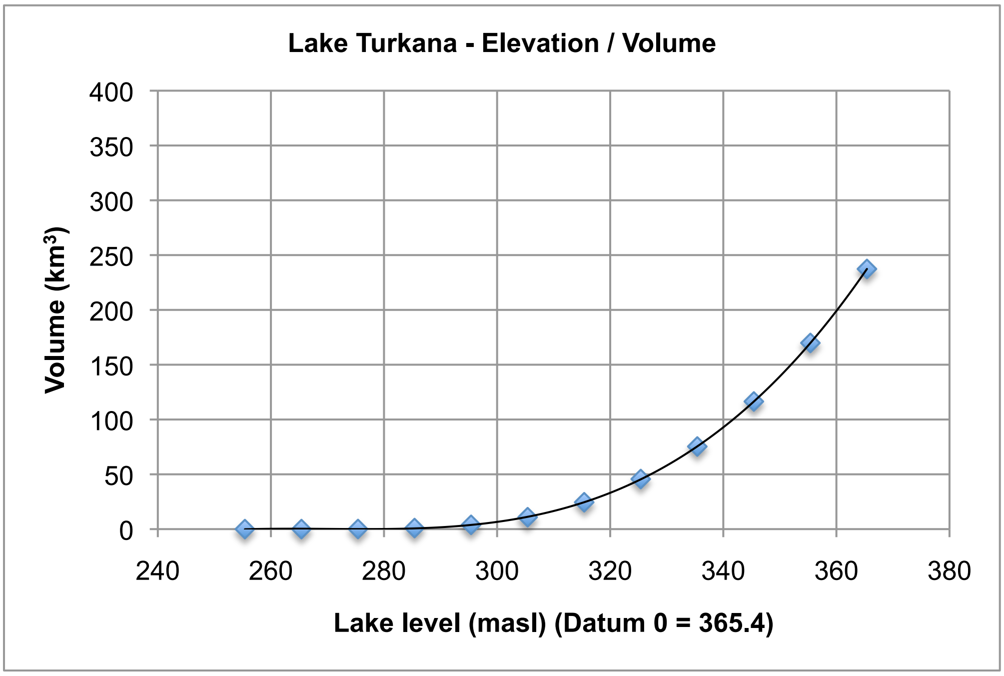
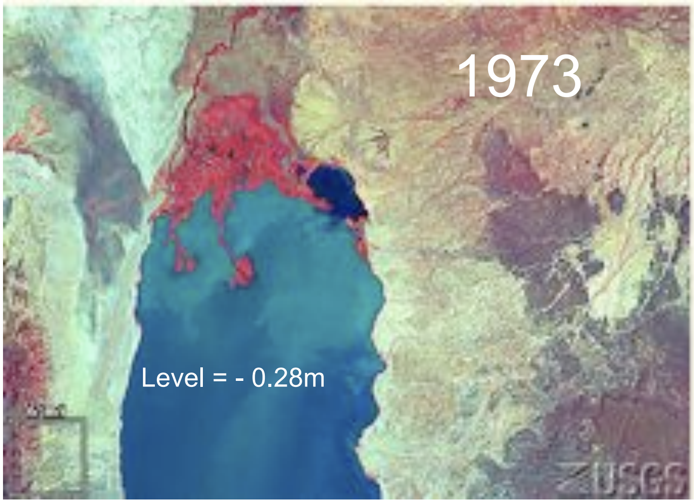


Figure 21: Lake Turkana Elevation / Area / Volume Curves
(Source: Derived from bathymetric survey of Hopson et al, 1982)

Figure 22: Omo Delta imagery showing changes over time
(Source: USGS website)

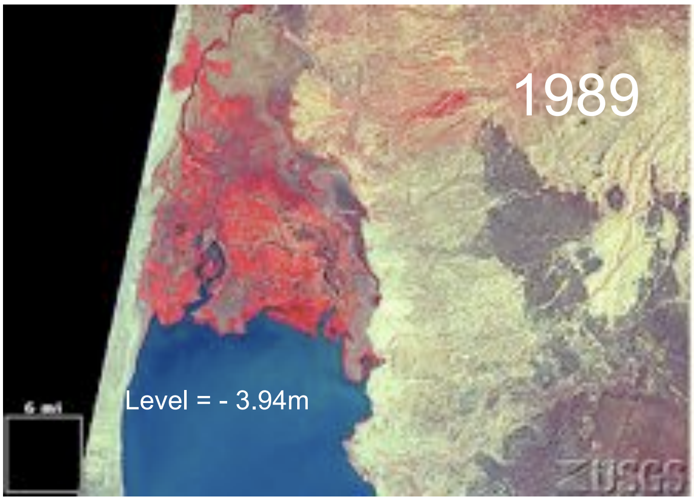


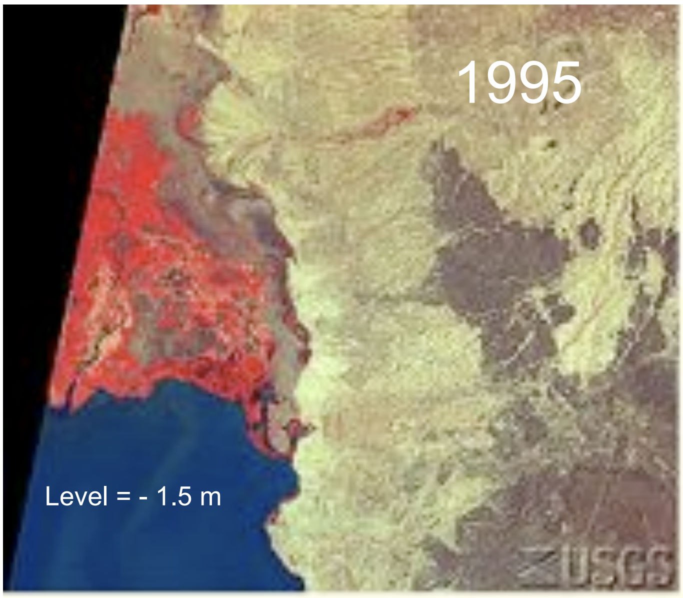
Notes:

1973: A large part of the delta can possibly be seen submerged, probably dating from the level rise following the1940s and 1950s low period.

1989: Lake level 3.7m lower than 1973. Very close to lowest ever level. Hence delta much larger due to reduced water level.

1995: 2.4m higher than 1989, 1.2m lower than 1973. Delta not reduced much since 1989, but much larger than in 1973.





The images below are of general / historical interest. They show a very small portion of the delta, and hence are not easily comparable with the 1973, 1989, and 1995 imagery above.

Figure 23: Omo Delta, 2009
(Source: EEPCO, Agriconsulting S.p.A & Mid-Day International, 2009)

Figure 24: Omo Delta 1972-75
(Source: Hopson et al, Vol.1, 1982)

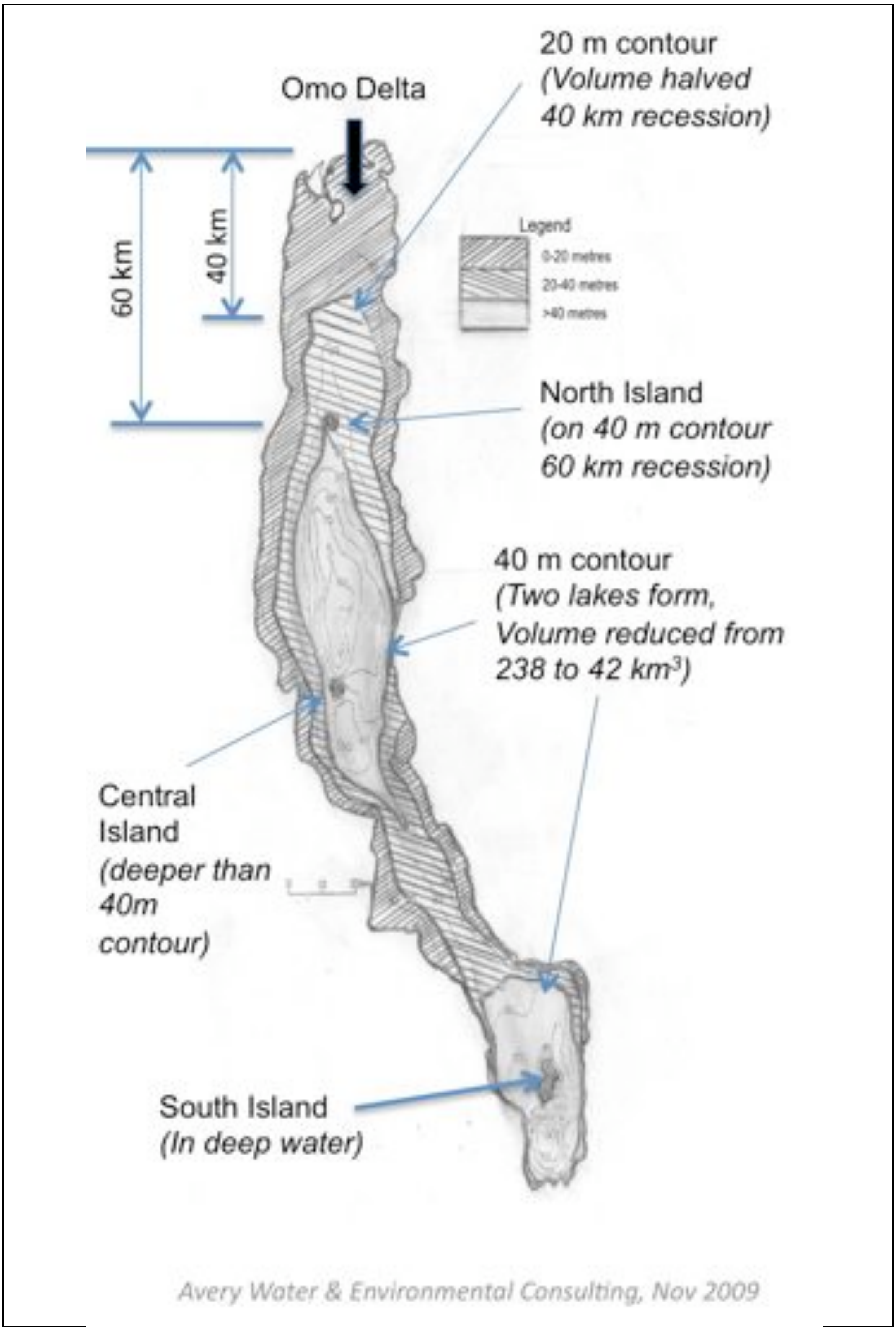


Figure 25: Lake Turkana depth zones
(*Source of base map: Hydrographic survey data published by Hopson et al, 1982)*
(*Source of overlay: Avery, 2009)*

2.8 Lake Turkana water level records

2.8.1 Lake gauge readings

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:

"…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 been fragmented. The history is as follows:

- 1949-62: Gauge operated at Ferguson's Gulf by the Water Development Department, Nairobi.
- 1962-66: Gauge submerged by rising lake level, and records ceased.
- 1962 onwards: Intermittent records.
- 1971-75: Gauges set up by Lake Turkana Project in Ferguson's Gulf (Hopson et al).
- 1975-84: Three spot readings between 1976 and 1985 (see Figure 4-1-2 NIVA, 1988).
- 1985-88: Records collected by Lake Turkana Limnological Study (NIVA / KMFRI).
- 1988-date: No daily lake level data. The data is taken "occasionally due to logistical challenges". 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 MoWI (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, Vol.VI, A1, C5).

Butzer's valuable work on 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 / KMFRI, 1988). The gap from 1976 to 1985 was "infilled" by NIVA / KMFRI.

Figure 26 presents the Butzer record extended by NIVA / KMFRI to 1988.

It is important to note the -3.1m level at which Ferguson's Gulf becomes dry (relative to the Hopson Datum 1972 Zero=365.4 masl). The Gulf was reported to have "distinct algal flora", there was a high primary production of algae, and the fish yields were "phenomenally high". It was reported to be the most productive fishing zone on the lake (Hopson et al, 1982). The character of the Gulf today is different. There has been sedimentation and the western shore has been invaded by *Prosopis juliflora* scrub (Pers.Comm. Dr. Ojwang, KMFRI 2010, Ngece, 2010). More details can be found elsewhere (Mbogo, 2010).

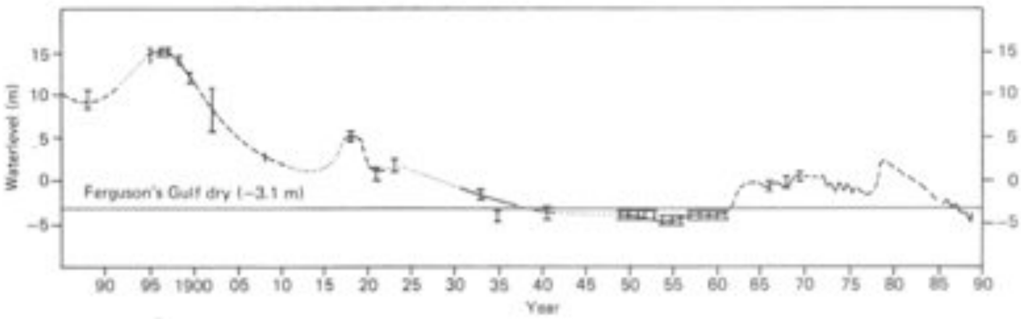


Figure 4.1-1 Water level of Lake Turkana 1888-1988. 0 m = ca. 365 m above sea level. Data from 1888-1970 from Butzer (1971), 1971-1975 from Hopson (1982).

Figure 26: Lake Turkana water levels
(Source: Butzer, 1971, Hopson et al, 1982, NIVA/KMFRI, 1988)

2.8.2 Satellite radar altimeter readings of lake level

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), is routinely monitoring lake level variations throughout the world. Several satellites are, or have been, collecting radar altimeter data at time intervals varying between 10 and 35 days, as shown in Figure 29.

The satellite orbit is 1,336 km above earth. The satellite track over Lake Turkana is reproduced in Figure 30 and the data available since 1992 is reproduced in Figure 31, from various satellites.

The radar altimeter measurements reflect the mean of several readings along the chosen transect, and accuracies are likely to be 10 cm rms (Pers. Comm. Birkett, UMD, 2009). The Lake Turkana transect crosses roughly mid-lake, on a line from the Kerio/Turkwel mouth on the western shore, to Allia Bay on the NE shore. 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, it is assumed that the level measurements are representative of the lake as a whole. The winds also create waves, which can affect measurement.

This satellite data is also available for other lakes in the region, hence permitting comparison of trends.

The following other sources were also checked, and the Turkana data was identical:

- *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.

2.8.3 Comparison of lake gauge and satellite radar altimeter datasets

2.8.3.1 KMFRI provided lake gauge data

To obtain current data on lake levels, the Kenya Marine Fisheries Research Institute (KMFRI) was approached. KMFRI operate a research station on the western shore of Lake Turkana at Kalokol, near Lodwar.

The annual data series of lake levels from 1880 – 2008, as provided by KMFRI, is presented in Figure 27 below. From 1880, the lake declined 20 metres to its lowest recorded level in the 1940s and 1950s, before rising sharply in the 1961 floods, and then dropping to close to its lowest 1940s/50s levels in the late 1980s. The historic pre-1988 data was based on work done by Butzer, Hopson et al, NIVA / KMFRI, and Kolding. KMFRI provided an extended data sequence since 1988 to date. The data as provided is attached in Annex 7.

The KMFRI data has anomalies, which were referred back to KMFRI. The data in Annex 7 shows a sharp rise in the early 1990s (red dotted line in the Figure below shows the KMFRI data displaced upwards), which is greater than the rise following the exceptional 1961 floods, and also exceeds the rise associated with the exceptional El Nino rains of the late 1990s. The late 1990s rise in the KMFRI data is also incompatible with the Omo River inflow database, which does not show any such increase in flows during that period (see Table 11). On the other hand, other regional lakes such as Lakes Victoria and Naivasha did show a steep rise over this period, but very much less than the KMFRI data indicates for Turkana.

The best explanation is that the later KMFRI data includes a datum shift relative to the earlier series. This is most likely as a consequence of the datum shift between the Hopson and NIVA study periods. The shift was 5 metres, and the effect of downshifting the KMFRI data by this amount is shown in the Figure below. The resultant adjusted sequence (blue dotted line in the Figure below) is consistent with data presented in another publication, with which a KMFRI staff member was involved (Figure 28 – Johnson and Malala, 2009). However, the Johnson & Malala datum differs, as it appears to tally with the level at which Ferguson's Gulf dries.

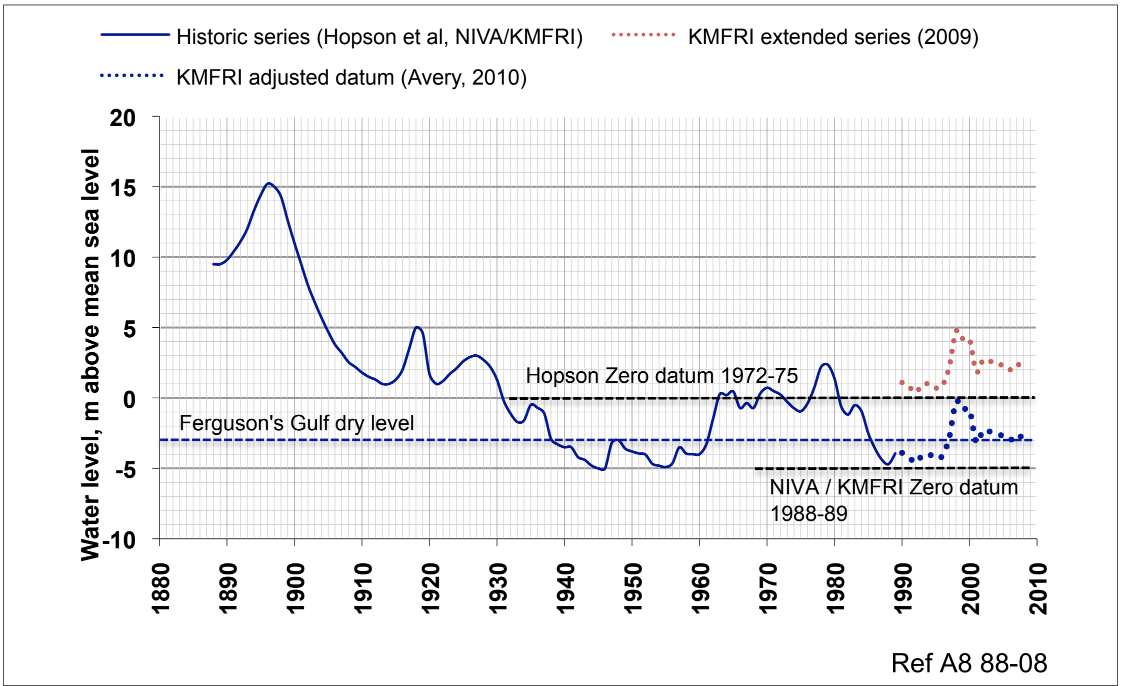


Figure 27: Lake Turkana 1888 – 2008: Annual water level series

(Source: KMFRI, Kenya, but adjusted by this study to one consistent datum)

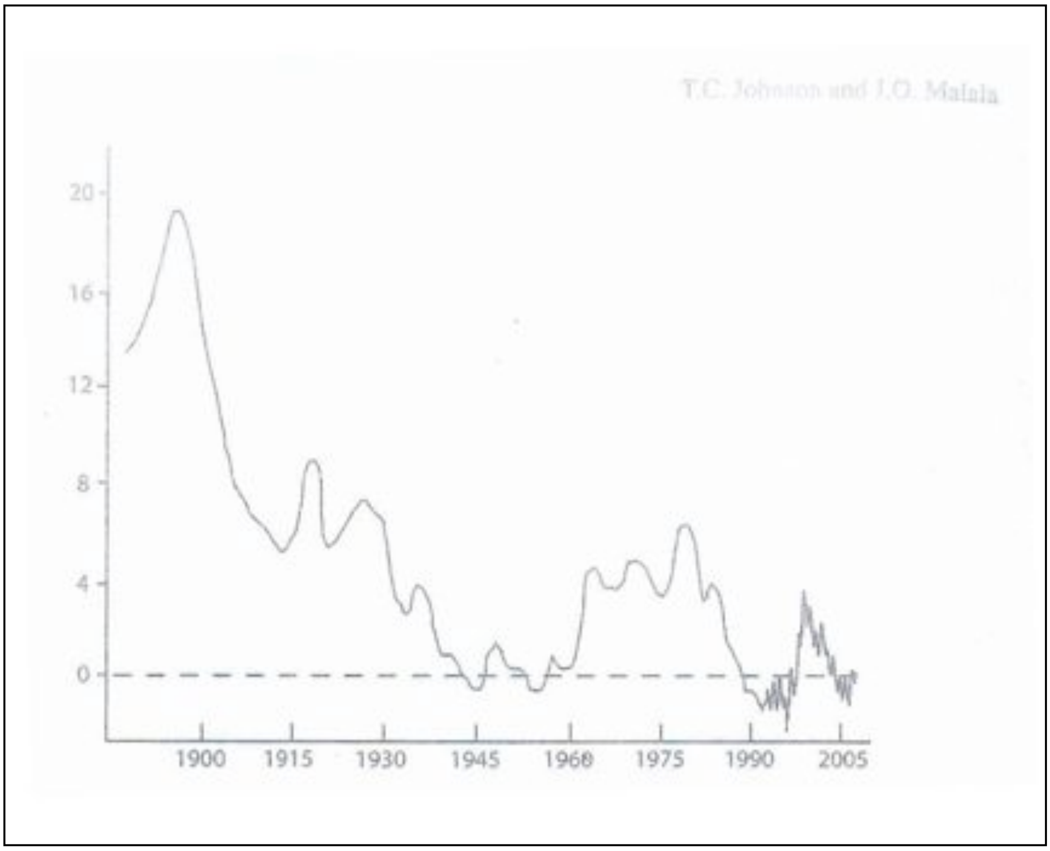


Figure 28: Lake Turkana lake levels
(*Source: Johnson and Malala, 2009)*

2.8.3.2 Satellite radar altimeter data compared with gauge data

The radar altimeter data in Figure 31 has been 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 has been compared with the GOHS/Legos data set in Figure 35. After adjusting to a common datum, the curves are almost identical.

The KMFRI provided lake level data is compared with the satellite data in Figure 32. The KMFRI Zero datum was stated to be relative to Zero=365.4 masl (the Hopson datum 1972 lake level - refer to Annex 7), but is more likely to be 0=360.4 masl (NIVA datum), as discussed above.

The satellite data zero datum is the 10-year mean of the satellite data-base prior to 2010, and hence is not linked to the other lake datums in use. When compared to the satellite data, the lake gauge data shows further anomalies, best seen by reference to Figure 33. For instance, the sudden drop in 2001 is improbable, and the very recent satellite data showed the lake level falling whilst the gauge data showed the lake rising.

The falling trend on Lake Turkana in September 2009 has been compared with other regional lakes, for instance Lake Victoria and Lake Tanganyika, where the falling trend is also shown – see Figure 34. The general decline in levels, which is shown by the lake level gauge data since 2006, is contradicted by the satellite radar altimeter measurements. The lake gauge data as supplied is unfortunately suspect.

In Figure 34, the trends on the four lakes shown by satellite radar altimeter measurements are generally similar, with Turkana peaking slightly later on account of its catchment being further north. All lakes show an increasing water level trend since 2006, apart from Lake Tana in Ethiopia whose outflow is regulated.

The big Omo River floods reported in July 2007 (EEPCO, Agriconsulting et al, 2009) are reflected in the subsequent USDA-FAS lake level peak towards the end of 2007 in Figure 31 and Figure 33.

The annual cyclical changes shown for the various lakes are interesting to note.

2.8.3.3 Establishing satellite data mean sea level datum

The GOHS/Legos satellite lake level data is presented in Figure 35, as this data is usefully expressed relative to mean sea level. The GOHS/Legos datum has been compared with the Ferguson's Gulf datum established by Hopson et al. The Hopson Zero Datum was based on the lake level in September 1972, which pre-dates the satellite radar altimeter database. It has earlier been established that the 1972 Zero Datum equated to 365.4 masl. A useful lake level benchmark when looking at satellite data is the condition of Ferguson's Gulf. The Gulf is known to become dry at the level -3.1m, which is equivalent to 362.3 masl on the 1972 datum (365.4 – 3.1 = 362.3).

Landsat imagery has recently been placed in the public domain. For Ferguson's Gulf, imagery since 1984 has been accessed through the USGS website, and samples are included as Figure 36. There are gaps in the imagery for the Gulf, but the available data has been studied, and notes on findings are included in Figure 35.

The Omo Delta imagery is compared for two different years for which lake levels were similar – see Figure 37. The delta extent is much the same in the two images, perhaps slightly extended in 1995 due to sediment deposition, hence tending to confirm the datum.

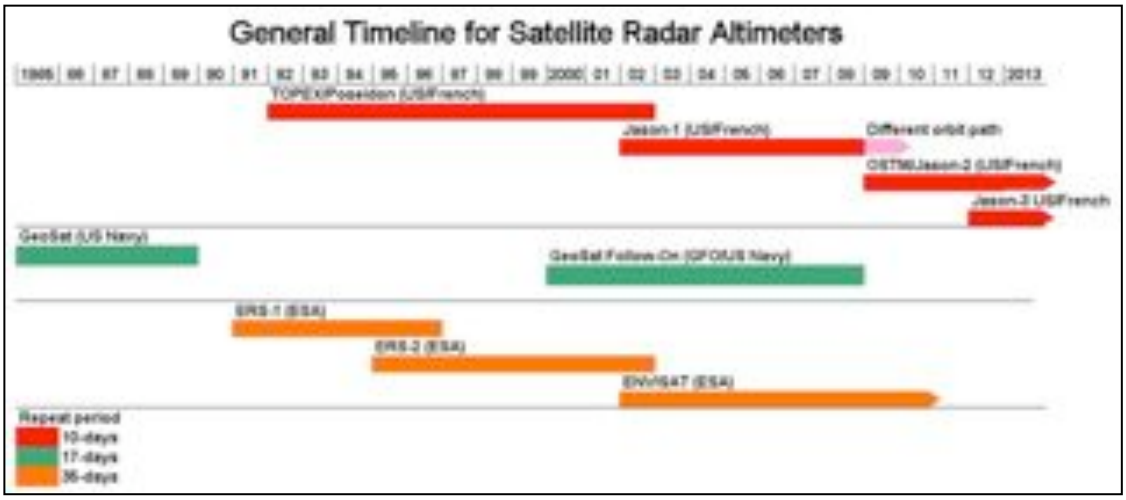


Figure 29: Satellite radar altimeters – Timeline
(Source: USDA-FAS website)

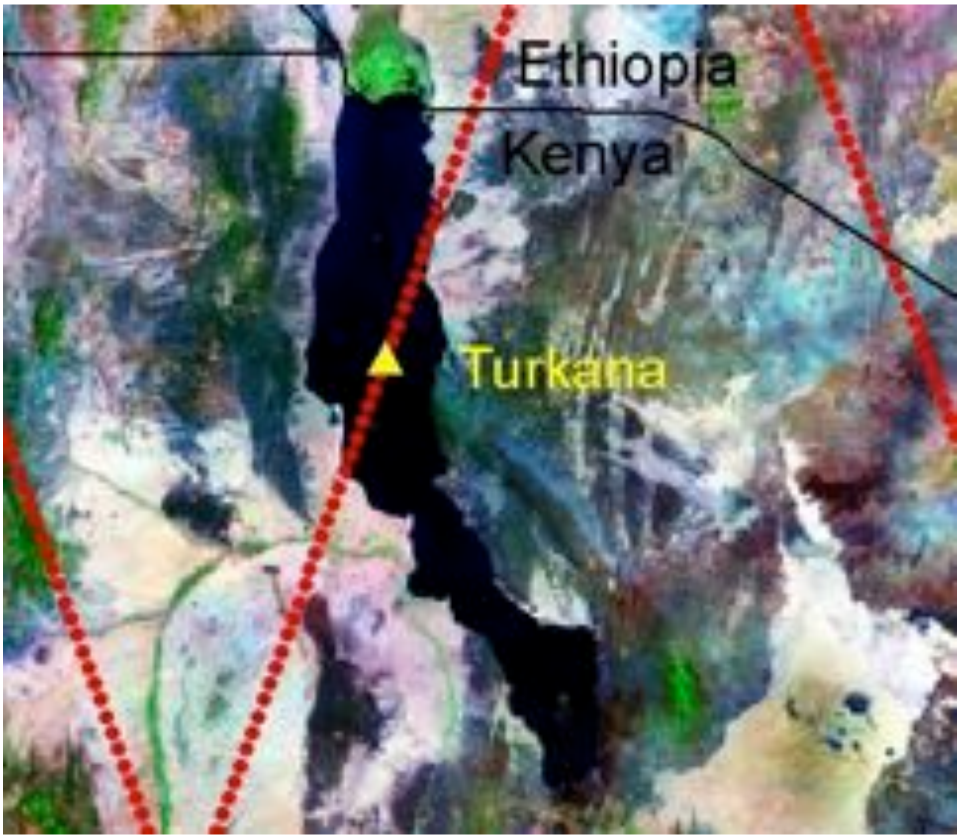
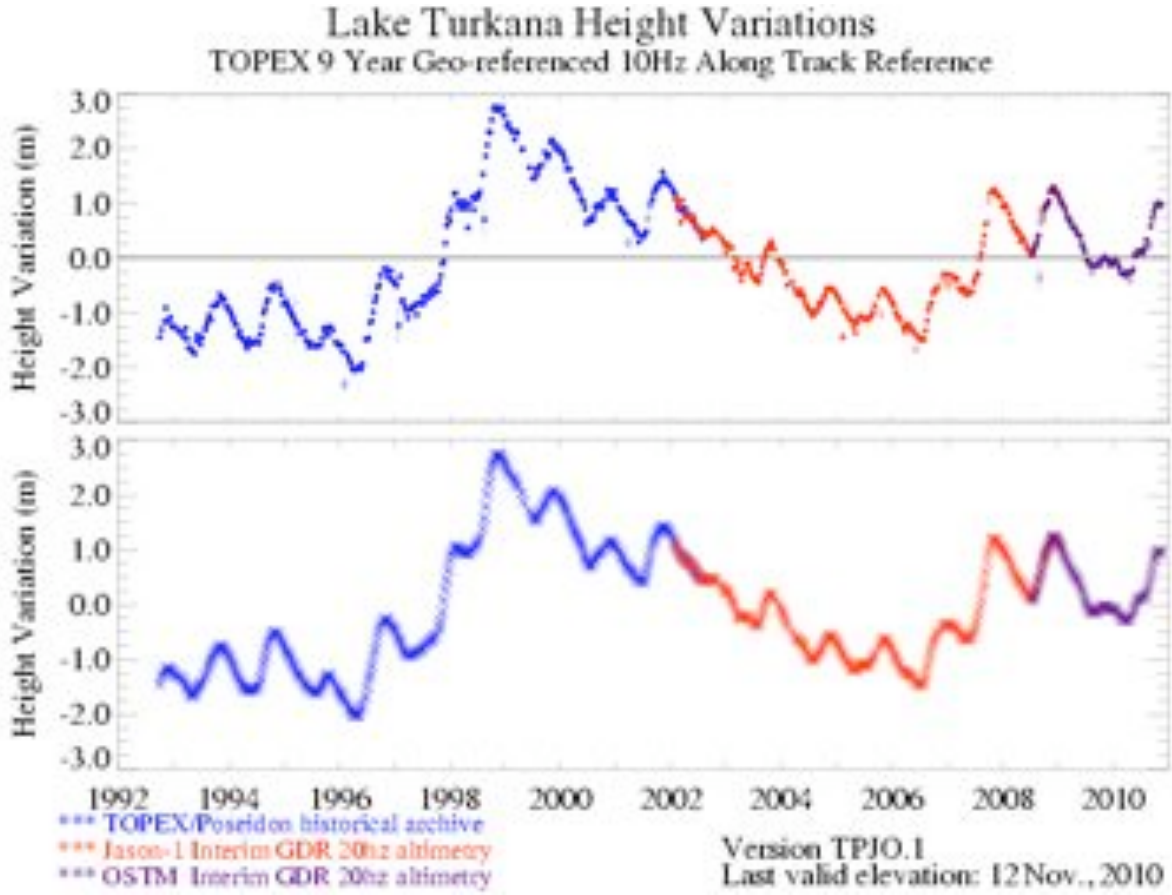


Figure 30: Satellite radar altimeter track over Lake Turkana
(Source: USDA-FAS website)



Notes: *(Ref USDA-FAS website):*

1. The Zero datum for the dataset is the average of the 10-year dataset prior to 2010.

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.

Figure 31: USDA satellite radar altimeter measurements
(Source: USDA-FAS website – updated November 2010)

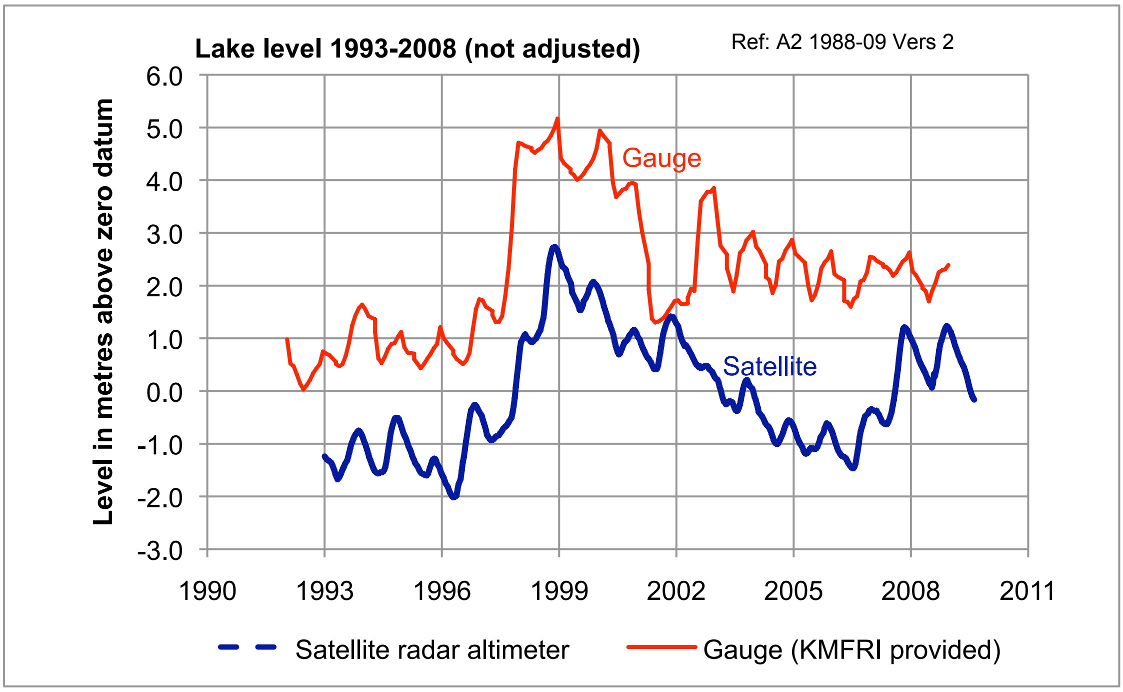


Figure 32: Lake Turkana 93-08 KMFRI and Satellite data compared
(Source of level data: KMFRI for gauge data; USDA-FAS for satellite data)

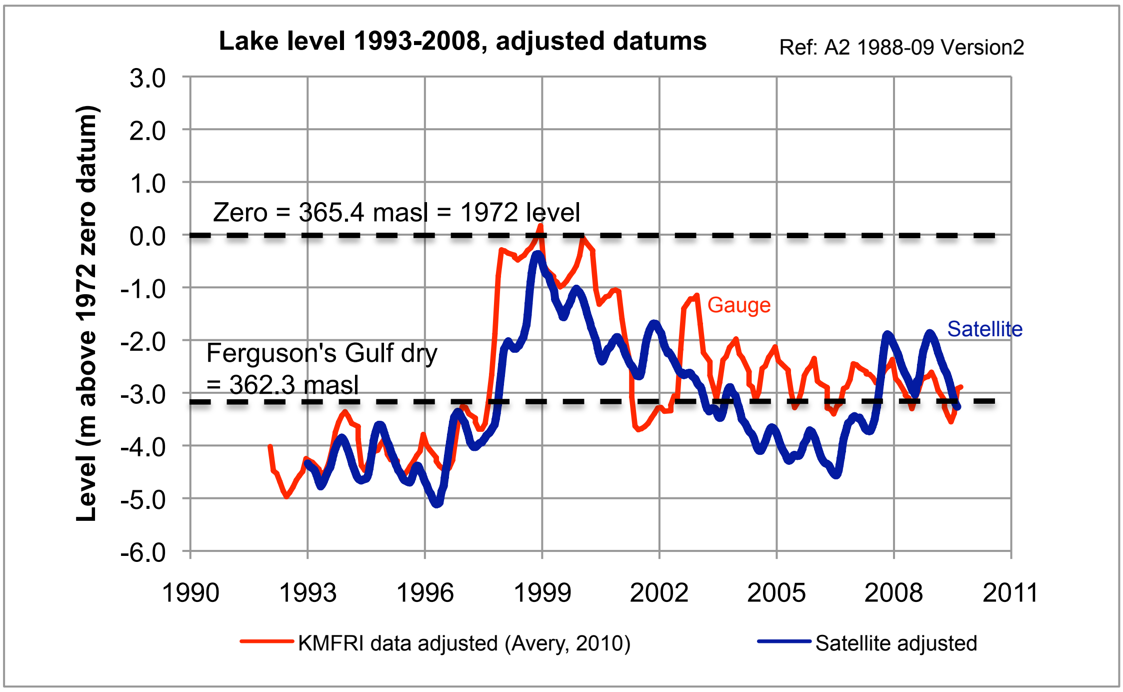


Figure 33: L.Turkana Gauge and Satellite data superimposed
(Sources: KMFRI for gauge data; USDA-FAS for satellite data)

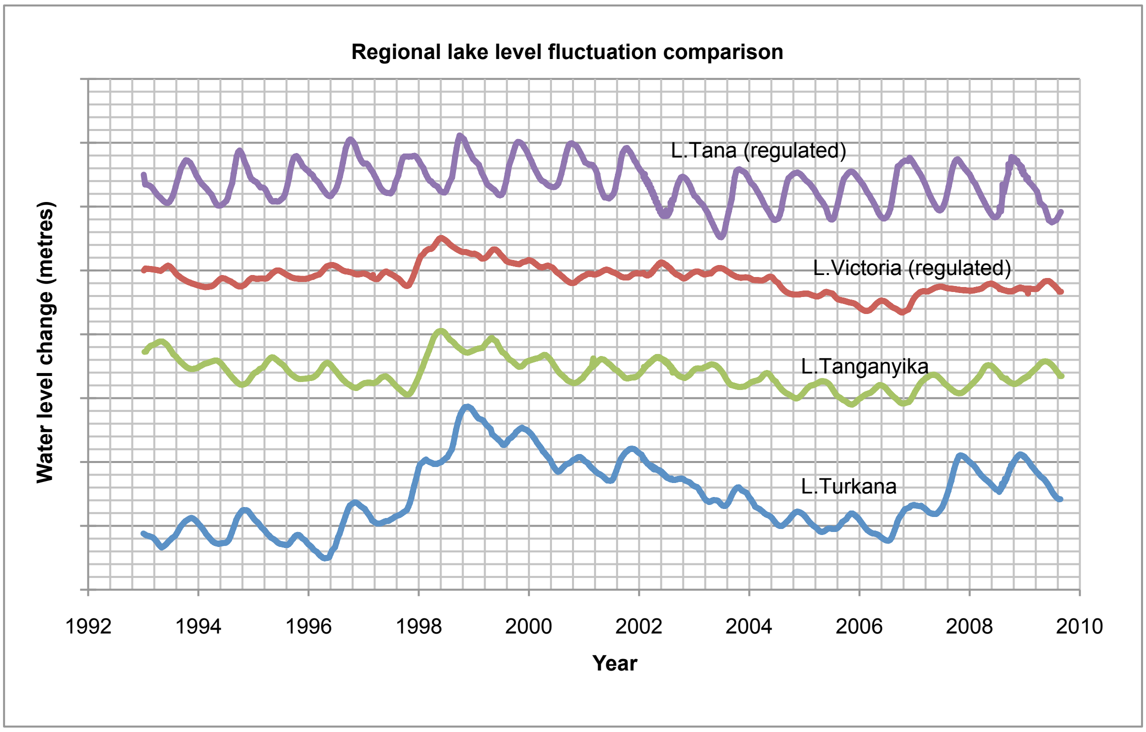


Figure 34: Regional lake level comparison
(Source: USDA-FAS satellite data)

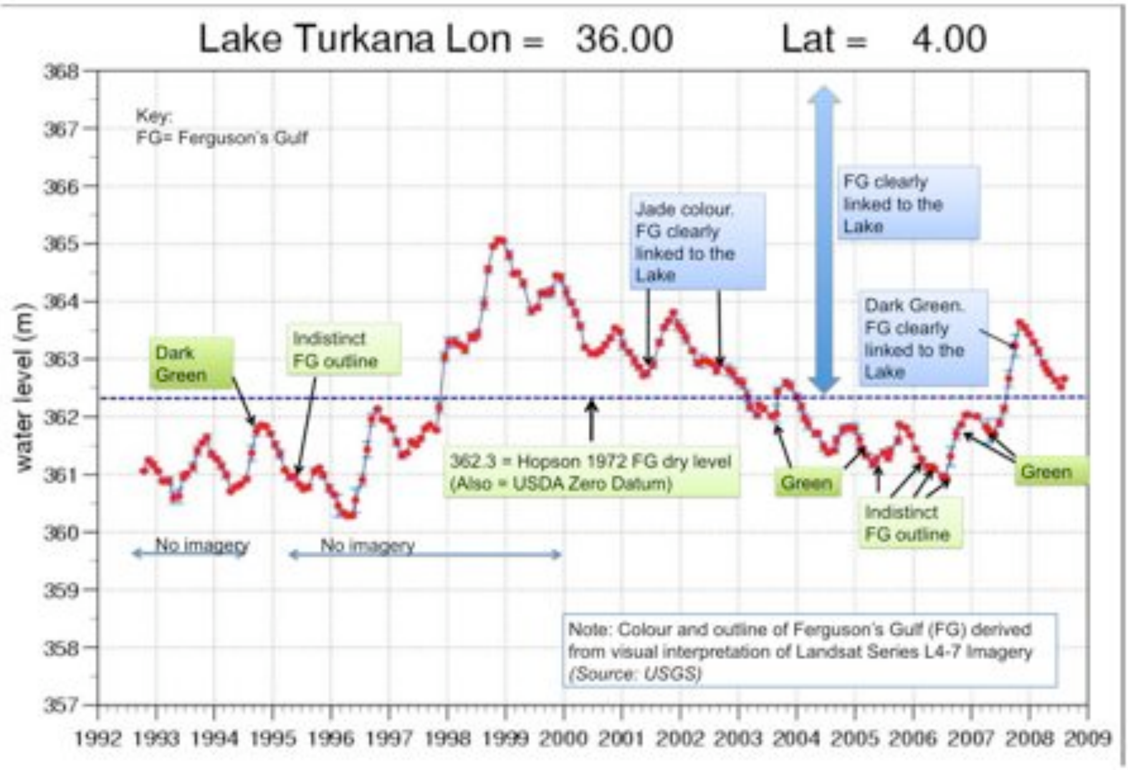


Figure 35: GOHS / Legos satellite radar altimeter data and Ferguson's Gulf
(Source: GOHS / Legos for satellite lake level data)

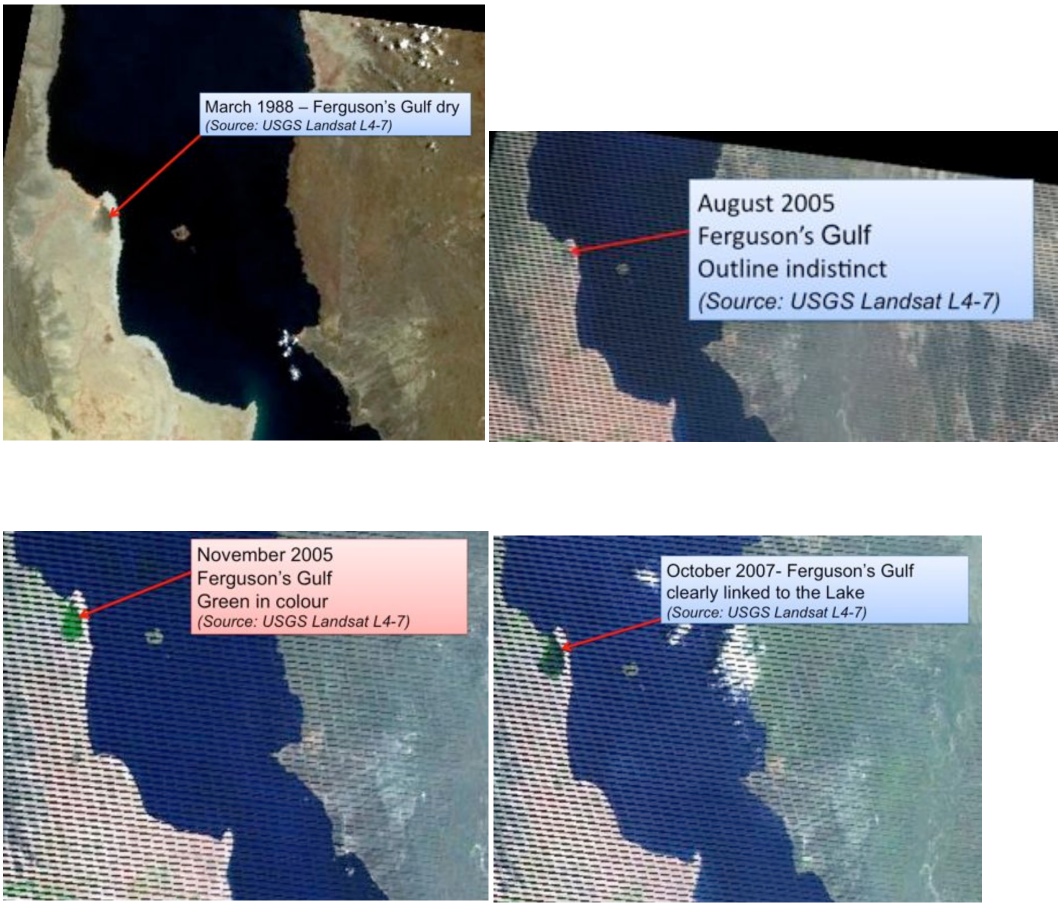


Figure 36: Landsat imagery of Ferguson's Gulf
(Source: USGS website)

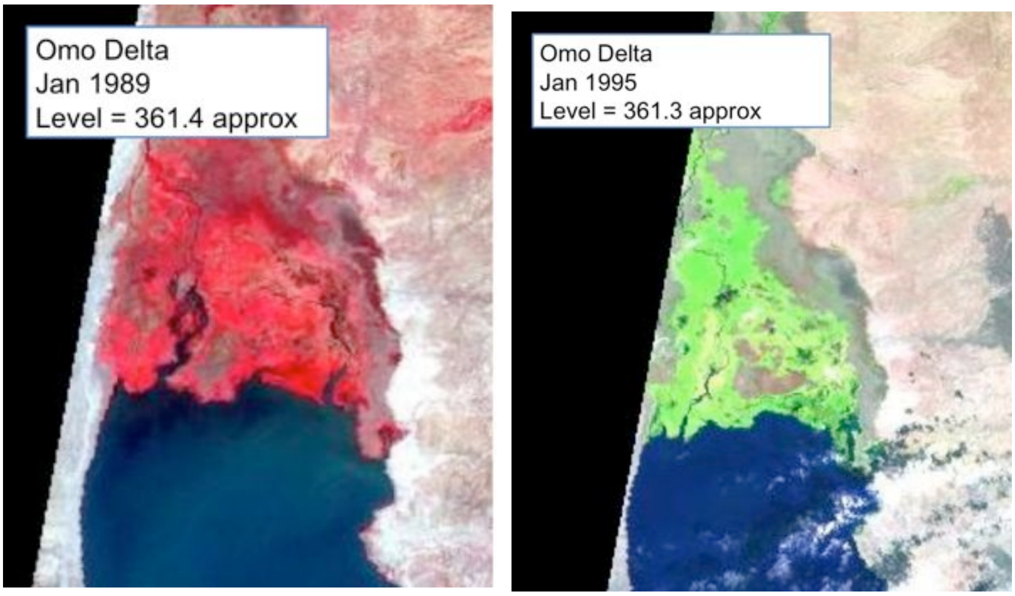


Figure 37: Omo Delta in 1989 and 1995
(Source: USGS website, Landsat imagery L4-7)

2.9 Lake Turkana salinity levels

2.9.1 Measurements of electrical conductivity of lake water as indication of salinity

2.9.1.1 Historical electrical conductivity data

The lake has been a closed basin ever since it became disconnected from the Nile River system 7,500 years ago (Butzer, 1972). Evaporation rates are more than ten times the rainfall. A volume equivalent to the entire annual Omo River flow is evaporated annually. 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 high electrical conductivity, but the levels of salinity are very much lower than they might be. The present salinity levels are equivalent to a lake only 600 years old (Hopson al, 1972). Hence, the salts are being removed through other processes, and at a considerable rate.

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/KMFRI, 1988, citing Yuretich et al). The process is accelerated at 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, 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, and this is compensated by deep reverse bottom current to the south-east, 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 conductivity of the lake during 1972-75 (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 conductivity was about 80 μS/cm (conductivity is related to salinity).
- Previous historic lake conductivity measurements were reported for the "Central Sector" of the lake:
    - 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.
- 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 Lake Turkana Limnology Project also presented conductivity measurements (NIVA, 1988), and reported levels of 3,800 μS/cm in August 1988, and an increase of 500 μS/cm over the period 1984-88 due to evaporation was noted. The period was particularly dry and the lake was declining to one of its lowest levels ever, hence concentrating salts faster than usual.

2.9.1.2 Recent electrical conductivity data from KMFRI

Recent conductivity data was requested from KMFRI, and measurements from 1997 to 2002 were kindly provided. 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. A summary of readings is included below:

Table 13: More recent electrical conductivity data for Lake Turkana
(Source: KMFRI, 2009)

Date	Ferguson's Gulf μS/cm	Main Lake μS/cm	Crater Lake μS/cm
22/10/1997	4,800	3,400	-
08 – 10/1999	4,974	3,290	-
20/12/2000	5,930	3,270	-
31/03/2001	5,520	3,360	-
14/03/2001	-	3,420	10,590
22/02/2002	6,900	3,830	-

The readings tabulated in Table 13 do not extend beyond 2002 and are not much changed since the readings taken in 1956. More recent studies confirmed that conductivity (EC) levels in the main lake have remained fairly constant over the last 30 years (Mbogo, 2010, citing Ojwang et al, 2007).

It is also interesting to note the much higher EC readings that occur within the Crater lakes on Central Island, and that the fish within Crater Lake A (or sub-species - FoLT, 2010) comprise 5 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 concentrations and will not be adversely affected by high salinity in the foreseeable future…(ibid., p.1565, Chapter 5)". It should be mentioned that the species diversity in Crater Lake A is very much less than the main lake, as would be expected, and is restricted to a few species only (FoLT, 2010) which have survived since the time there was hydraulic connection with the main lake. The last time that the Central Island crater and main lakes were connected was about 1902 (Hopson et al, 1982). The water level in the Crater Lakes follows the main lake level, as it is sustained through percolation from the main lake nearby. Although more concentrated, changes in cationic composition of the Crater Lake A's chemistry have been slight (ibid.)

The vulnerability of the fish and food chain to increasing salinity in Lake Turkana remains to be tested and the limits remain to be established.

A comparison with other African lakes is presented in the Table below. The classic paper of Talling and Talling (1965) arbitrarily classified lakes into three classes according to ionic content:

- 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. 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 cychlids (*Alcolapia* spp) that have evolved to survive in the lower ionic content springs feeding these lakes, and their associated lagoons. The small cychlids in Lake Nakuru were introduced from Lake Magadi's springs and lagoons because they are salt tolerant.

Table 14: Comparison of African lake conductivities @ 20°C
(Source: Talling et al, 1965, and others as listed)

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

2.9.1.3 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 the lake chemical balance that there is no major sub-surface flow from the lake to the west and south. Hence water losses from the lake are assumed to be predominantly evaporative.

2.9.1.4 Salinity increase with volume changes

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.

2.9.2 Lake Turkana fisheries

2.9.2.1 Previous research

Lake Turkana and the Omo delta have 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 and 1900: Collections of fish from the Turkana Basin by Dr Donaldson Smith, during two visits.

b) 1908-15: Fish collections from the Omo River and north end of Lake Turkana (Boulenger, 1909, 1911, 1915).

c) 1931-32: Cambridge University Expedition (Beadle 1932, Worthington 1932, Worthington & Ricardo 1936, Trewavas 1933).

d) 1932-33: Mission Scientifique de l'Omo sampled fish from the Omo River and delta (Pellegrin 1935).

e) 1960-64: Hamblyn (1960) and Mann (1964).

f) 1972-75: Lake Turkana Project, UK Overseas Development Administration and Kenya Fisheries Department (Hopson et al, 1982).

g) 1985-88: Norwegian Institute for Water Resources Research (NIVA) and Kenya Marine Fisheries Research Institute (KMFRI) – Lake Turkana Limnological Study (Kallqvist et al, NIVA, 1988).

h) 1987-89: Department of Fisheries and Marine Biology, University of Bergen, Norway – The fish resources of Lake Turkana and their environment (Kolding, 1989).

The Lake Turkana Project's work is a remarkable detailed study. A bathymetric survey of the 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 manufactured in Scotland and transported to the lake through the Port of Mombasa and overland from the Kenya coast and finally through the Chalbi Desert, specifically for the research project.

Photo 4: RV Halcyon – Research Vessel, 1972-75

NIVA later 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).

2.9.2.2 Lake Turkana Ichthyofauna and habitat

The following interesting facts are derived from Chapter 5 of the Lake Turkana Project (Hopson et al, 1982), written by A.J. & J. Hopson, 1982:

The lake ichthyofauna identified in 1982 was recorded as 48 species, ten of which were endemic to the lake. 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 (see sections above). 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 are specific to the Omo River. 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 38):

- *Littoral Community:* Inhabits the inshore belt, in waters from the shore to 4m 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 4m contour and depth 10-15m (Characteristic species on soft substrates are *Labeo horie, Citharinus citharus*, and *Distichodus niloticus*; Relatively little data on rocky substrates at equivalent depths but *Bagrus docmac* probably occurs).
- *Offshore Demersal Community:* Ranges throughout deeper waters within a 3-4m band following the bed of the lake. The inshore limits vary 8 to 20m 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 demersal community to 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 5m in turbid waters to 30m 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 depth range up to 60m. Larger fish are scarce but adult *Engraulicypris stellae* 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).

More recent bibliography states that the number of species of fish recorded had increased to 60 species (KWS Tourist Map of Sibiloi National Park, also KMFRI 2007 citing Luc Devos, Fishbase 2000).

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).

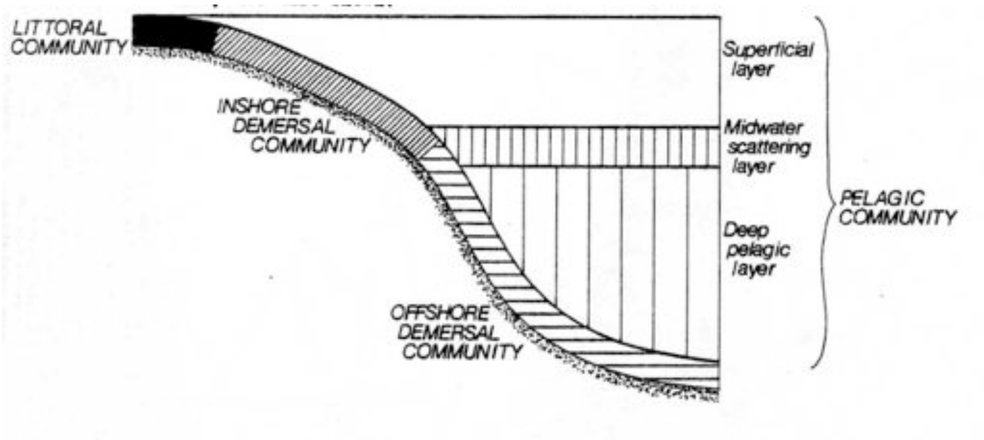


Figure 38: Diagrammatic section of fish community zones
(Source Figure 5.2, Hopson et al, 1982)

(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).

2.9.2.3 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 (ibid.):

- Five species spawn only in the Omo River (*Alestes baremose, A.dentex, Citharinus citharus, Distichodus niloticus, Barbus bynni).*
- One of the 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).*

2.9.2.4 Food sources for fish (after Hopson et al, 1982)

Figure 39 below summarises the fish feeding habits (ibid). The food sources are listed, and all the information is from the work of Hopson et al, 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 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)".

2.9.2.5 Plant nutrients (after NIVA, Kallqvist et al, 1988)

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 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 15: 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 (1988)	Central Sector	< 100
2007	Getabu et al (2007)	Lake	1.4 – 89.9
2007	Getabu et al (2007)	Omo River	> 20

(Sources: Given in Second Column in the table above)

2.9.2.6 Commercial fisheries

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).

A variety of traditional methods have been used. Rafts were made from doum palm logs. *Sarotherdon 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).

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).

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 17 and Figure 41 present some fish catch records held by the Fisheries Department, as published by Hopson up to 1976, plus there is one record for 1984 included by NIVA (NIVA, 1988); and the data has been supplemented by more recent data to 2007 (Mbogo, 2010, and Ministry of Fisheries Development statistics, 2000-2005).

The Turkana catch records are put into perspective with the catch in other Kenya lakes in Table 17 below. Lake Turkana ranks 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 almost half the area of Lake Turkana. Lake Turkana thus provides only about 4% of Kenya's annual freshwater fish catch.

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 16.

NIVA also 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 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 not 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 are speculative, and NIVA noted that the Hopson data is based on a higher lake level. NIVA considered the figures realistic (NIVA, 1988). KMFRI have cited a potential of 88,404 tonnes annually (Ojwang et al, KMFRI, 2007 P.v). Mbogo cites a potential of 37,000 tonnes annually (Mbogo, 2010).

Almost 30 years have elapsed since the Hopson studies, and the fisheries catch recorded in recent years has 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 3.1m below the 1972 zero datum. 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, p.1572). 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/Kallqvist et al, 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.

2.9.2.7 Lake Turkana fisheries – export potential and the parasite challenge

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).

The widespread infestation of most fishes by a custody parasite was earlier documented by KMFRI (Ojwang et al, KMFRI, 2007, P.95). "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.)". Elsewhere in the same report it is stated that "…preliminary investigations of

Nile perch suggest that the parasite has no known human health related implications (ibid, P.95)". The parasites are also being studied by Masaryk University (Jirku et al, 2010).

In the context of potential, Kolding's research findings should be borne in mind (Kolding, 1993). Some of the findings were presented above, and caution and realism is advised in commercial fisheries expectations, especially as the lake is often treacherous for boats due to its high winds.

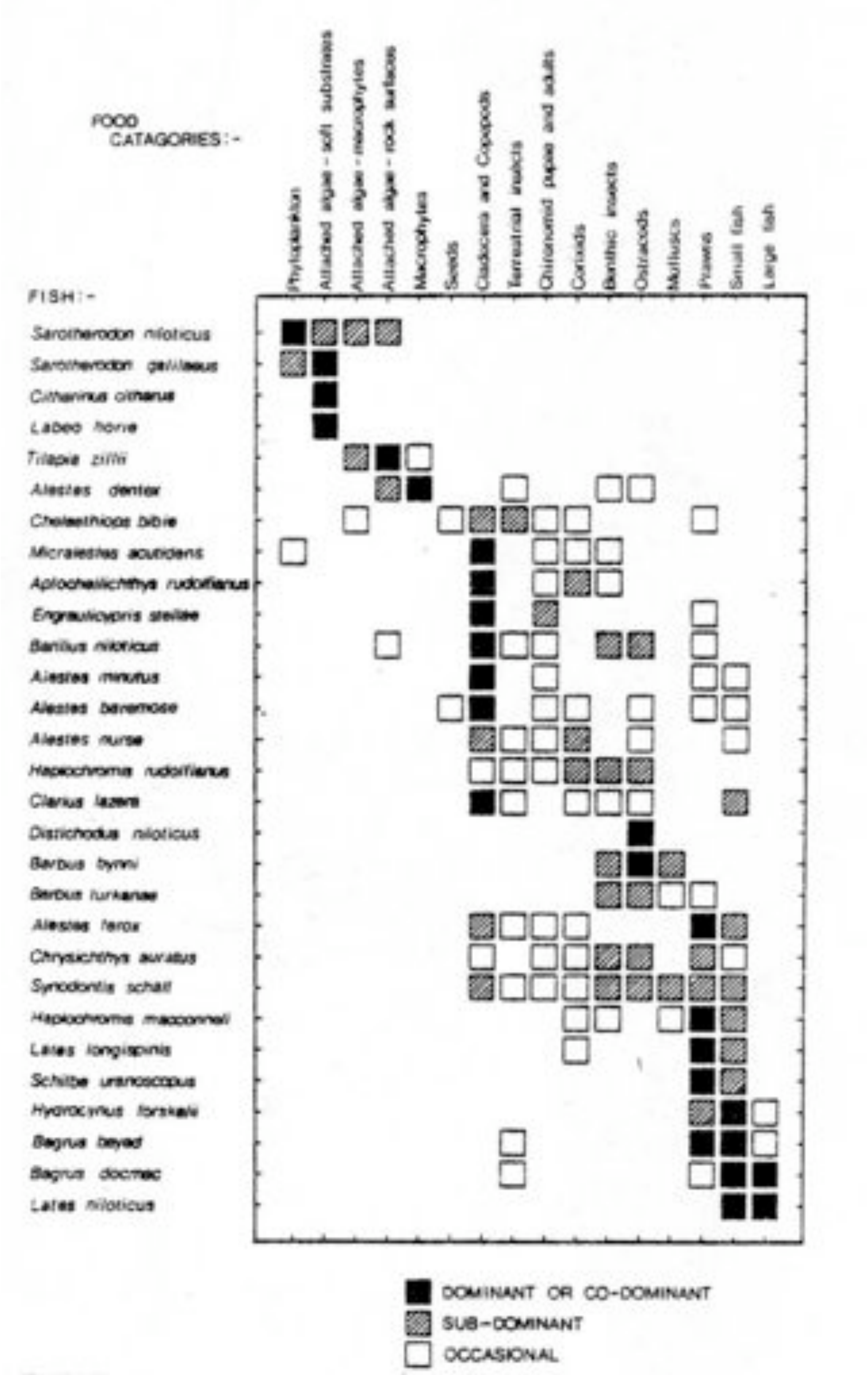


Figure 39: Food sources for fish (Hopson et al, 1982)

Fishermen, near Loyangalani

Fishing net with catch

Fish drying in the sun

Sports fishermen at Allia bay

Nile Perch being weighed

Photo 5: Fishing on Lake Turkana
(Source: Sean Avery Photo Archive)

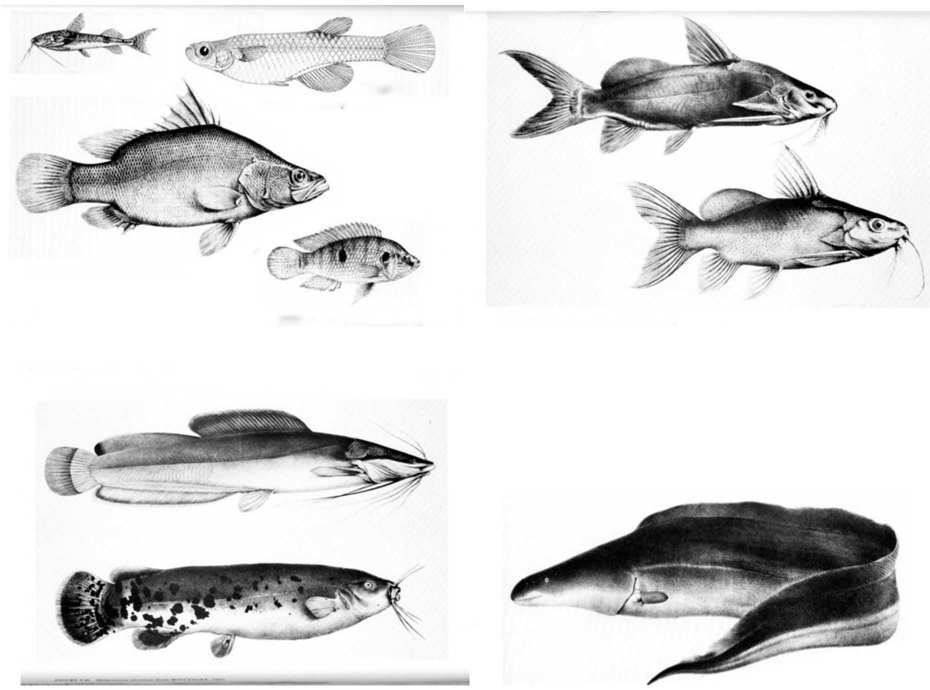


Figure 40: Some of Turkana's fish
(Source: Selected images of fish extracted from Hopson et al, 1982)

Table 16: Commercial fish catch records for Lake Turkana
Tonnes “equivalent wet weight”, n.d. signifies “no data”

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	

Year	Catch (tonnes)	Source of this other data
1984	8,500	NIVA, 1988
1999	5,239	Mbogo, 2010
2006	4,550	Mbogo, 2010
2007	9,000 [6]	Mbogo, citing Ojwang

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 t (UNEP); (5) Hopson et al, 1982, p1577; (6) Mbogo 2010 (citing Ojwang, 2007), Year 2007 catch=9,000 t, sustainable yield=37,000 t annually; (7) H=Heavily exploited; L=Lightly exploited; (8) 2,850 t 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 t applicable to Ferguson’s Gulf at optimal conditions, 500 t applicable to remainder of lake); (10) Hopson et al Table 13.2, Alestes minutus and A. ferox not included above (minute fish and not commercial), yield=560,000 t (approx).

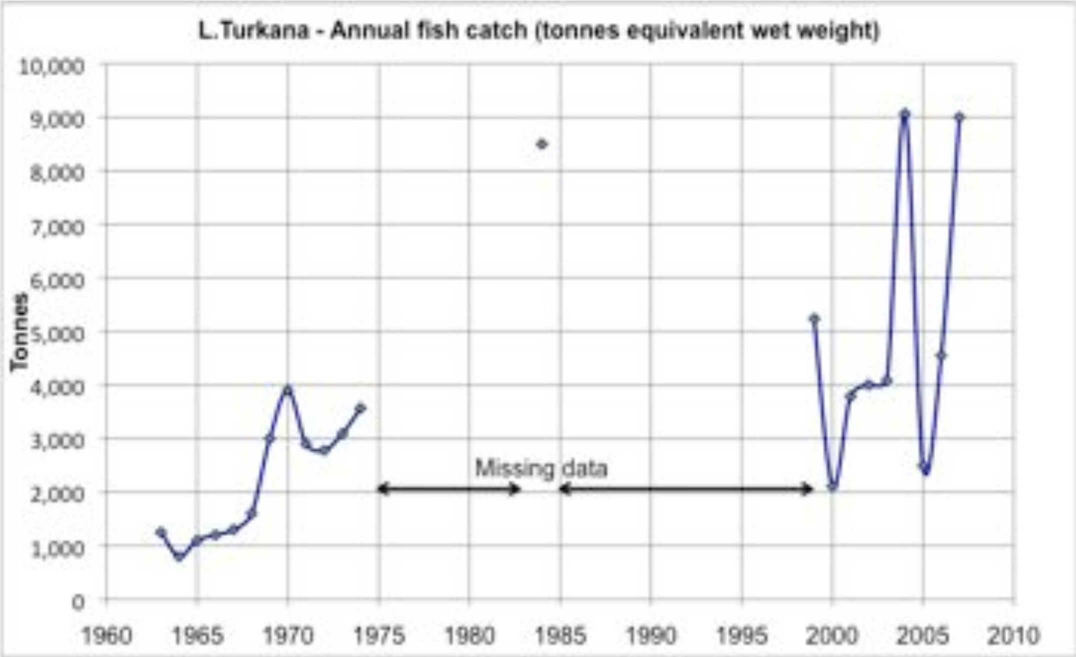


Figure 41: Lake Turkana fish catch records
(Source: Ministry of Fisheries Development records, Hopson et al, NIVA)

Table 17: Kenya'a national fish production statistics (values in tonnes)
(Source: UNEP - see Notes below)

	2003 (2)	2004 (2)	2005 (2)
Lake Victoria (1)	105,866	115,747	133,526
Lake Turkana	4,004	4,180	2,493
Lake Naivasha	39	62	99
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

Notes:

(1) Kenya's fishing area of Lake Victoria is 4,260 km^2 (National Assembly, 2009)
The total fish yield of the entire Lake Victoria is said to be 800,000 t (LVFO)

(2) Source: UNEP (UNEP, Status of Environment and Natural Resources Statistics…)

(3) Other Source: MoFD data. MoFD data for 2004 (9,067 t) suspect and disregarded.

2.9.2.8 Environmental factors affecting fisheries

The environmental factors affecting the fish were listed as follows (after Hopson et al 1982, and NIVA 1988):

- *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 – discussed earlier in Section 2.9.1.2*)*, 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 north-westerly 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 NW wind-induced surface currents carry zooplankton in the surface layers, which concentrate on the 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 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-plain" 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.
  - 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 mm 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".

2.9.2.9 Ferguson's Gulf

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" (Kolding, 1992).

The Gulf is vulnerable to drops in lake level, and becomes dry whenever the lake level falls below -3.1 metres. 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" was associated with "droughts in shallow lakes" (ibid.).

2.9.2.10 Recent review of baseline of limnology and fisheries

AFDB 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.):

- 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 (at Kalokol, Kataboi, Namaduk, Nahukui, Todenyang, Lowereng'ak, Eliye). Three are located on the eastern side (at Ileret, Moite, Loyangalani).
- 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 citing Ojwang et al, 2007), which was about one quarter of the minimum estimated potential of 37,000 tonnes annually (Mbogo 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 will not be repeated here. There is also data on recent localised research into water quality, taken from the KMFRI report dated 2007.

2.9.2.11 Conclusions and recommendations by NIVA / KMFRI / Kolding

It is relevant to repeat the findings of NIVA / KMFRI in 1988, and reported by Kolding in 1992, as they confirm the earlier findings of Hopson, and the recommendations are 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 irrigation development and other developments in the Omo Basin, for instance Gibe IV and V:

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 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).

2.9.3 Potability of the lake's saline waters

Sampling of the lake and spring water quality was beyond the scope of this study. However, a literature review has been undertaken and the results included below. The chemistry in the two tables below is similar, and will be discussed further below. Immediately apparent are the high dissolved solids, high sodium and chlorides, unacceptably high fluoride levels, high pH.

Table 18: Composition of Lake Turkana waters
(From Walsh & Dodson, 1969)
(Original data published in parts per 100,000 and converted here to parts per million, ppm)

	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

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 19: Major ions in River Omo and Lake Turkana waters
(Source: Hopson et al 1982)

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

Kenya's water quality standards for rural and community water supply include limits which are tabulated in Table 20 (MoWD, JICA Sectoral Report C, 1992).

Table 20: Water quality standards for rural and community water supply

	Lake Turkana	Permissible level (1)	Limit (1)	Guide Value (Max allowable) (2)
Electrical conductivity, 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
Sources: (1) MoWD / JICA Sectoral Report C, 1992, (2) Second Schedule, EMCA Water Quality Regulations, 2006) (3) Tables above

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 health risks attached.

Various classifications are used 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 according to degrees of salinity, as follows (Wikipedia):

1,000 – 3,000 mg/l	*Slightly saline*
3,000 – 10,000 mg/l	*Moderately saline*
10,000 – 35,000 mg/l	*Highly saline*

Based on the USGS classification (Wikipedia), Lake Turkana's waters are "slightly saline". Based on drinking water standards, the waters are "saline".

Kenya's Ministry of Water guidelines for livestock water quality are reproduced in part, as follows, in Table 21.

Table 21: 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 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.

The fluoride level at >10 ppm is well in excess of acceptable limits for both human and livestock. The following risks apply to fluoride consumption (WHO, 1984):

- Fluoride > 1.5 ppm, mottling of teeth can occur
- Fluoride 3.0 to 6.0 ppm, skeletal fluorosis can occur
- Fluoride > 10 ppm, crippling fluorosis can occur

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.

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. Livestock tolerance 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 limits.

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.

Various water sources are utilised by people around the lake, and these are likely to be very much better quality. These sources are described in an earlier section of this report. People traditionally seek better quality water from springs and through wells dug within dry river beds. Some water quality data was found in the literature. The Loyangalani Springs have electrical conductivity 554 μS/cm (Hopson et al, 1982), well within acceptable limits. The same study measured electrical conductivity in the Kalokol Gorge pools to be 850 and 803 μS/cm.

Routine water quality monitoring is recommended to establish trends. 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 would exacerbate the situation, and would increase the significant health risks associated with the persistent traditional local practise of drinking the lake waters.

2.9.4 Comments on irrigation suitability of the lake's slightly saline waters

Typical water quality guidelines for irrigation water are presented in Table 22 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 22. Hence the lake water is unsuitable for irrigation under normal conditions.

Kenya's '*Standards for Irrigation Water*' are partly reproduced in Table 23. 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 barren and desolate area. There are numerous windmill and portable motorised pumps to be seen along the Omo River banks (Sogreah, 2010).

Table 22: 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 23: Kenya's '*Standards for Irrigation Water*'

Parameter	Lake values	Permissible Level (2)
pH	> 8.5	6.5 – 8.5
Fluoride, mg/L	> 10.0	1.0
Chloride, mg/L	> 500	0.01
Total dissolved solids, mg/L	> 2,400	1,200

Source: (2) EMCA (2006), Ninth Schedule.
Note that selected parameters only are listed in the table above.

2.10 Climate and Rainfall in the Omo Basin

2.10.1 Climate Zones of Ethiopia

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 2,400m, with daily temperatures ranging from near freezing to 16°C.
- "Weina Dega" or "temperate zone", which consists of parts of the central plateau, ranging in altitude between 1,500m and 2,400m.
- "Kolla" or "hot zone" which generally comprises areas below 1,500m altitude, the Danakil Depression and tropical valleys of the Blue Nile.

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).

2.10.2 Tropical climate and the ITCZ

The seasonal variation in climate stems from the oscillation of the ITCZ (Inter Tropical Convergence Zone). 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.

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, and remains to the south through December, January and February. 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).

2.10.3 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).

Annual rainfall varies from 1,900 mm/annum in the north / central areas of the Omo Basin, to less than 300 mm/annum in the south (Woodroofe & Associates).

The annual rainfall generally diminishes through the Basin as the river drains from the highlands in the north to Lake Turkana in the south. Updated rainfall data was obtained from Ethiopia's National Meteorological Services Agency (NMSA), for three selected rainfall stations within the Omo Basin, for the period 1956-date.

The annual rainfall fluctuation over time for the three selected stations is presented in Figure 42 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 monthly rainfall variation over the Basin has been analysed in Figure 43. In the north of the Omo Basin, the rainfall seasonality is uni-modal, but it becomes increasingly bi-modal towards the Equator, as reported by others (Studio Pietrangeli, Agriconsulting etc).

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)"

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

The impacts of climate change were 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). That 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.

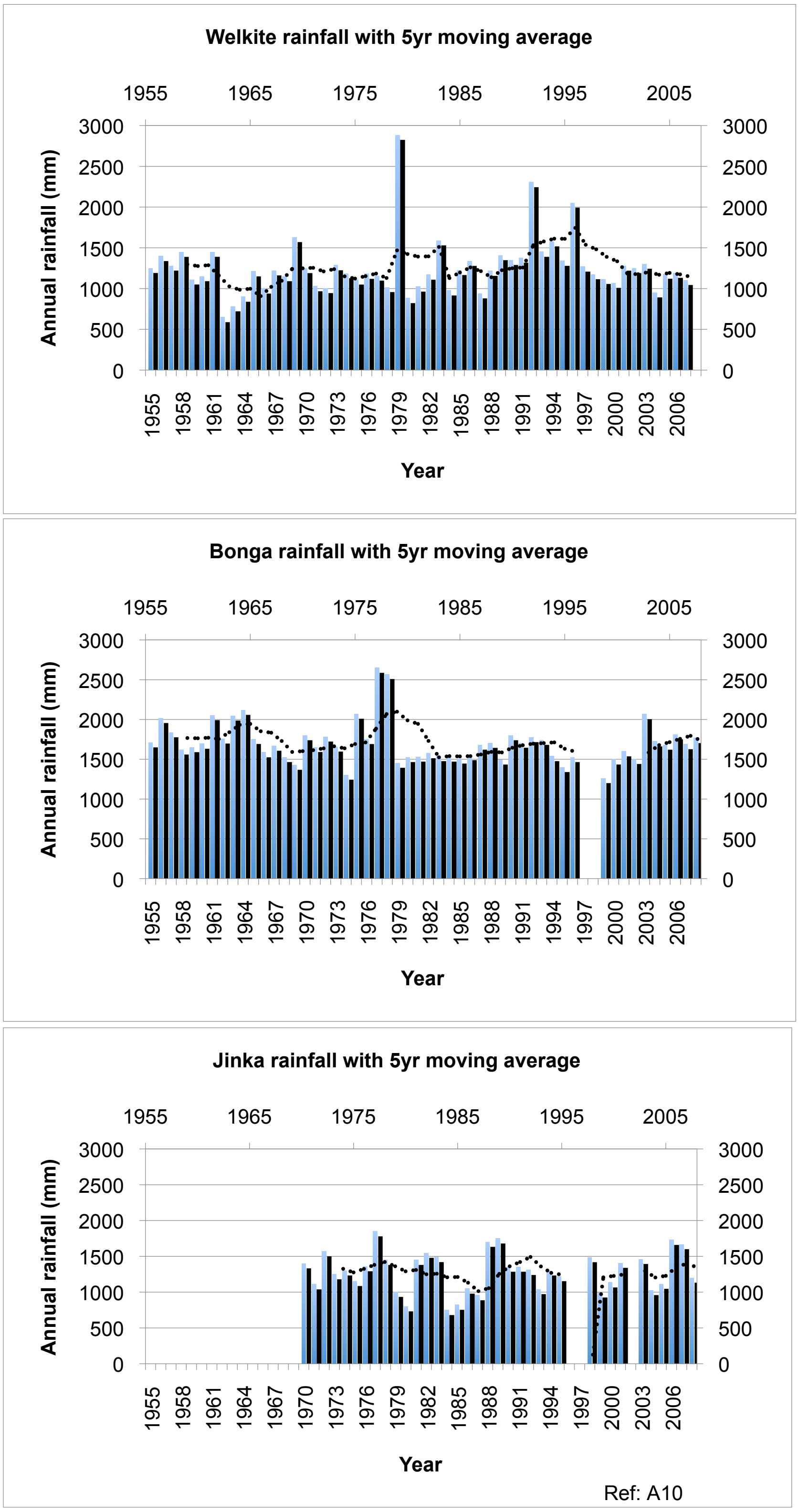
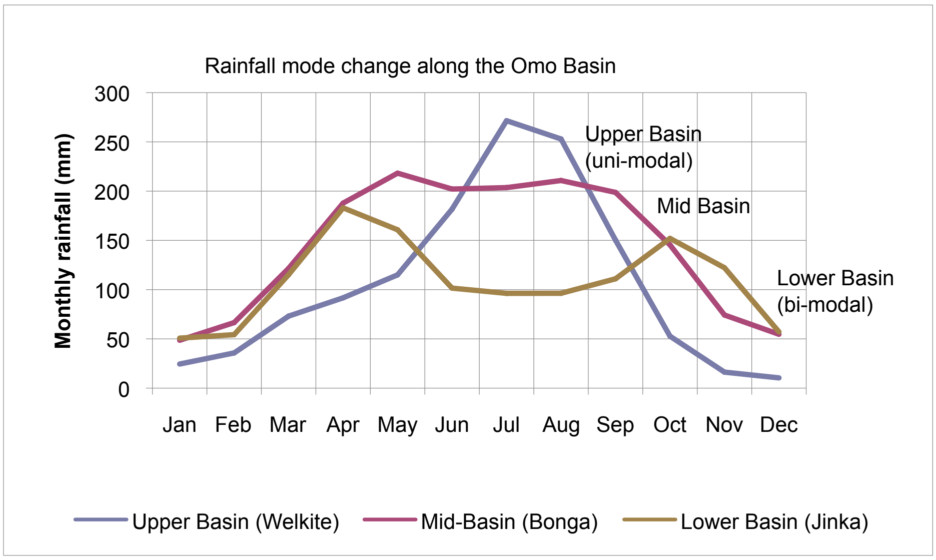


Figure 42: Annual rainfall variation in the Omo Basin at three selected stations (1955-2008)
(Source: Monthly data obtained from NMSA, Addis Ababa)



Notes on rainfall data sources:

Welkite:	Altitude 1550 m	Lat. 8° 16' N,	Long. 37° 49' E (1954 – 2008)
Bonga:	Altitude 1650 m	Lat. 7° 13' N	Long. 36° 14' E (1953 – 2008)
Jinka:	Altitude 1480 m	Lat. 5° 47' N	Long. 36° 34' E (1970 – 2008)

Figure 43: Omo Basin rainfall patterns (1955 – 2008 data)
(Source: Monthly data obtained from NMSA and Omo-Basin Integrated Development Master Plan, Vol.VI, A1)

2.10.4 Climate variation on Lake Turkana's shores

Rainfall data was obtained from the Kenya Meteorological Department (KMD) for stations adjacent to the shores of Lake Turkana, and this data is included in Annex 2, and is summarized in Table 24 below. Note that stations other than Lodwar have a high proportion of days with "missing data"; hence these records are less useful than the Lodwar data. There is an increase in rainfall towards the northern end of the lake. There are no stations at the southern end of the lake, but the southern end is even more arid and rainfall can be expected to be lower than at Lodwar.

The monthly average rainfall variation displayed by this data is represented graphically in Figure 44. Rainfall on Lake Turkana is very much lower than within the Omo Basin, which receives 1,900 mm in its upper parts. The bi-modal rainfall pattern observed in the lower Omo Basin is also found along the shores of the lake, as is to be expected. The "greener" characteristics of the Omo Basin are clear in the 3-D satellite image in Figure 4, in contrast to the barren landscape around the lake.

The long-term annual rainfall series for Lodwar is plotted in Figure 45. The average and moving average are both plotted.

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 1940s, 1950s, and 2009, as follows (grouped within decades):

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

The data and comments in this section relate only to the lakeshore itself, and do not reflect the changes in lake level which are controlled by the Omo River flow, which in turn is controlled by the very different 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 24: Rainfall data for Lake Turkana

Station No	*Latitude*	*Longitude*	*Station Location*	*Years Record*	*Start Year*	*% Data*
8535001	N 04° 32' 00"	E 35° 55' 00"	Todenyang	39	1959	59%
8635000	N 03° 07' 00"	E 35° 37' 00"	Lodwar	69	1940	97%
8736002	N 03° 32' 00"	E 35° 53' 00"	Loyangalani	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%

Station No	*Jan mm*	*Feb mm*	*Mar mm*	*Apr mm*	*May mm*	*Jun mm*	*Jly mm*	*Aug mm*	*Sep mm*	*Oct mm*	*Nov mm*	*Dec Mm*	*Ann mm*
8535001	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
8635000	7.7	7.0	24.6	45.6	23.1	5.6	14.9	10.4	5.5	10.7	21.9	11.2	188.0
8736002	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	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	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

*Note: Monthly data purchased from the Kenya Meteorological Department, Nairobi (*Annex 2*)*

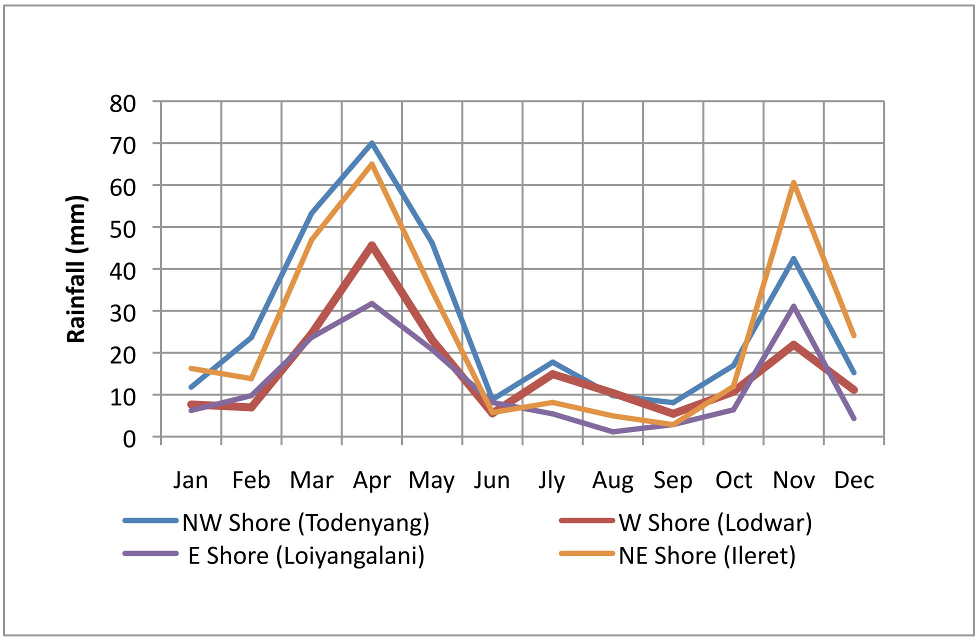


Figure 44: Monthly rainfall variation along the shores of Lake Turkana
(Source: Monthly data from Kenya Meteorological Department, Nairobi - Annex 2*)*

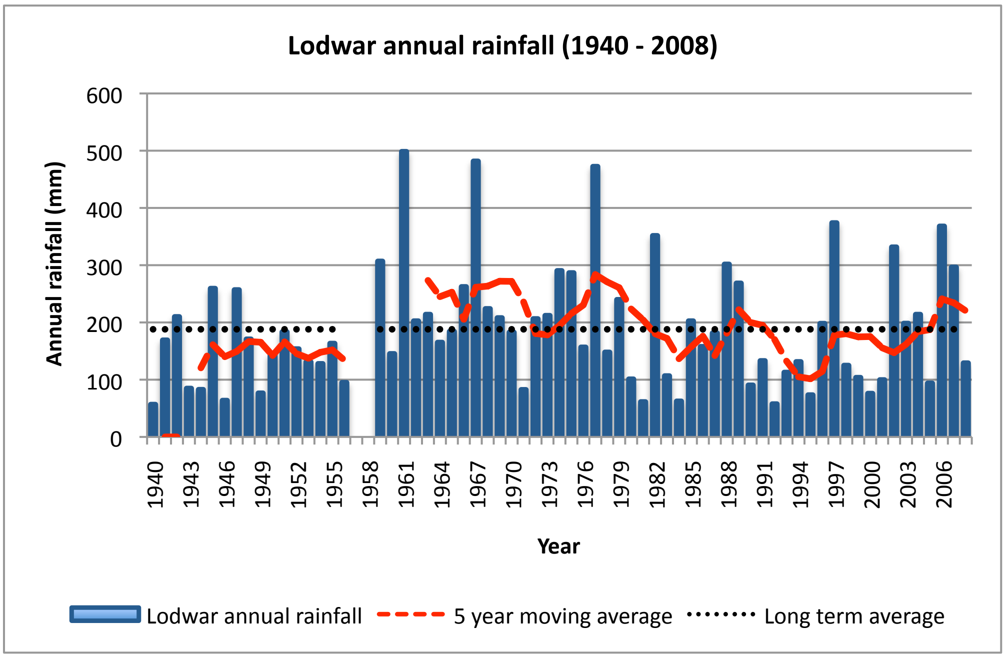


Figure 45: Annual rainfall fluctuations on western shore of Lake Turkana (Lodwar)
(Source: Monthly data from Kenya Meteorological Department, Nairobi - Annex 2*)*

2.11 Lake Turkana evaporation losses

Lake Turkana is located within a very arid environment, with a potential evaporation rate ten times the annual rainfall. In arid areas, the evaporation assessment is critical in regard to open waters in reservoirs and lakes.

The theoretical basis of calculations considered by some to be the most suitable in Kenya, is the Penman method (Kalders, 1988). The Penman method enables derivation of potential evapotranspiration from meteorological data. Such data is often not available. However, there is a full meteorological station at Lodwar, and the Penman evapotranspiration rates calculated for this station are reproduced in Table 25 (ibid).

Note the following from the table:

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.
4. The annual evapotranspiration is 2,625 m/year (7.2 mm/day).

Evaporation rates are traditionally measured using evaporation pans. However, the actual evaporation from a large open water surface is very much less than measured from a pan. The ratio of "pan" to "open water" evaporation has a typical value in the range 0.60 to 0.70, known as the "pan coefficient" (Linsley, Kohler, Paulhus).

An evaporation tank located next to the lake on Longech Spit near Lodwar (during the Lake Turkana Project 1972-75), recorded evaporation rates of 5.8 m/year (15.9 mm/day). This pan data also confirmed there are no seasonal changes in evaporation, and that "relatively high evaporation rates persist throughout the year" (Ferguson & Harbott, 1982). Application of pan coefficients to the measured lakeshore pan evaporation yields the following potential open water evaporation rates:

- *Pan Coefficient = 0.6:* Daily evaporation = 9.5 mm/day
- *Pan Coefficient = 0.7:* Daily evaporation = 11.1 mm/day

Ferguson & Harbott also presented data from a Piche evaporimeter from which an estimate of 3.2 m/year (8.8 mm/day) was derived.

Ferguson & Harbott noted that the 5.9 m/day (15.9 mm/d) pan measurement might have been affected by the fact that the water temperature in the pan was 3 degrees higher than in the lake water body. 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 lower night temperatures associated with desert regions, with the reverse effect on evaporation rate.

Ferguson & Harbott also examined lake level recession rates as another means of assessing evaporation. They observed that the lake level falls at a constant rate during the first part of the year. They assumed that 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/annum (6.4 mm/day). They then assumed this to be the actual lake evaporation rate. Their 6.4 mm/day measurement would equate to an equivalent pan coefficient on measured pan data of 0.4, which is low. Whilst it is reasonable to assume minimal rainfall, it will be shown elsewhere in this report that the low flows from the Omo may not be zero, and that the evaporation rate is likely to be higher than 6.4 mm/day. It should also be noted that Turkana experiences ferocious dry winds off the adjacent desert areas, and the wave action and surface turbulence can also be considerable, all of which contributes to evaporation.

For this study, satellite radar altimeter lake level data has been downloaded for the lake for the period 1993–2008 (courtesy of USDA-FAS). This data comprises an averaged lake level every 10 days. The lake level changes have been computed, and the values ranked into an ascending series, and then plotted in Figure 46, with the following results:

- *Highest value*: 10.5 mm/day.
- *2% Exceedence*: 8.2 mm/day.
- *5% Exceedence:* 7.1 mm/day.
- *10% Exceedence:* 6.3 mm/day.

Unfortunately, there is no coincident river inflow data in the period since 1992 with which to separate out the components in the water balance. The only Omo inflow records were collected in the period 1977 – 1980. 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. Unfortunately, there is no lake level data for this period.

It will be demonstrated later in this report that a water balance model for the lake achieves balance at an evaporation rate loss in the range 7.2 to 7.8 mm/day, which is the same as the calculated evapotranspiration rate for Lodwar Met. Station (Table 25 below), and referred to above. Note that percolation losses are assumed negligible, and would be included within the lake recession measurements attributed to evaporation. Hence the assumed evaporation loss is a total loss inclusive of seepage to groundwater, and takes into account the salinity effects on evaporation.

Table 25: Penman Evapotranspiration for Lodwar Met. Station, No.8635000

Month	Average Temp (^{o}C)	Dew Point Temp	Sun hours per day (hrs)	Et per day (mm)	Et per month (mm)
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					2,625.3

Source: Kalders, 1988, Lodwar Met. Station (altitude 506m above mean sea level).
Et = Evapotranspiration = 2,625.3 mm/annum = 7.2 mm/day.

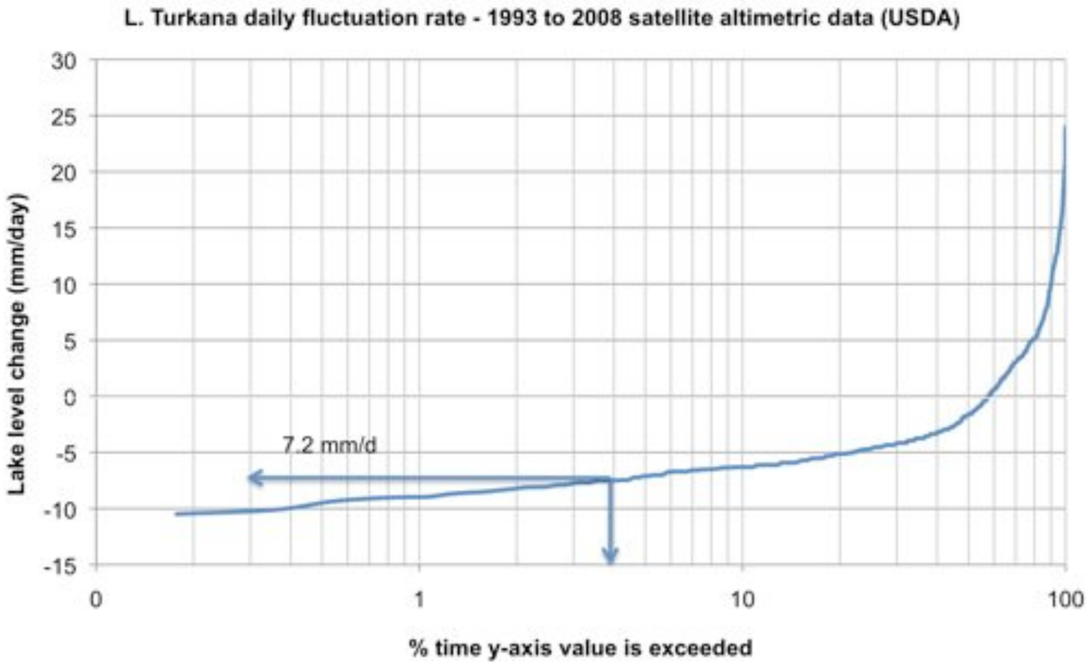


Figure 46: Daily lake level fluctuation rates

2.12 Summary of changes and impacts on Lake Turkana

It is evident from Section 2.9 that the Omo River influences the lake in several respects, as follows:

- The river carries salts, minerals and essential nutrients into the lake.
- Sediment deposition rates have been estimated to be 4.3 mm/day in 1972-75. The sediments create a delta zone, and sediments are also distributed throughout the lake by currents.
- 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, the following changes need to be considered in regard to the impacts of the proposed Omo Basin hydroelectric and other proposed development schemes affecting river flows:

- Sediments and minerals, which naturally pass down the river to the lake, will be intercepted by the impounding reservoirs. 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 area from which the flood flows derive nutrients. The reduction in overtopping will impact the replenishment of wetlands in the delta.
- Nutrient inflow patterns to the lake will alter, not only because of the dams 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.
- Consumptive use of water within the Omo Basin will reduce volumes 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 3.1m 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, 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.

3 LAKE TURKANA WATER BALANCE

3.1 Introduction to the water balance

In Section 1, the climatic, hydrological and bathymetric data and physical characteristics have been presented for the Lake Turkana Basin. Unfortunately, measurement of 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 2.8.2), hence monitoring can continue since lake level is a direct consequence of inflow.

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 losses being replenished through the annual inflows from the Omo. If inflows exceed evaporation losses, the lake 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.

Hence any consumptive use of water within the Omo Basin can only result in the shrinking of Lake Turkana, with consequences that have not been determined.

3.2 Ecological flows needed to sustain the lake

Lake Turkana is effectively an evaporation pond. The entire Omo River 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.

The lake ecology's behaviour patterns are governed by sun light, 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 / KMFRI, 1988), but the 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 the increasing human and 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 Project will store Omo river waters for subsequent release through turbines to generate hydroelectric power. Gibe III is a renewable energy project, and such projects are encouraged in this era of countering global warming effects due to fossil fuel burning.

The Gibe III Project subsequently recognised the need for ecological flows to sustain the downstream riverine environment, and the Project considers there is need to mitigate the effects of increasing floods on the traditional cultivation practices in the lower Omo Basin. The Project identifies many of the impacts in qualitative terms, but a method of deriving the appropriate ecological flows quantitatively and scientifically has not been presented, and the impacts on Lake Turkana have not been considered at all.

The Gibe III Project has proposed an ecological flow from the dam of 25 m^3/sec, to be sustained as a minimum at all times. The selected value appears to have been based on the lowest monthly runoff of 25.2 m^3/sec in March 1973 (see the derived Gibe III inflow sequence from 1964 – 2001, Table 3.1 Agriconsulting SpA et al, 300 ENV RAG 003B). This low flow of 25.2 m^3/sec was sustained for the month of March in 1973, for one month only. A prolonged sequence of low flow at this level has not been experienced, and its ecological effect has not been assessed. The transmission losses in the channel have also not been assessed, so it is not known what proportion of this water will be lost. Based on experiences elsewhere, transmission losses could be appreciable, as the river travels over 600 km in its passage from Gibe III to the lake. The 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. The increased abstraction is 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).

The Gibe III Project has also proposed an "ecological flood" of 1,000 m^3/sec in the month of September, to be sustained for ten days. The basis for this 10-day flood duration has not been established. It has been assumed in the EIA that one flood is ecologically sufficient, but what is the basis for this assumption? 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 (Hughes et al, 1998). The above South African methodology requires the assessment of the following flow proportions that make up the total flow volume:

- 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 be introduced to cater for sustaining the lake ecology. This aspect is critically important as the flood plain fisheries have been found highly dependant on flood pulses (Kolding, 1993), as discussed elsewhere.

There are established methods, which for a project of this magnitude should be implemented as a basis for guiding sustainable development of the Basin.

An example is IFIM (Instream Flow Incremental Methodology), described by HR Wallingford as "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" (DFID funded *Handbook for the Assessment of Catchment Water Demand and Use*).

The present study presented in this report can evaluate the runoff changes, but the impacts on ecology need to be the subject of a separate study, although comments are made based on published research. The study of flood sequences and durations will be recommended as an essential extended part of this study.

The "dampening" impact of the proposed "average year" regulation on the lake level cycle is demonstrated in Figure 47. The 10-day proposed controlled flood is included within the average flow for the month of September. The CESI flows are adjusted for rainfall and evaporation losses from the lake surface. The typical 1.2 metre lake level rise and fall cycle is dampened to 0.8 metres.

Studies of fisheries in the tropics have shown that flood-plain fisheries are the most productive (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 (Kolding, 1993).

The above is entirely as expected, as ecologists believe 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.

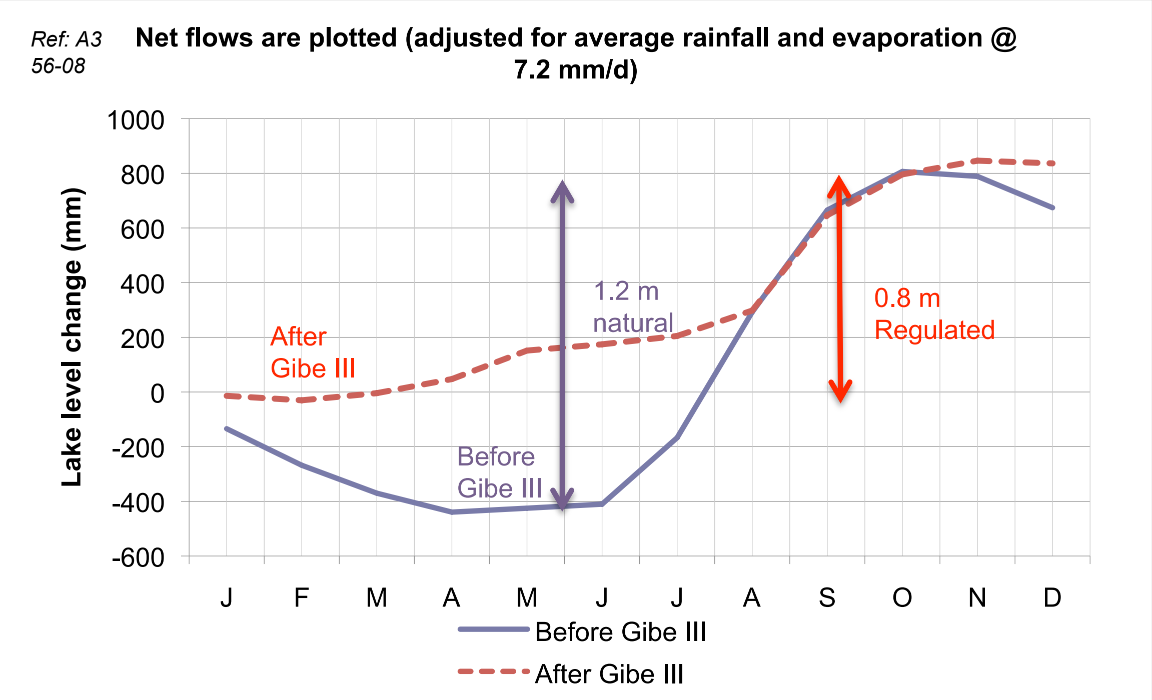


Figure 47: Impact of regulation on lake cyclical level changes

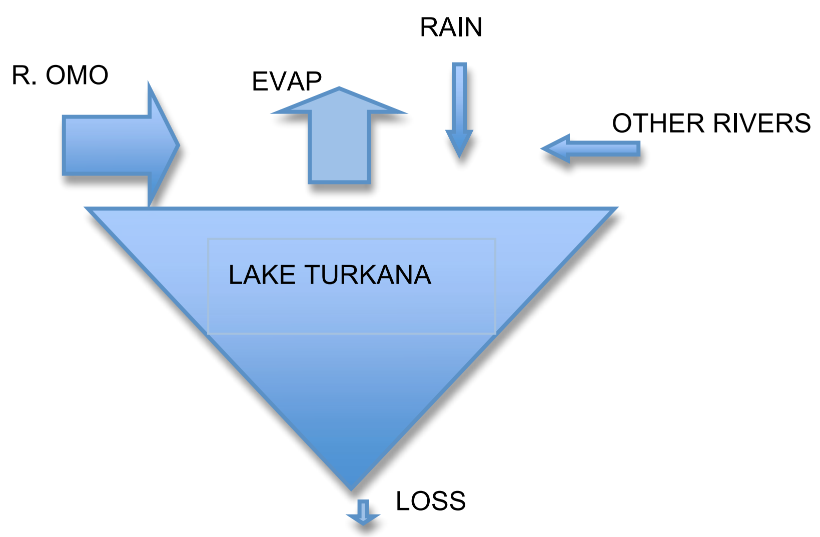
3.3 The water balance model

The water balance model can be described through various equations, as follows:

$\delta VOL / \delta T$	=	Q_{omo} + RAIN + Q_{other} – EVAP - LOSS
δT	=	T- (T-1)
δVOL	=	$VOL_T - VOL_{(T-1)}$
Q_{omo}	=	$Q_T - Q_{(T-1)}$
RAIN	=	$P_{Lodwar} \times F_1$
EVAP	=	$E \times A_T$
Q_{other}	=	$k \times RAIN \times F_2$
A_T	=	$K1.(ELEV_T)^5+K2.(ELEV_T)^4+K3.(ELEV_T)^3+K4.(ELEV_T)^2+ K5.(ELEV_T) + K6$

where:

δVOL	=	Lake volume level change in time δT
δT	=	Time elapsed since last measurement = T- (T-1)
Q_{omo}	=	Inflowing discharge volume from the Omo River during time δT
Q_T	=	Inflowing discharge volume from the Omo River at Time T
RAIN	=	Rainfall 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 to reflect extra rainfall over “lake surfaces”
F_2	=	Factor applied to Lodwar rainfall to calculate rainfall on “other catchments”
k	=	Catchment runoff coefficient for other catchments
Q_{other}	=	Inflowing discharge from other rivers
EVAP	=	Loss due to evaporation from the lake surface during period T- (T-1)
LOSS	=	Other losses or abstractions
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 (constant)
A_T	=	Lake surface area at Time T (varies with lake elevation)



3.4 The water balance model calibration

To calibrate any water balance model requires coincident measured inflow, rainfall, and evaporation data. In the case of Turkana, lake level data is available, but there is no 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 Lodwar Met. Station, and evaporation must be also be estimated from data on potential evapotranspiration. Hence assumptions must be made, and it is a priority that EWRA re-commence river flow gaugings at Omorate, as this station is essential to collect and track data on the Omo Basin outflows.

The only period where there was measured flow data for the Omo River was 1977-80, and unfortunately, this period coincided with a lapse in lake level readings following the conclusion of the Lake Turkana Project. However, there is a simulated flow sequence presented in the Omo Basin Master Plan. The correlation between the Master Plan simulated flows and actual measurements by EWRA has been shown earlier in Figure 16. The cumulative runoff volume over the two-year sequence was close, but the monthly distribution showed differences. Comments were made in Section 2.6.

Puzzling differences between the lake level gauge data and the satellite radar altimeter readings are mentioned in Section 2.8.3. Hence the lake gauge data will be treated with caution until it can be closely inspected. Raw data has been requested from KMFRI, but was not received at the time of finalising this report.

There was coincident Omo River simulated inflow data and satellite lake level data for the period 1993-94. The computed daily evaporation rate averaged 7.2 mm/day over this period. This is a total loss rate inclusive of underground seepage. Simulated monthly inflows from the Master Plan are plotted superimposed on the USDA-FAS website satellite data in Figure 53. The lake cyclical rise and fall is very evident in this 1993-94 monthly data set, the river peak flow occurred in the month of August, and the lake peak level was achieved in October / November, a time lag in this case of two to three months. This time "lag" is to be expected. For comparison, on Lake Tana in Ethiopia, the lake inflow/outflow peak lag is one month (Shimelis G. Setegn 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 – 3,600 km^2, it is smaller than Kenya's Lake Turkana. The Gilgel / Gibe 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.

A similar comparison is presented for 1972-75. This was the period of the Lake Turkana Project for which regular reliable monthly lake levels were recorded. The flows are however simulated flows from the Master Plan. The results are plotted in Figure 54. Again, the cyclical rise and fall of the lake is very evident, with peak flows 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.

3.5 Omo River inflows from 1993 – 2008 derived from lake level model

Due to the absence of data, the following assumptions have been made in the water balance modelling of the lake:

1. The rainfall on the lake surface is assumed to be *[1.2 x Lodwar Rainfall]*.
2. The "other rivers" are assumed to receive *[2 x Lodwar Rainfall]* with a runoff percentage 5% (applied to entire "other rivers" catchment).
3. Evaporation rate from the lake surface is assumed to be 7.2 mm/day, and this is an all-inclusive loss figure, inclusive of percolation/seepage into groundwater.

The lake surface area for computation of evaporation loss is computed from Figure 21.

The model has been used to compute the Omo River inflows from lake levels for three data sets, each for a range of different evaporation rates, and these inflows are then plotted against the inflow sequence derived in the Master Plan. The Master Plan flows are included earlier in Table 11. The model flows are plotted on the vertical axis, and Master Plan simulated flows are plotted along the horizontal axis, the graphs being referenced as follows:

- Figure 48, 1956 – 1994: Compared to the Master Plan flows, the model predicts higher flows at evaporation rates greater than 7 mm/day, and lower flows at evaporation rates less than 6.8 mm/day. The calculated "loss" for this period was 7.2 mm/day.
- Figure 49, 1972 – 1975: The calculated evaporation loss for this period was 7.8 mm/day.
- Figure 50, 1993 – 1994: The calculated evaporation loss for this period was 7.8 mm/day.

Reasonable correlation has been achieved between the model and previously published data, and an evaporation loss of 7.2 mm/day is a reasonable assumption, given the other assumptions.

The average monthly flow derived by the model from the 1993 – 2008 lake level record is presented in Figure 51 and compared with the Master Plan and Salini averages. Strictly speaking direct comparison should only be done with identical time periods, as it might otherwise be misleading, especially as the 1993-08 period reflected by the satellite records has been one of higher lake levels. Nonetheless, the comparison of trends is of interest. The lake-derived averages from this study plot are lag-delayed by one month, as the model assumes an instantaneous response, whereas in practise, the lake peak level occurs after the river peak inflows – see Figure 53. The lag can be built into the model, although this was not considered necessary for the purpose of this report.

Hence, knowing the Lodwar rainfall and the downloaded satellite radar altimeter lake level, the Omo river inflow from Ethiopia can be calculated accurately.

A sensitivity analysis is presented in Table 26 for the annual series 1956-94. The Master Plan average flow is 537 m^3/sec (recomputed to be 526 m^3/sec in Table 11), and for the model, the average discharge varied from 468 to 627 m^3/sec (for evaporation rates 6.4 to 8.3 mm/day). For the selected 7.2 mm/day evaporation, the average Omo inflow was 535 m^3/sec.

The satellite data / model annual sequence from 1993 - 2008 is presented in Table 27. The runoff in this period was on average 560 m^3/sec, although with some variability.

The Omo contribution to total lake inflows in the Table amounts to between 86% and 89% of the total (for the model assumptions adopted).

Table 26: Sensitivity analysis on varying evaporation rate (1956-96 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/sec)*	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

Ref: A4 56-08

Table 27: Mean annual R.Omo discharges derived from L.Turkana level changes 1993 – 2008

Year	Flow m^3/sec
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
Average	560

Ref: A5 93-94

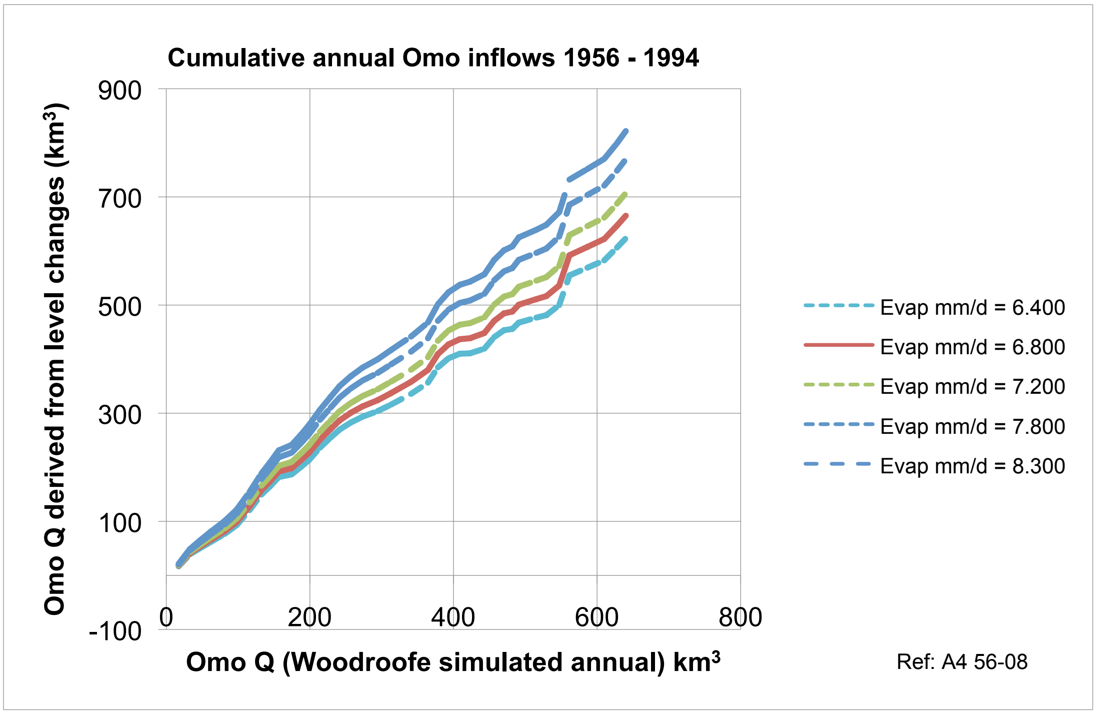


Figure 48: Cumulative simulated Omo flows 1956-94, various evaporation rates

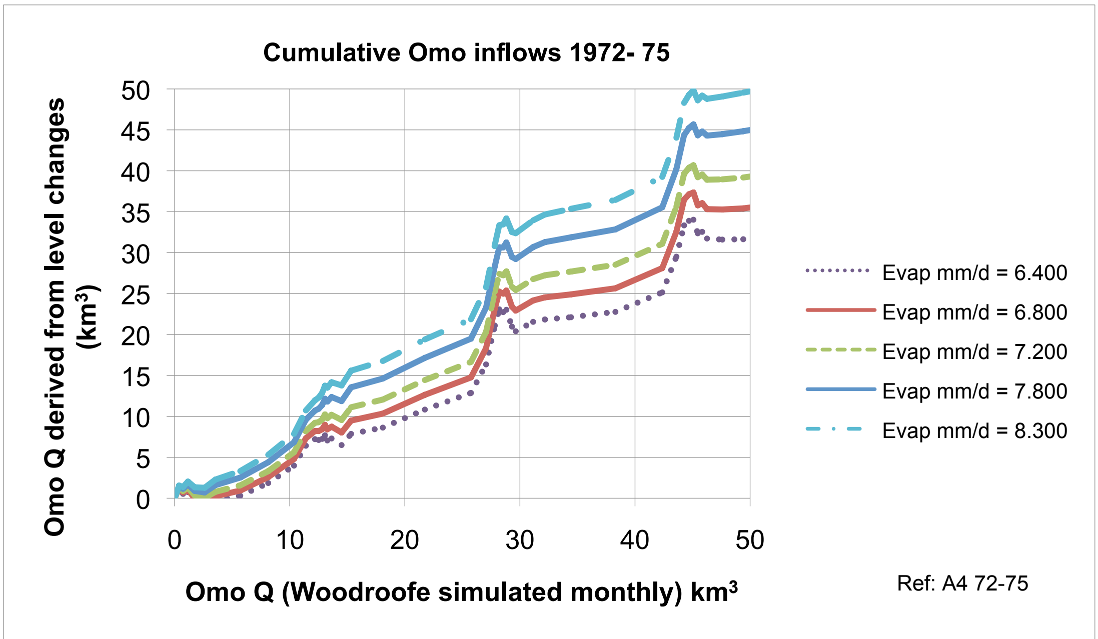


Figure 49: Cumulative Omo simulated flows 1972-75, various evaporation rates

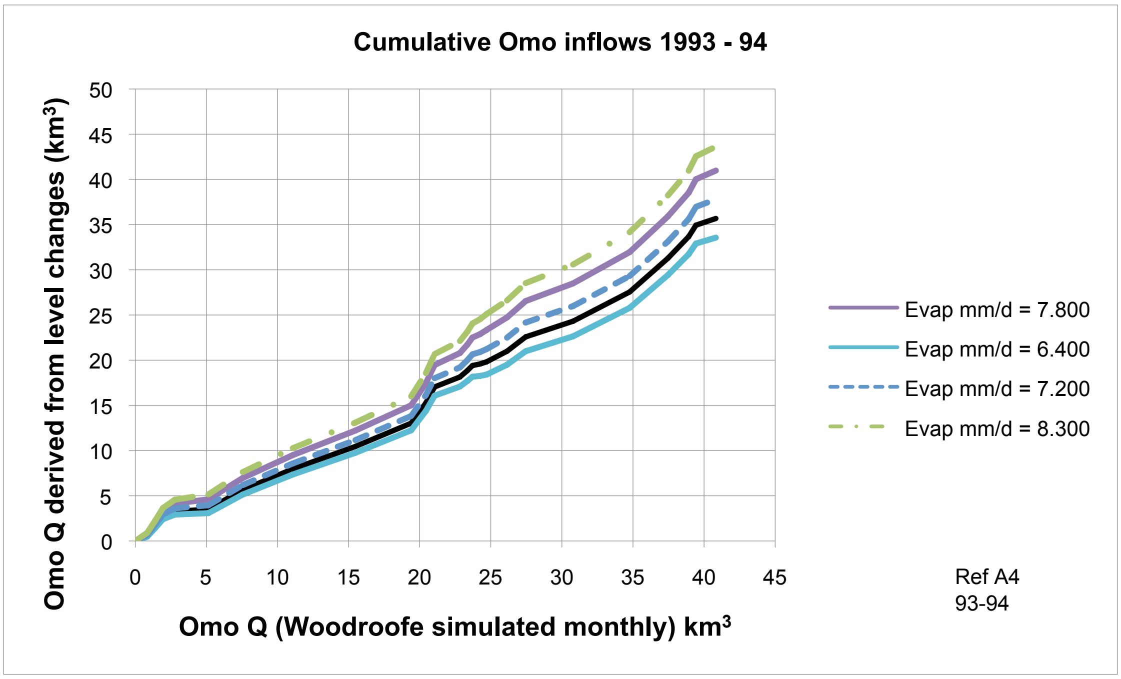


Figure 50: Cumulative Omo simulated flows 1993-94, various evaporation rates

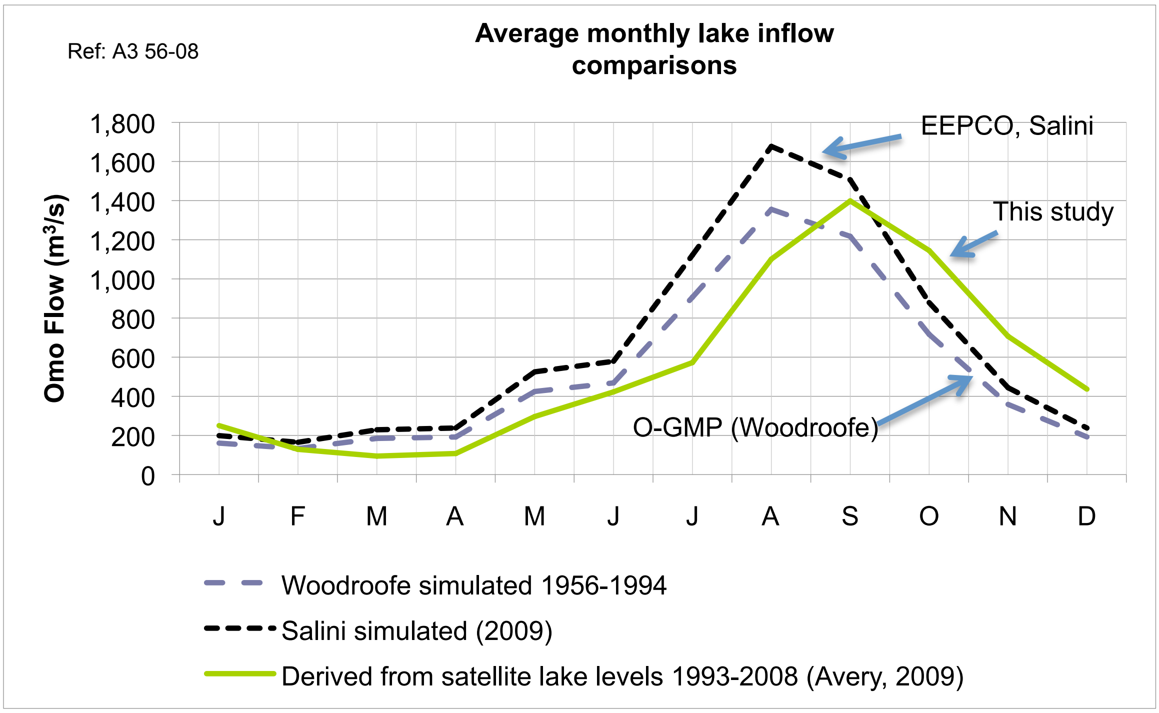


Figure 51: Omo average monthly lake inflows – different derivations

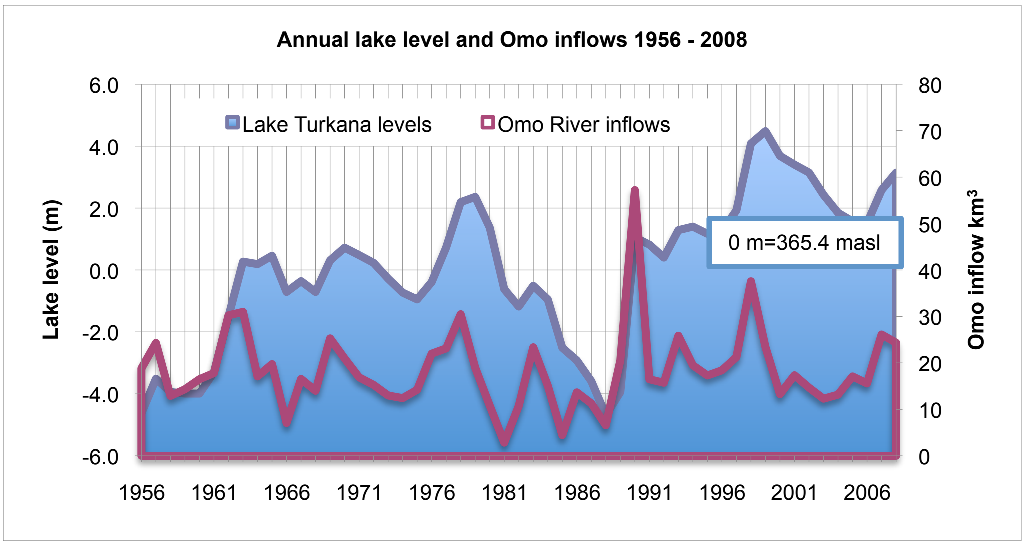


Figure 52: Lake levels and "modelled" annual Omo flows 1956 – 2008

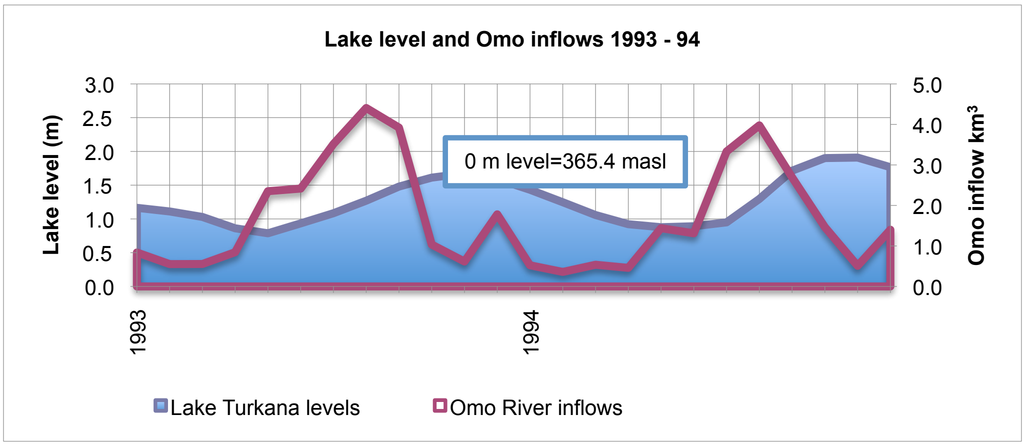


Figure 53: Lake levels and "simulated" Omo inflows 1993 – 1994 (Woodroofe data)

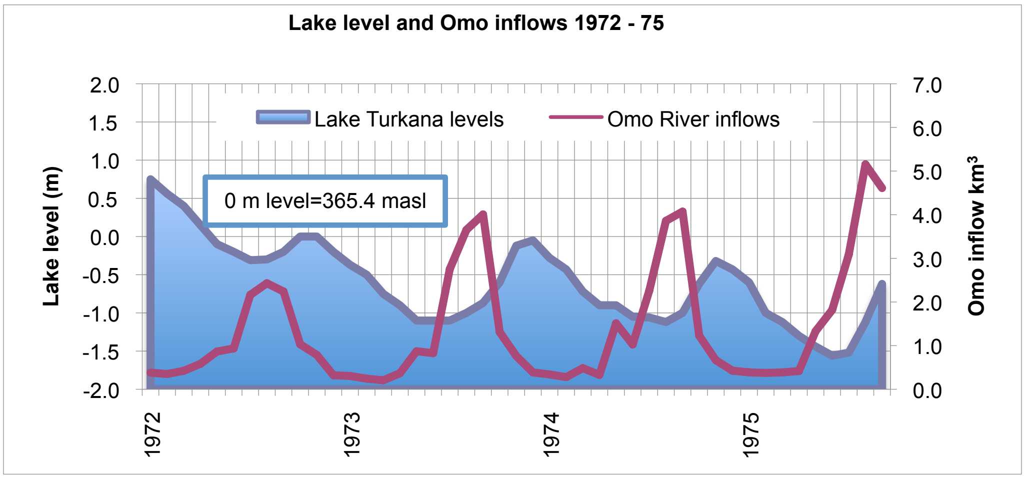


Figure 54: Lake levels and "simulated" Omo inflows 1972 – 1975 (Woodroofe data)

3.6 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. Gibe III intercepts 67% of Turkana's inflow. Hence lake levels will be reduced during this filling period, which will alter the subsequent lake level cycle.

The reservoir will have a gross storage volume 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 (Salini and Studio Pietrangeli, 300 GEO RSP 002A, 2007). Hence the total volume required in filling the reservoir is 16.36 km^3, which is not far short of the average annual inflow volume into Lake Turkana.

In Section 2.7.3 it was shown that the volume required to fill the Gibe III reservoir is equivalent to the volume stored in about two metres on the entire 7,500 km^2 Lake Turkana.

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/sec, and to release an "artificial flood" of 1,000 m^3/sec from 1st to 10th September each year.

The impact of the specified "average year" filling rules on the lake for the period 1993-2009, for instance, is as shown in Figure 55. 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 1993-2009 sequence, the lake start level would have been restored after about 6 years. The "equilibrium level", where evaporation matches inflows, would be restored about 15 years after filling had started. Based on average flows between 1993 and 2008, the "equilibrium level" is about +3m above the zero datum. Hence, the lake level cycle is altered, the cyclical annual changes are dampened, but ultimately the lake level is restored as the hydro scheme is not consuming water.

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. The dam is far from completion, hence its filling impact cannot be predicted yet with precision. Nonetheless, it can be concluded, as expected, that cycles will change, but long term, the lake level will be restored, albeit dampened.

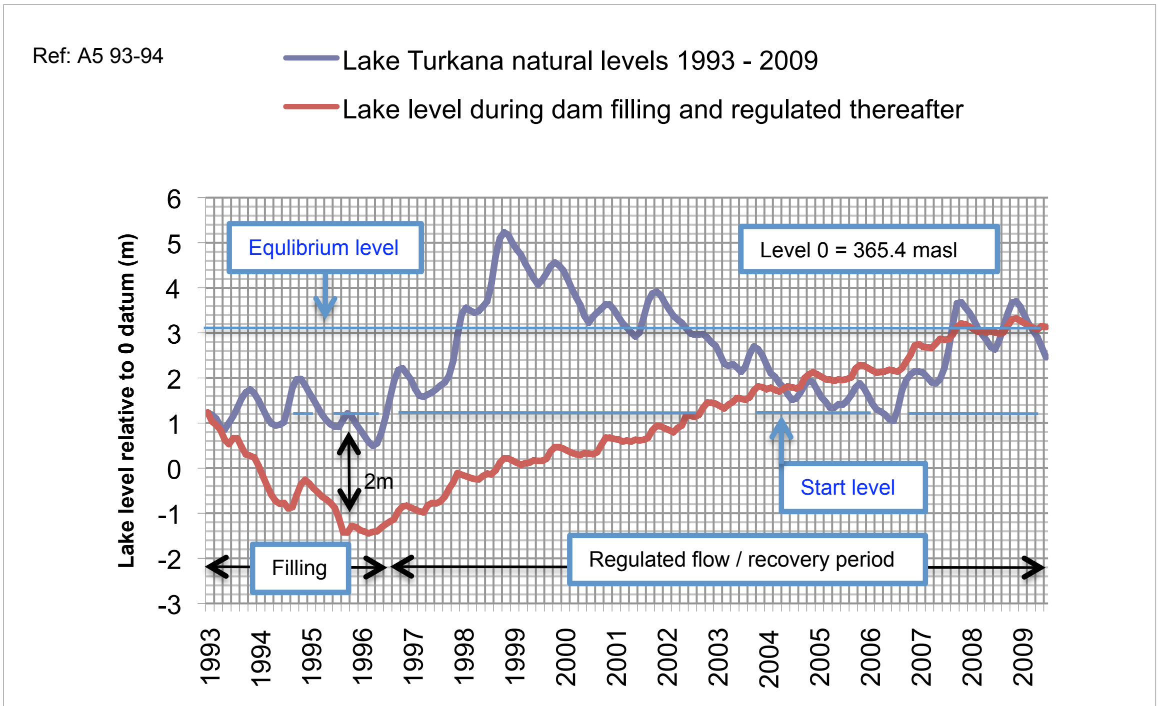


Figure 55: Effect of Gibe III filling and regulation

3.7 Water losses due to Gibe III during operation

It has been stated that the Gibe III dam will regulate flows and that there will be a "positive" water balance for Lake Turkana (EEPCO, 2009). It would perhaps be realistic to reflect the impact of not only Gibe III, but also Gibe IV and Gibe V. Although the Consultant has no details on the future plans, the term "positive" is perhaps misleading as no water will be added to the system, and some ecologists will disagree that regulation is ecologically "positive". Ecologists favour diversity, not uniformity, and there are numerous studies that demonstrate that flood-plain fisheries depend on water level changes from flood pulses (Kolding, 1993, 1994 and 2010).

A continuous flow sequence into the lake was not included in the EEPCO reports. Instead, average inflows were presented. This is reasonable as 67% of the Omo lake inflow will be regulated by Gibe III, and the proportion regulated will increase when Gibe IV and V are built. Hence ultimately, the flows into Lake Turkana will be largely regulated. Until Gibe IV and V are implemented, the catchment downstream of Gibe III will continue to provide variability of inflow.

The *Downstream Impacts EIA* (EEPCO, Agriconsulting et al, 2009) presents 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 study has indicated the following assessments of mean annual inflow into the lake over the period 1956-94:

- 526 m^3/sec - Woodroofe et al, 1996 – see Table 11.
- 560 m^3/sec - derived from lake levels – see Table 27.

The Omo average flows calculated by this study are very close to those calculated by the Master Plan 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). In the Consultant's experience, this assumption is quite high for arid catchments. Hence, the Salini contribution of the "Residual 2" catchment may be over-stated.

In theory, a hydroelectric power scheme does not "consume" water. The scheme stores water by means of 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. It is possible. If the flood plain areas inundated are reduced as stated, the evaporation due to flooding will be reduced.

On the other hand, the dam will be 243 metres high. The reservoir will thus impose a hydraulic head of 243 metres pressure, which is appreciable. It has been claimed by ARWG that losses of up to 75% could occur. These figures seem improbable and have not been substantiated (the Consultant requested substantiation from ARWG and there was no response). However, the Contractor's team (Salini et al) has been engaged in further geological site investigation of both the dam site and reservoir basin. In 2009, the reservoir area had not yet been studied due to the challenges of access (Salini et al, 300 GEO RSP 002A, 2007). However, studies have since been reported, and Salini remain of the view that there are no appreciable losses (Pers. Comm. Studio Pietrangeli, 2010). This view has not been disputed by others conducting reviews, such as Sogreah (Sogreah, 2010), and if there are any losses, the topography dictates that the losses will feed back into the Basin and will not be lost.

3.8 Effect of varying Omo River irrigation demand on lake levels

Gibe III is designed solely for hydropower generation. It is not designed as a multi-purpose reservoir, and hence is not supplying water for abstraction for irrigation or other consumptive use purpose. The reservoir formed by the dam will create head for power generation, and will store water, and this water will then be released back into the river as a regulated flow sequence. The scheme will not consume water, as all water passing through the turbines is returned to the river.

However, one of the stated benefits of the project ESIA (EEPCO, Agriconsulting, 2009) is enhanced food security as a consequence of the provision of a 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 states "…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...". Hence, some abstraction can be expected as an indirect effect of Gibe III, and this will reduce downstream flows below the figures that have been published, although the amount abstracted is stated to be negligible compared to the annual flows (EEPCO, Agriconsulting, 2009, and Sogreah, 2010).

The Omo-Gibe Basin Integrated Development Plan (the Master Plan) was published in 1996, and presents Year-2024 projected irrigation development of the Omo Basin that had been estimated to require 16% of the water resources of the Basin (Table 2). More recent assessments of potential irrigated area are conflicting. CESI suggested an irrigation area 50% larger (CESI SpA, 2009, 153,000 ha), whereas Sogreah derived a "suitable" area of 79,000 ha which is very similar to the Master Plan. Earlier reports by World Bank and FAO cited prospective irrigation areas five times the area proposed in the Master Plan (Section 1-6), but these figures are high. However, there could be long-term prospect for much larger abstraction from the Omo than was considered in the Master Plan.

The impact of the various hypothetical water utilisation rates on the available natural lake level sequence is shown in Figure 56. Also tested is an abstraction double the Year-2024 Master Plan demand, for the reasons discussed above. This graph presents the monthly lake flow sequence since 1993, the period for which satellite radar altimeter levels are available. The "0" datum level is based on the September 1972 lake level. The recorded lake level sequence shows that the lake rises slightly over this period. The impact of the hypothetical superimposed abstractions up to the 2024 demand level is to reduce the lake to a level approaching the historic low lake level.

The equilibrium lake levels (when evaporation and inflow balance) occur at the following levels:

Natural flows 1993-2008:	+3.1m
2009 O-GMP Basin Demand:	-3.9 m
2024 O-GMP Basin Demand:	-8.4 m

It must be emphasised that large-scale irrigation provision is definitely not a consequence of the Gibe III project, but is a separate area of inevitable basin development, independent from the Gibe III dam project. The above data is presented so that parties concerned with impacts fully appreciate that once the Gibe III dam is filled, the annual water balance of Lake Turkana is not reduced by the hydro-power project, except negligibly in regard to added losses, but that the biggest impacts can be expected to arise from Ethiopian Government plans for large scale irrigation within the Basin. These have not been studied in this Report, but they must be taken into account at some point, as it will be futile to disregard developments in the Basin as a whole as they affect mitigation measures. As developments are inevitable to cope with rising population pressure and food security needs, a balanced view needs to be agreed between

Kenya and Ethiopia, through detailed studies and dialogue, on what environmental impact is acceptable, and on what mitigation measures can be adopted, and how they will be managed. This process has already begun.

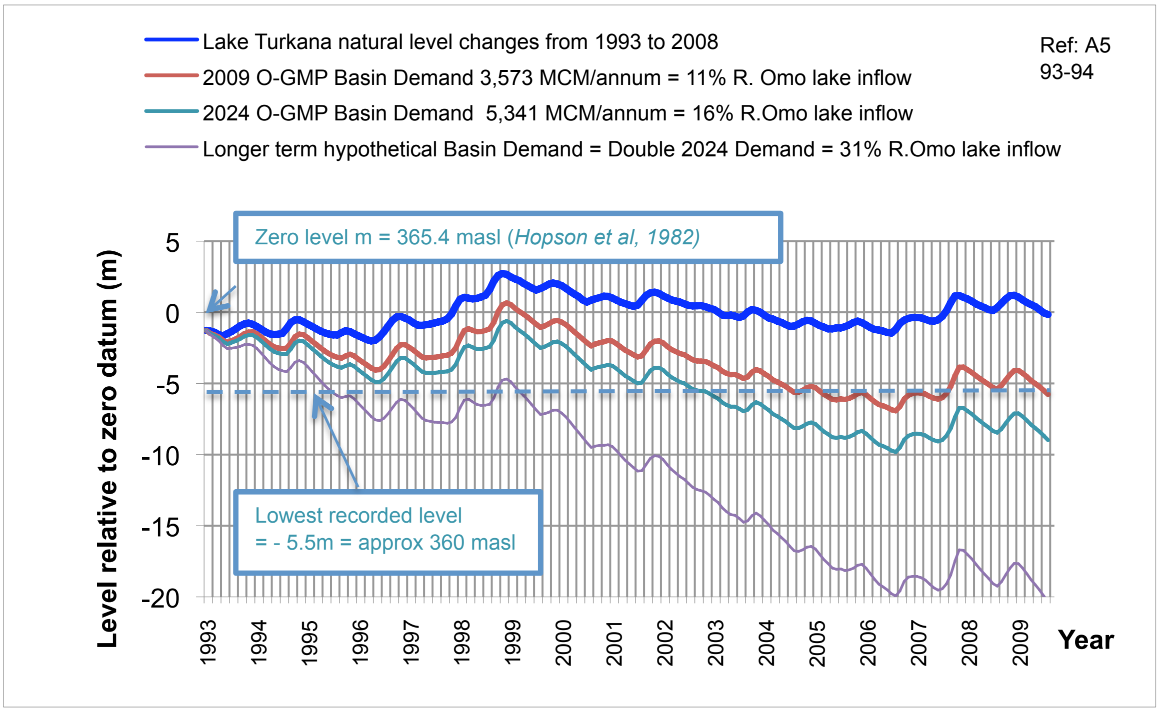


Figure 56: Lake drawdown for various abstraction rates, 1993-2008 flows

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

1) Lake Turkana is located in a semi-desert very arid area of northern Kenya, bordering Ethiopia, an area of scant and precious water resources. It is Kenya's harshest climatic zone. The area has been marginalised, there are frequent security challenges, infrastructure is poor, and lacking social services. People are largely traditionally nomadic pastoralists. They are poor and literacy levels are low. Population increase and food security are challenges, and the area has received food aid for 50 years. The area is a "hot-spot" for land degradation, with studies suggesting that livestock numbers exceeded the land-holding capacity in the 1990s.
2) The lake area receives sporadic rainfall averaging an estimated 200 mm/year at Lodwar, increasing to the north of the lake, and diminishing to the south. The lake catchment extends into the Ethiopian highlands where rainfall averages 1,900 mm/year. With the exception of the Omo River, most rivers are seasonal, presenting flash floods and no sustained flows.
3) The lake has undergone many stages of climate change. The lake was once 80 metres higher during a more humid climate (7,500 years BP). At that time the lake linked to the Nile 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. 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. The poor water quality will be improved where lake water is diluted by the Omo fresh water inflows in the north of the lake.
5) Apart from some small springs, the only significant perennial fresh water resource is the Omo River, whose catchment is entirely within Ethiopia. Kenya's Kerio / Turkwel Basins contribute very little water to the lake. 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.
6) 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 are 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, and research is also needed to ascertain the effect of more rapidly induced increased salinity. A doubling of salt levels would lead to changes in fauna and flora.
7) The fish breeding process is controlled almost entirely by the effects on the lake of seasonal floodwater pulses from the Omo River.
8) 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 in a year. The lake sustainability depends entirely on what happens within the Omo Basin, which provides almost 90% of the lake water inflow.
9) 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, sustains a population of agro-pastoralists who also engage in fishing. Fisheries are therefore very important.

10) 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 previously been assessed.

11) Developments within the Omo Basin will impact the fisheries resources of Lake Turkana. The fish resources are known to decline with flow reductions. 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 updated. This update study would look at the present fisheries resource and its utilisation, and impacts on the resource as a consequence of human activities, and would evaluate the effects of prospective changes in the Omo Basin.

12) 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. The extent and effects of the reduced flows have not been fully assessed, and they are to some 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 expected to stimulate small-scale irrigation.

13) 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, which is independent of Gibe III. If the lake level falls, biomass reduces and the fish population falls.

14) 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. The effect of this would need to be studied by the irrigation scheme developers.

4.2 Recommendations

1) The hydrological study presented in this report should be taken forward and refined, 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.

3) Rainfall measurements throughout the Basin should continue.

4) The lake level gauge at Ferguson's Gulf should be restored to routine reliable monitoring status, with a permanent reference datum established on the shore above the highest water level. We understand that this was commenced earlier this year (Pers. Comm, MoWI, Nairobi, 2010). The USDA-FAS satellite radar altimeter readings should continue to be processed and compared with the lake gauge data.

5) 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.

6) The proposed regulated flow sequence from Gibe III needs to be reviewed to take into account the anticipated benefits of increased food security arising from changes in agricultural practices.

7) The impact of the construction of the proposed Gibe IV and Gibe V dams on the proposed Gibe III regulated flow sequences needs to be evaluated to determine the revised flow that will reach Lake Turkana, including stating how the ecological flood will be managed in these circumstances.

8) The potential water utilisation within the Basin for irrigation needs to be reviewed, and the impact on Lake Turkana's levels can then be refined based on this information.

9) The impacts of Gibe III, IV and V and other developments, and the impact of a regulated flow sequence, on water quality and nutrient / sediment transport to the Lake, need to be assessed.

10) A scientifically proven and appropriate method of assessing ecological flows in the Omo needs to be chosen and utilised, and a similar methodology should be derived for the lake.

11) The status of Lake Turkana's fisheries resource needs to be updated to determine changes that have taken place since the detailed studies were done 30 years ago, and taking account of research since that time. 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 regulation, as well as livestock grazing of littoral zones. A start with a review has been made by the AFDB funded baseline study of Mbogo, 2010.

12) Bathymetric surveys of the northern end of the lake should be conducted to identify changes that may have taken place in the last 30 years. The present shoreline should also be mapped from satellite imagery and compared with the original surveys.

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.

14) A full evaluation of the economic value of the lake as a "resource" should be produced.

15) A thorough socio-economic and livelihood evaluation survey of the lake-dependant communities should be undertaken. Steps to achieve this have included the AFDB funder study of Kaijage & Nyagah (2010).

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. An integrated basin development ESIA is required.

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6 ANNEXES

Annex 1: Satellite imagery interpretation

(Source: Ngece, 2010)

The zones studied by Ngece are reproduced in the figure below.

The tabulations for 1973 and 2008 have been reproduced in Table 28, and a trend analysis has been added. Note the following:

1. All woodland areas have diminished.
2. The figures for the Omo delta cannot be directly compared with the other "boxes" as they reflect an increase in delta area as a result in falling lake level over the period studied.
3. The fall in lake level over the period studied is evident from the reduced water area apparent for the Box 3 and 4 data.
4. The alien plant *Prosopis juliflora* invaded the "Box 4" zone at some point between 2001 and 2008. This alien species is extensive in Baringo District and is found throughout northern Kenya. The species is said to have arrived in Kenya in the 1980s. The plant is native to Mexico.

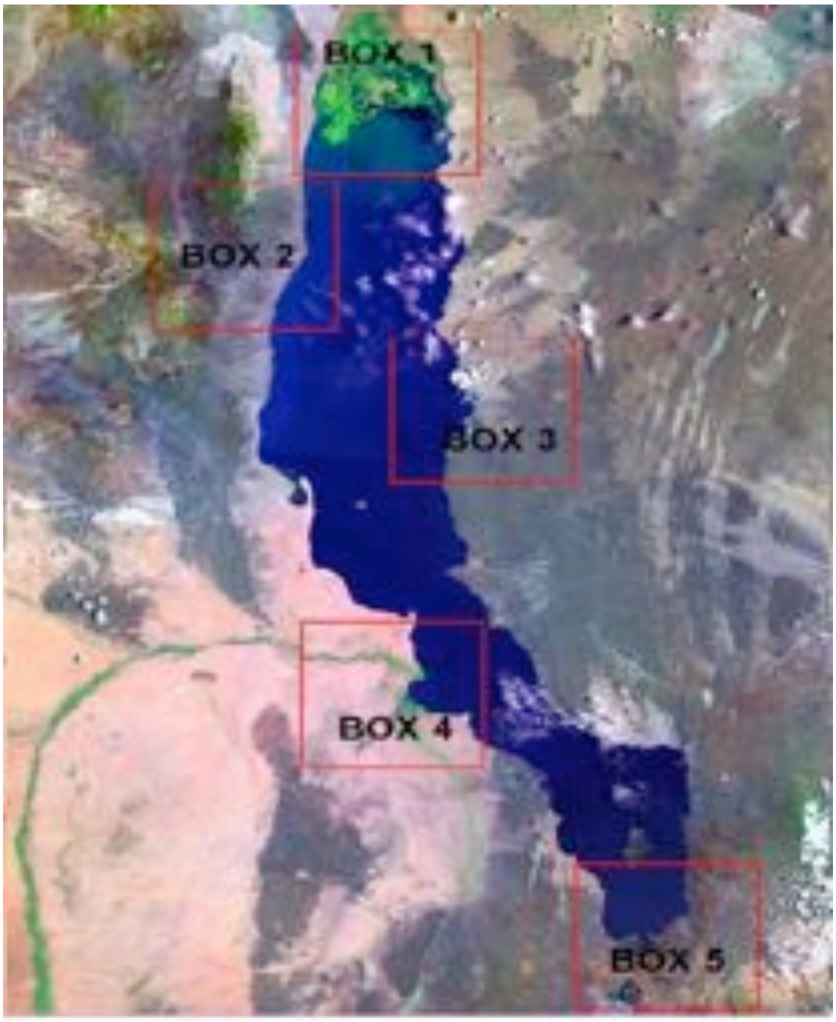

Figure 57: Zones studied by Ngece (Ngece, 2010)

Table 28: Vegetation coverage in selected area, and trends
(1973 and 2008 columns abstracted from Ngece, 2010)

Box 1: Omo Delta (1)	***1973***	***2008***	***Trend***	***Trend***
Water	99,837	53,767	54%	Fall
Woodland	14,906	17,682	119%	Rise
Closed shrub	30,723	26,148	85%	Fall
Sparse shrubs	9,841	15,706	160%	Rise
Grassland	7,516	18,497	246%	Rise
Swampy grassland	2,048	33,152	1619%	Rise
Bare ground	551	443	80%	Fall
Box 2: Lokitaung				
Water	37,720	38,056	101%	Rise
Woodland	40,848	38,274	94%	Fall
Closed shrub	68,978	1,295	2%	Fall
Sparse shrubs	15,557	14,062	90%	Fall
Grassland	812	2,757	340%	Rise
Swampy grassland	0	0	-	
Bare ground	1,484	1,295	87%	Fall
Box 3: Koobi Fora				
Water	61,382	60,340	98%	Fall
Woodland	695	0	-	Fall
Closed shrub	92,700	68,384	74%	Fall
Sparse shrubs	6,694	36,675	548%	Rise
Grassland	0	0	-	-
Swampy grassland	0	0	-	-
Bare ground	3,927	0	0%	Fall
Box 4: Turkwel/Kerio deltas				
Water	49,676	43,213	87%	Fall
Woodland	21,643	9,397	43%	Fall
Closed shrub	5,761	11,086	192%	Rise
Sparse shrubs	85,456	48,456	57%	Fall
Grassland	1	48,576	`>1000%	Rise
Bare ground	2,860	2,063	72%	Fall
Prosopis	1	1,895	>1000%	Rise
Box 5: South end				
Water	37,947	37,884	100%	Fall
Woodland	0	1,542	>1000%	Rise
Closed shrub	62,127	50,729	82%	Fall
Sparse shrubs	62,392	73,366	118%	Rise
Grassland	397	322	81%	Fall
Bare ground	2,241	1,506	67%	Fall
Source: Ngece, 2010				

Note(1): Lake level fell from 1973-2008, hence land area of Omo delta increased

Annex 2: Rainfall data - stations around the lake
(Source: Kenya Meteorological Department, Nairobi, values in millimetres)

Station_ID	Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
8535001	1959											3.1	0
8535001	1960	12.7	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0
8535001	1961	0.0	0.0	36.4	50.7	27.9	3.8	21.6	42.2	2.5	17.9	243.2	91.0
8535001	1962	0.0	0.0	79.5	42.0	247.7	22.1	0.3	0.5	0.0	25.4	55.8	11.4
8535001	1963	12.4	23.3	30.0	84.7	24.2	0.0	0.0	3.8	0.0	0.0	154.9	80.0
8535001	1964	0.0	65.6	103.1	91.4	0.0	0.0	93.9	25.4	25.4	0.0	0.0	14.0
8535001	1965	30.5	0.0	31.2	64.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.7
8535001	1966	0.0	144.7	152.4	227.2	35.6	0.0	0.0	72.4	22.0	25.9	9.6	0.0
8535001	1967	0.0	5.1	134.6	228.0	309.4	28.4	298.7	0.0	22.1	40.9	176.9	11.7
8535001	1968	0.0	19.4	40.4	223.1	40.8	3.8	3.8	0.0	0.0	0.5	0.0	12.7
8535001	1969	79.8	130.6	81.0	72.9	230.5	0.0	0.0	0.0	9.6	45.5	31.5	0.0
8535001	1970	67.1	0.0	66.5	125.0	13.2	1.0	5.5	0.0	0.0	12.7	0.0	7.7
8535001	1971	0.0	0.0	0.0	97.3	65.5	2.0	0.0	22.9	0.0	0.0	11.0	33.2
8535001	1972	0.0	5.6	2.5	33.7		32.8	0.0		2.5	46.5	120.6	1.0
8535001	1973	2.8	0.0	0.8	35.2	67.6							
8535001	1974												0.0
8535001	1976					10.0	11.5				0.5	42.2	11.0
8535001	1977	32.8	1.3	6.7	68.2	28.0							0.0
8535001	1978	13.2	39.0	34.3	6.9	0.0	0.0	0.9	4.7	56.5	10.6	80.8	69.6
8535001	1979	0.0	19.3	69.6	5.0	25.6	47.7	2.5	4.5		30.6	21.6	
8535001	1980	6.0	5.2	11.1	41.9	68.6	0.0	0.0	0.0	0.0	0.3	73.0	0.0
8535001	1981		3.5	193.3		0.0	0.0	8.7	5.5	0.0	0.0		0.0
8535001	1982		24.1	54.7	35.0	36.0	2.1	3.1	35.0	0.0	33.3	41.6	23.3
8535001	1983	1.2	0.0	6.7	67.6	0.0	2.0	2.8			3.7	14.7	0.0
8535001	1984	0.0	8.5	0.0	44.8	18.7	0.0	12.0	0.0	26.0	0.0	90.3	18.8
8535001	1985	5.2	6.2	53.4	60.7	5.9	0.0	9.6	0.0	0.0	10.8	26.5	0.0
8535001	1986	0.0	0.0	99.4	73.4	14.0	38.7	0.0	1.0	2.0	7.4	15.6	21.2
8535001	1987	1.7	32.4	103.6	127.3	46.2	33.5	0.0	0.0		1.5	18.7	
8535001	1988		4.6	6.7	146.7	1.2	0.0	31.6	36.6	17.2	52.8	0.0	7.1
8535001	1989	1.3	111.9	56.7	18.2	89.2	0.0	9.8	6.3	32.3	3.3	19.1	20.3
8535001	1990	32.0	85.7	59.5	34.0	9.6	0.0	0.0	0.0	0.0	27.8	0.0	6.0
8535001	1991	44.6	2.0	29.4	23.7	64.9	15.3		0.0	0.0	10.2	15.7	0.0
8535001	1992	0.0	20.9		38.7	0.0	0.0	21.0		6.2	21.0	16.3	18.6
8535001	1993	17.2	55.0	6.9	8.2	15.6	2.0	0.0					
8535001	1994	0.0	3.0	129.0	27.7	94.0	6.0	8.0	22.7	0.0	21.5	115.0	9.7
8535001	1995	0.0	6.5	71.8	60.5	0.0	4.2	30.2	0.0	5.5	42.4	3.0	
8535001	1996		27.9	58.5	22.5	26.0	53.4	7.6					
8535001	2000	0.0	0.0	2.5	3.6	0.0	0.0	0.0	0.0	0.0	63.5	0.0	7.0
8535001	2001	17.1	0.0	52.6	159.3	0.0	0.0	14.8	0.0	5.6	3.0	0.0	
8536001	1959			40.2	41.7	32.6	0.0	0.0			0.6	28.3	11.4
8536001	1960	17.5	1.3	58.8	47.0		0.0	45.7	0.0	0.0	0.0	21.6	24.1
8536001	1961	30.8	7.6	78.9	50.4	43.2	22.4	7.1	16.0	0.0	74.0	264.0	96.0
8536001	1962	6.4	0.0	31.5	8.9	38.2	8.9	17.5	0.0	2.5	46.2	63.8	76.5
8536001	1963	7.6	32.6	25.4	104.1	12.7	1.8	0.0	0.5	0.0	1.3	216.0	64.6
8536001	1964	8.9	5.6	11.5	33.3	0.0	0.0	2.5	0.0	0.0	3.8	0.0	41.8
8536001	1965	0.0	0.0	29.9	44.5	6.3	0.0	0.0	0.0	0.0	5.1	70.5	0.0

8536001	1966	11.4	18.0	36.4	116.0	19.3	0.0	0.0	53.1				
8536001	1967	0.0	5.1	0.0	52.4	140.5	5.1	74.8	0.0	0.0	16.4	64.8	2.5
8536001	1968	0.0	9.1	91.6	177.7	7.9	21.2	0.0	0.0	0.0	12.7	24.4	21.6
8536001	1969	28.4	11.2	50.4	1.1	93.5	0.0	0.0	0.0	0.0	9.7	67.2	0.0
8536001	1970	75.3	5.1	32.0	52.0	26.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8536001	1971	0.0	0.0	8.8	48.5	1.8	0.0	0.0	0.0	0.0	1.1	108.5	0.8
8536001	1972	0.0	2.4	0.2	1.7	17.7	5.2	0.0	0.0	0.0	39.1	65.9	17.6
8536001	1973	0.1	0.0	0.0	17.7	41.7	0.0	37.5	0.0	0.0	0.0	23.5	0.0
8536001	1974	41.5	7.1	14.5	54.7	46.1	0.0	1.5	3.9	0.0	0.0	9.8	0.0
8536001	1975		13.0		34.4	54.9	11.5	6.6	0.0	0.0	15.2		
8536001	1976	0.0	32.5			27.4	10.6	6.8	0.0	19.6	0.0	22.7	1.8
8536001	1977	69.5		7.5								109.9	
8536001	1978	5.0	46.0	104.2	23.5	4.1	0.0		0.0			80.7	29.0
8536001	1979	49.6	25.1	68.4	0.0	25.4	47.8	7.0	0.0	0.0	16.2	43.1	45.3
8536001	1980	4.8	1.5	13.3	116.0	88.5	0.0	0.0	0.0	0.0	17.0	50.4	0.0
8536001	1981	0.0	4.3	240.6	58.6	8.5	0.0		9.7	3.4	10.2	24.0	0.0
8536001	1982	8.6	10.7	44.4	49.9	61.4	12.0	4.5	3.5	0.8		90.8	54.6
8536001	1983	2.8	74.2	6.6	64.3	9.9	6.0	2.8	7.6		6.7	46.6	6.6
8536001	1984	5.0	6.3	9.1	78.0	15.2	0.0	0.0	0.0	3.7	0.0	90.4	67.4
8536001	1985	54.0	3.3	108.7	90.1	48.7	0.0	1.0	0.0	0.0	0.5	18.6	5.4
8536001	1986	0.0	13.5	92.7	89.0	9.7	5.0	0.2	0.0	1.2	2.1	36.8	6.8
8536001	1987	2.0	5.0	28.0	85.0	22.2	0.8	0.0	0.0	3.8	1.1	53.9	13.0
8536001	1988		11.8	26.4	144.0	7.2	23.9	21.9	19.1	12.8		15.4	26.8
8536001	1989	1.8	53.1	59.6	91.0	75.8	0.0	5.4	0.0	12.5	4.0	24.9	21.6
8536001	1990	24.8		68.2	118.6	35.4	0.0			3.7	38.1		
8536001	1991	83.1	7.2	137.9	0.0								
8536001	1992	0.0	0.0	0.0	11.0	5.0	2.0			0.0	12.2	45.6	12.2
8536001	1993	27.4	33.8	4.6	18.3	84.6	38.8	0.0	0.0	0.0	15.8	34.4	
8536001	1994	3.2		110.6	85.2	17.9	0.3		7.0	0.0	2.0	208.4	
8536001	2001	20.3	56.0	46.0	45.9	0.0	0.0	3.9	12.7	0.0	20.4	22.1	12.7
8536001	2002	13.4	0.0	65.3	74.0	139.8	0.0	0.0	0.0	0.0	28.5	62.9	126.8
8536001	2003	20.6	1.5	39.3	184.3	84.4	0.0	0.0	9.2	0.0	9.4	46.4	8.1
8536001	2005	4.5	0.0	17.0	110.3	0.0	0.0	0.0	0.0	36.0	10.0	25.0	0.0
8536001	2006	0.0	0.0	53.1	72.3	0.0	0.0	0.0	20.9				
8536001	2007	6.0	22.0	15.6	104.6	2.5	7.0	39.0	20.0	0.0	0.0		
8635000	1940	1.0	19.8	23.4	9.2	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8635000	1941	0.0	0.0	39.4	50.0	30.9	0.0	0.0	0.0	0.0	0.0	39.9	8.9
8635000	1942	0.0	0.0	107.8	21.9	52.0	1.3	0.0	15.5	0.0	0.0	0.0	11.4
8635000	1943	2.5	4.1	0.0	17.0	9.9	18.3	0.0	33.0	0.0	0.0	0.0	0.0
8635000	1944	0.0	0.8	5.4	17.6	10.4	0.0	17.3	0.0	0.5	14.7	9.7	6.3
8635000	1945	1.3	0.0	0.0	0.0	44.9	15.8	8.1	31.0	57.4	84.6	9.1	7.1
8635000	1946	0.0	0.0	1.1	11.9	1.3	1.3	4.1	23.7	0.0	16.0	0.5	3.8
8635000	1947	0.0	13.5	1.3	123.0	5.1	2.9	37.9	53.3	0.0	11.7	4.1	4.1
8635000	1948	0.0	0.0	23.1	17.8	94.8	0.0	6.9	8.6	0.0	12.0	7.6	0.0
8635000	1949	0.0	4.1	0.0	45.0	2.8	6.1	2.8	3.5	0.0	0.0	0.8	11.4
8635000	1950	0.0	0.0	81.4	39.1	0.0	0.5	6.9	0.0	0.0	15.2	0.0	0.0
8635000	1951	1.0	0.0	23.2	69.4	0.5	1.8	31.7	0.0	0.5	0.0	17.7	37.6
8635000	1952	0.0	5.6	1.5	119.7	22.1	0.0	2.8	1.0	0.5	0.5	0.0	0.0
8635000	1953	0.0	0.0	32.8	37.6	0.5	0.0	5.6	0.0	0.0	21.4	21.2	11.9
8635000	1954	0.0	0.0	0.5	39.8	49.0	6.6	15.7	2.8	4.6	2.0	0.5	6.4
8635000	1955	17.6	3.6	2.1	8.1	0.5	0.0	0.0	63.1	3.8	0.0	43.2	21.3
8635000	1956	54.1	1.3	9.4	7.3	0.0	5.1	10.9	0.0	2.8	1.0	0.0	3.0
8635000	1957	m	m	m	m	m	m	m	m	m	m	m	m

8635000	1958	m	m	m	m	m	m	m	m	m	m	m	m
8635000	1959	7.7	24.6	149.2	42.0	62.0	0.0	1.8	3.0	5.5	0.0	9.2	1.8
8635000	1960	28.7	0.3	26.0	46.8	23.1	0.0	14.0	0.0	0.0	0.0	6.4	0.0
8635000	1961	0.0	0.5	5.0	34.8	2.8	16.2	15.3	30.0	0.0	88.7	107.4	197.7
8635000	1962	7.9	0.0	23.4	18.5	107.0	0.8	4.6	1.6	0.0	5.9	32.8	0.0
8635000	1963	0.5	17.6	4.8	39.9	1.3	0.0	1.1	60.9	0.0	1.6	70.4	15.8
8635000	1964	13.0	22.2	20.8	17.4	0.0	6.6	4.3	8.6	0.0	0.0	0.0	72.2
8635000	1965	0.3	17.9	50.4	101.8	0.0	0.0	0.0	0.0	0.0	0.7	13.1	0.0
8635000	1966	0.0	41.6	19.9	121.3	0.0	0.0	0.5	51.9	0.4	11.4	15.3	0.0
8635000	1967	0.0	1.5	13.0	185.7	35.1	4.3	132.1	0.0	0.0	5.8	104.1	0.0
8635000	1968	0.0	28.4	28.5	144.6	0.4	3.7	0.0	0.0	0.0	0.0	0.0	18.3
8635000	1969	53.2	17.9	43.5	0.4	45.8	0.0	0.0	0.0	0.7	39.2	7.3	0.0
8635000	1970	74.4	0.0	10.1	54.5	41.6	0.0	0.9	0.4	0.0	0.0	0.8	0.0
8635000	1971	15.4	0.0	0.7	47.1	5.8	10.6	1.0	0.0	0.0	0.7	0.6	0.6
8635000	1972	0.0	33.8	0.4	48.2	0.9	7.1	0.0	0.0	9.5	52.9	53.4	0.1
8635000	1973	0.1	0.1	0.0	6.0	56.5	9.3	54.9	2.4	36.9	3.5	42.3	0.0
8635000	1974	0.7	0.3	94.8	53.4	22.0	0.0	90.2	28.7	0.0	0.0	0.0	0.2
8635000	1975	0.2	0.0	17.4	75.3	38.6	40.7	108.2	1.7	0.2	4.3	0.0	0.0
8635000	1976	7.3	2.7	4.6	17.4	14.6	26.3	76.3	0.0	1.6	0.0	1.9	4.0
8635000	1977	43.3	11.7	0.8	161.5	17.2	0.0	8.2	0.5	0.3	67.9	149.7	11.2
8635000	1978	1.5	30.6	39.5	45.6	1.9	0.0	12.5	0.0	7.2	4.4	3.3	1.4
8635000	1979	11.2	8.3	32.5	61.3	76.5	5.6	0.0	4.4	1.4	0.0	34.5	4.1
8635000	1980	0.8	0.0	1.4	45.6	32.9	0.0	0.0	0.0	0.0	0.3	20.0	0.0
8635000	1981	0.0	0.0	43.6	13.6	1.7	0.0	0.0	1.8	0.0	0.6	0.0	0.0
8635000	1982	0.0	30.5	32.6	29.0	16.6	0.0	0.7	0.0	1.2	5.6	164.6	70.7
8635000	1983	0.0	15.2	0.0	1.9	5.2	0.0	14.9	25.6	22.8	1.5	1.8	17.7
8635000	1984	8.5	0.0	4.0	25.2	0.0	0.0	0.8	0.0	0.0	10.7	1.7	11.5
8635000	1985	20.2	0.7	32.8	71.4	68.6	0.0	5.7	0.0	0.0	0.0	3.1	0.0
8635000	1986	0.0	3.9	41.5	79.9	1.5	23.5	0.0	1.4	0.0	0.0	1.7	4.3
8635000	1987	0.8	0.0	0.0	79.4	38.4	40.4	0.0	0.0	0.0	0.0	22.4	0.0
8635000	1988	2.7	0.0	0.5	87.0	6.1	1.5	73.2	48.0	71.4	8.5	0.3	2.4
8635000	1989	0.0	19.6	48.0	8.1	70.7	0.0	29.0	0.0	39.4	0.0	6.3	47.4
8635000	1990	1.1	21.2	13.6	18.0	4.1	0.0	0.0	10.4	0.0	15.8	0.0	6.2
8635000	1991	14.2	0.4	46.2	8.3	38.5	0.0	4.9	8.6	0.0	8.8	1.1	2.0
8635000	1992	0.0	3.6	14.4	16.8	10.6	0.8	0.0	0.4	0.0	2.9	6.1	2.0
8635000	1993	9.0	8.9	2.6	0.5	77.3	10.4	0.0	0.0	0.0	0.0	4.0	0.0
8635000	1994	0.0	1.0	18.9	50.8	7.5	1.4	4.5	10.7	0.0	8.5	27.6	0.4
8635000	1995	0.0	6.3	9.1	27.3	0.0	2.8	2.3	1.4	19.4	1.6	0.0	3.1
8635000	1996	6.1	1.9	35.9	23.3	19.2	52.7	45.5	0.0	0.0	0.0	13.5	0.0
8635000	1997	0.0	0.0	2.0	123.3	0.4	0.0	36.1	37.0	0.0	30.0	139.6	5.5
8635000	1998	13.1	5.3	2.3	13.4	20.8	41.6	1.2	26.6	0.0	0.0	0.6	0.0
8635000	1999	0.0	0.0	43.4	27.4	5.6	0.0	13.3	0.0	0.0	0.7	4.1	9.2
8635000	2000	0.0	0.0	0.0	9.5	0.0	0.0	3.7	0.0	0.0	41.9	4.8	16.0
8635000	2001	23.5	3.1	34.4	6.6	0.0	0.0	20.2	2.5	1.2	5.1	2.1	1.0
8635000	2002	10.0	0.0	87.8	56.6	130.6	1.6	0.0	0.0	0.0	19.4	5.4	20.2
8635000	2003	0.0	0.0	79.7	61.8	38.6	0.0	0.0	13.4	0.0	0.0	0.0	4.8
8635000	2004	58.9	0.0	4.0	66.2	13.2	0.0	0.0	0.0	26.2	1.2	39.8	4.4
8635000	2005	0.6	0.0	17.4	7.8	0.0	5.2	31.6	0.0	28.9	0.0	2.3	0.0
8635000	2006	1.1	4.3	34.5	36.5	1.2	0.0	5.1	27.1	0.2	46.2	154.1	57.7
8635000	2007	0.0	29.2	18.7	92.9	53.4	0.0	29.4	52.4	16.4	0.0	3.5	0.5
8635000	2008	1.0	0.0	39.0	9.8	0.8	0.0	0.0	0.0	5.1	42.2	31.2	0.0
8636001	1980	0.0	0.0	0.0	69.8	106.8	0.0	0.0	0.0	0.0	2.3	35.5	0.0
8636001	1981	0.0	0.0	227.2	73.7	0.5	0.0	0.0	4.5	0.0	1.3	12.8	2.0

8636001	1982	2.8	2.3	60.2	113.5	9.7	0.0	0.0	0.0	0.0	53.3	109.8	9.0
8636001	1983	0.0	24.7	0.0	81.9	6.3	0.0	137.9	14.2	25.7	16.6	4.9	1.7
8636001	1984	0.0	0.0	3.2	37.4	0.0		0.0	0.0	21.1	0.0	26.7	15.4
8636001	1985	2.3	2.7	30.4	72.0	0.0	0.0	0.0	0.0	0.0	0.0	23.9	402.7
8636001	1986	1.1	1.1	60.1	101.8	6.7	19.2		0.0	0.0	0.0	8.3	18.4
8636001	1987	3.4	2.1	18.7		5.0	45.0	0.0	0.0	0.0	0.0	2.0	0.0
8636001	1988	8.7	0.0	10.8	23.0		6.0	36.3	0.0	19.0	16.4	0.0	1.2
8636001	1990	0.0	100.2	111.8	31.4	0.0	0.0	0.0		0.0	6.0	6.0	3.0
8636001	1991	0.0	0.0	2.5	0.0		0.0	0.0	8.0	0.0	0.0	3.0	0.0
8636001	1992	0.0	2.5	0.0	33.6	0.0	0.0	7.0		0.0	1.9	3.5	4.2
8636001	1993	72.3	28.1	0.0	0.0	35.0	0.0		0.0	0.0	0.0	9.5	0.0
8636001	1994	0.0	2.0	10.3	108.8	13.5	0.0	8.0		0.0	7.0	24.6	
8636001	1995	0.0	21.5	20.5	20.3	24.5	0.0		0.0	0.0	2.0	5.0	24.3
8636001	1996	10.9	11.3	9.9	17.9	1.8	30.8	11.5	0.0	1.1	0.0	8.0	0.0
8636001	1997	0.0	0.0	4.9	54.2	1.7	10.0	18.0	0.0	0.0	10.0	84.6	
8636001	1999								0.0	0.0			
8636001	2003	20.6											
8636001	2006					0.0		0.0					
8736000	1959										7.1	29.8	20.4
8736000	1960		0.0	135.7	8.9	0.0	0.0	12.7	6.4		22.6	24.7	2.5
8736000	1961	6.4	0.0	16.0	89.9	40.2	4.9	7.1	112.7	11.7	167.8	364.4	75.6
8736000	1962	57.2	0.0	28.4	85.6	52.7	0.0	0.0	0.0	0.0	28.4	108.4	49.0
8736000	1963	8.9	3.8	82.3	176.6	1.1		0.0				98.4	
8736000	1972			0.0									
8736000	1973	77.5			18.8	26.6	0.0	33.5	0.0	3.3	16.0	137.1	4.0
8736000	1974	1.2	2.0	155.2	60.2	45.4	0.0	40.8	11.9	0.0	0.0	31.2	
8736000	1975	32.6	0.0	0.0	62.4	100.5	45.9	11.2	0.0	0.0	0.0	8.1	0.0
8736000	1976	0.0	0.0	3.8	11.8	7.4	3.1	7.1	0.0	0.0	75.0	0.0	6.0
8736000	1977	50.0	20.0	20.0	448.0	160.0	0.0			0.0	10.0	422.0	65.0
8736000	1978	28.0	40.0	167.0	45.0	0.0	0.0	5.7	27.0	50.0	127.0	118.5	
8736000	1979	139.0	18.0	74.0	85.6	7.8	18.4	0.0	0.0	0.0	24.0		20.0
8736000	1980	4.8		0.0	150.0	86.3	0.0	0.0		0.0	0.4		0.0
8736000	1981	3.7			325.8	95.6	0.0	0.0	0.7	0.0		3.5	79.5
8736000	1982	0.0	2.0	0.0	208.9	52.0	0.0	0.0	0.0	0.0	115.7		73.5
8736000	1983	0.0		0.0	14.8	19.0	4.0	2.5	52.9	3.0		4.4	25.5
8736000	1984	0.0	0.0	0.0	4.5	26.5	0.0	0.0	0.0	3.0	16.6	123.0	146.0
8736000	1985	10.0	0.0	134.7					0.0				
8736000	1986			13.8									
8736000	1987				19.5	6.1	1.7					19.7	
8736000	1988	0.0	0.0	220.1	94.4	0.0	0.0	38.0	6.0	0.0	5.0		
8736000	1989	10.0	35.0	46.0	155.0	35.0					19.0	132.0	62.0
8736000	1990	35.0	125.0	127.0	131.0						64.0	83.0	78.0
8736000	1991	39.0		31.0	45.0						1.3	13.0	
8736000	1992		4.0	0.0	38.3	0.1					26.0	38.0	104.0
8736000	1993	101.0	59.0		4.2	49.0	10.0				9.9	9.9	2.8
8736000	1994			0.2	44.7	24.9			4.8		17.5	73.7	35.5
8736000	1995		7.1	26.2							51.0		25.0
8736000	1996			59.2	0.0	5.9	32.5	3.4				18.3	
8736000	1997			1.1	38.9	10.2		1.7			20.9	421.0	179.0
8736000	1999			143.0	46.0			0.9				68.0	
8736000	2000									0.2	1.5	10.8	72.0
8736000	2001	171.0										0.0	
8736000	2002	47.0		176.9	69.0	83.0				13.0	84.0	53.3	305.0

8736000	2003			27.0	62.0	210.0						96.0	45.0
8736000	2004	108.0											
8736002	1973						0.0	8.2	0.0	3.4	0.0	124.4	0.0
8736002	1974	0.0	6.0	5.0	16.0	24.5							
8736002	1977	17.7	0.0	1.5		57.1				0.0	57.7	0.0	
8736002	1978	1.9	12.1	128.6							5.6	35.2	
8736002	1979	43.0	16.0	45.2	34.5	43.0				0.0		1.5	
8736002	1980	0.0	0.0	0.0	24.0	99.8	0.0	0.0	0.0	0.0	16.0	19.1	0.0
8736002	1981	0.0	0.0	120.4	9.9	10.4	0.0	0.0	1.0	0.0	3.5	1.0	0.0
8736002	1982	0.0	11.0	17.0	13.1	16.1	0.0	0.0	0.0	0.0	3.9	131.0	0.0
8736002	1983	1.4	33.9		61.5								
8736002	1984	0.0	0.0	1.2	5.0		0.0	0.0	0.0	24.0	1.5		
8736002	1985		9.0										
8736002	1986	0.0	0.0	4.2	74.5	0.5	38.5						
8736002	1987	0.0	0.0	0.0	135.4	0.0	112.2	0.0	0.0	0.0	0.0	30.2	0.0
8736002	1988	15.9	0.0	2.2	36.1	11.2	0.7	34.8	0.0	18.8	0.0	0.0	0.9
8736002	1989	0.0	23.6		75.6	64.2	0.0	4.0	0.0	5.7	0.0	2.1	26.0
8736002	1990	3.5	35.9	28.5	8.0	0.0	0.0	0.0		0.0	1.5		0.0
8736002	1991	12.4	17.3	15.9	7.5	15.0	0.0	0.0	0.0	0.0	6.8	23.4	20.4
8736002	1992		4.7	10.5	18.4	2.2	3.5			0.0	4.5	0.8	4.5
8736002	1993	29.0	33.6	0.3	0.0	23.3	0.0	0.0	0.0	0.0	0.0	21.9	0.0
8736002	1994	0.0	2.1	29.8	51.2	20.6	0.0	1.5	14.0	0.0		25.2	3.8
8736002	1995	0.0	13.0	16.2	16.5	25.4	0.0			0.0	1.2	1.0	0.0
8736002	1996		7.0		4.1	1.4		0.0	0.0	0.0	4.0	22.9	1.7
8736002	1997			22.0	69.4	0.6	0.0	22.7			9.1	109.5	7.4
8736002	1999	0.0	0.0	25.1	0.0	0.0	0.0	15.0	0.0	0.0	0.0	10.1	
8736002	2000	0.0	0.0	0.0	6.0	0.0	0.0	0.8					
8736002	2005						0.0						

Annex 3: Notes on Soil Map for Turkana area

Soil descriptions are given as follows, working in a clockwise direction around the lake *(Sombroek et al, Kenya Soil Survey):*

- *North-Eastern Lake Shore:* This area includes the Sibiloi National Park and its famous fossil beds and petrified forest. The area is accessible by road from North Horr, which is on the edge of the Chalbi Desert.
  - W2: Badlands developed on various older lacustrine and volcanic rocks, excessively drained soils.
  - L6: Plateaus and high-level structural plains away from the lake, flat to gently undulating, well drained soils developed on Tertiary igneous rocks
  - H_s1: Step-faulted scarps of the Rift Valley, slopes variable, well drained soils.

- *Eastern Lake Shore:* This shoreline is less accessible by road.
  - H9: Soils developed on undifferentiated Tertiary volcanic rocks.
  - L6: Described above.

- *South-Eastern Lake Shore (Loyangalani):* This is the most accessible part of the eastern lake shore, and Loyangalani is the most important centre on the eastern side of Lake Turkana, with a mission, tourist hotel, and an increasing settlement.
  - Pl1: Lacustrine Plains: Imperfectly drained soils developed on sediments from pyroclastic rocks and olivine basalts.
  - F8: Footslopes, well drained soils developed from colluvium from various volcanic rocks (mainly basalts)
  - R7: Volcanic footridges (dissected lower slopes of older volcanoes), with well drained soils.
  - M7: Well-drained soils developed on olivine basalts and ashes of major older volcanoes. The volcano in question is Mt Kulal, which looms over Loyangalani and the lake.
  - Hs1: Step-faulted scarp, described above, running along the shore to the south end of the lake.

- *South End of the Lake: (The Barrier Volcanic Complex):* This area is very inaccessible.
  - Hs1: Scarp described above, running along both south-eastern and south-western shores.
  - M1: Mountains and major scarps with steep slopes and excessively drained soils. The Barrier Volcanic Complex is an E-W trending whale-back ridge, 20 km in length and 15 km wide, which forms a natural dam blocking Lake Turkana from the Suguta Valley to the south (ref British Geological Survey). Interestingly, the Suguta Valley is almost 100 metres below the water level in Lake Turkana. In spite of this hydraulic gradient, seepages from the lake into the Suguta Valley are low (British Geological Survey)

- *South western shore*: This area is also inaccessible by road.
  - Hs1: The scarp described above, continues along the shoreline, rising to the Loriu Plateau to the south-west.
  - H9: Hills and minor scarps, well-drained soils developed on volcanic rocks.
  - Ux7: Uplands, undifferentiated levels, undulating to rolling, soils developed on volcanic rocks.
  - Pl3: Lacustrine Plains, soils developed on sediments.
  - A8: Floodplains, soils developed on sediments. The flood plain is the Turkwel and Kerio Rivers, which drain into the lake.

- *Western Shore:* There is good road access to Lodwar in this area, and the road continues north up to Todenyang. Lodwar is the most important centre on the western lake shore.
  - D1 + Pl3: Dunes, Lacustrine Plain. This is the area between Eliye Springs and Ferguson's Gulf. Eliye Springs has sandy beaches as one would see on the Kenya Coast.
  - Y5: Piedmont Plains, nearly flat.
  - W2: badlands, as seen across the lake from here.
  - Dl + Pl3: More dunes and plains are found to the north near Todenyang. Further back from the lake, the topography rises to hills.

- *Northern End:* This comprises the Omo delta, much of which is within Ethiopia. The delta is being formed through the deposition of sediments carried by the Omo River from the Ethiopian highlands.

Annex 4: Terms of reference agreed with AFDB

Phase 1:

The following preliminary hydrological data collection / analysis must be done:

1. Obtain all relevant reports (courtesy of AfDB offices).
2. Obtain the natural flow sequence into Lake Turkana broken down into the respective tributaries – Salini to kindly provide the data used to prepare Figures 7.3, 7,4, and 7,5 of their EIA Report. This should be monthly data for each month of each year of record. Preferably the daily data series should also be provided, all in electronic form.
3. Obtain the modified flow sequence in to Lake Turkana – Salini to kindly provide, as above, broken down into tributaries.
4. Obtain the historic river flow record for the Omo River from Mott MacDonald / Sogreah. Obtain the flow sequence for the Gibe III site from Mott MacDonald / Sogreah.
5. Obtain tabulated data on licensed and other water abstractions from the Omo River below the Gibe III dam site.
6. Obtain the basin averaged rainfall series for the Omo Basin. This data is required on a monthly basis for each year of record.
7. Obtain the World Bank Omo Basin Climate Change Study.
8. Obtain the monthly evaporation data, rainfall data for the proposed impoundment.
9. Derive the elevation / area / storage relationship for Lake Turkana – this can be derived from bathymetric survey data (available off the internet).
10. Compile the Lake Turkana level data series since 1900. Data is available in published papers on the internet up to the year 1994, but the more recent data should be sought from Kenya's WRMA. Other possible sources of data are the National Museums of Kenya, Kenya Wildlife Service, and Kenya Marine Fisheries Institute.
11. Request Salini to provide substantiated calculations of reservoir leakage losses, and assess the impact of these losses. The EFTA study includes "review and comment on the geological data to assess its adequacy and reliability when compared to the water tightness of the reservoir………" The findings should be made available to the Consultant, and need to be translated by Salini into annual seepage loss calculations.
12. Request EEPCo to provide data on inflow / outflow for Gibe I and determine whether the reservoir losses (leakage and evaporation) have, or can be, quantified.
13. A simple water balance will be undertaken through a spreadsheet to assess the fall in Lake Turkana's levels that would arise from various assumed leakage rate scenarios.
14. Obtain historic and latest satellite imagery to map the present delta extent, and its change over time.
15. Obtain historic and latest satellite imagery of the entire lake, in order to map the lake perimeter recession over time.
16. A reduction in Lake Turkana lake level will be accompanied by a corresponding increase in salinity. The lake water is present potable to local people and their livestock. The increase in salinity with lake recession will be computed, and the point at which potability ceases to be possible will be investigated.

The following key Government agencies are potential custodians of raw hydrological data, and they should be contacted to obtain a full list of data availability:

- Kenya Water Resources Management Authority
- Kenya Marine Fisheries Institute (research station at Kalokol on L Turkana)
- Kenya Wildlife Service (Allia Bay station in Sibiloi National Park, L Turkana)
- National Museums of Kenya (Museum + Research Station at Koobi Fora, Sibiloi NP)
- Ethiopian Electric Power Company
- Ethiopian Water Resources Authority

An initial desk study is proposed as soon as AfDB staff can obtain all the Section 2 Reports listed early.

A brief report will be presented as follows:

- Verify that 80% of the inflows to lake Turkana depend on Ethiopia's Omo River. Comment on earlier impacts of Kenya's Turkwel Dam Project on lake levels.
- Assess the fluctuation in Lake Turkana water levels over the past century. This time series will be contrasted to other lakes in the region to see if the trends are comparable. The lake level decline will be graphically presented and the timing of Gibe I dam commissioning, and Gibe II and 3 construction, will be superimposed, plus any other notable developments known within the Omo Basin.
- Assess the historic changes that have occurred in lake perimeter (from available satellite imagery) and forecast the further reduction that might occur.
- Assess the impact of the Gibe III filling on Lake Turkana lake levels.
- Assess the impact of various Gibe III reservoir leakage scenarios on the Lake levels.
- Assess the impact of reduced lake levels on rising lake salinity levels, and contrast these salinity levels against the limits acceptable to the aquatic environment, fish, livestock, wildlife, and humans.
- Other potential hydrological impacts will be listed. For instance, the following spring to mind:
    - The impact of reduced lake levels on the breeding grounds of the Nile crocodile, for instance within the crater lake on Central Island.
    - The impact of a dam-break situation.

This preliminary report will assess data quality. The Report will assess the impacts on lake levels, and will determine the extent that additional studies are needed.

Phase 2:

Methodology is to be determined following Phase 1.

Annex 5: "Facts" On Gibe III (EEPCO, May 2009)

(EEPCO's reaction to the issues raised by BBC's documentary and environmental activists)

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1. Design considerations during reservoir impounding:

a. Dec 31st 2011: Reservoir impounding will start; the ecological flows of 25-50 m3/sec will be released.

b. April 1st 2011, Middle Level Outlets will be opened - a flood will be released in the July – Sept period, 7-10 day duration, 1,250 – 1,600 m3/sec

c. Dec 2012, max operating level will be reached

d. June 2013, all units will be commissioned, discharge will be 950 m3/sec

2. Design considerations - Minimum environmental flow:

An ecological flow of 25-50 m3/sec will be discharged to guarantee the sustainability of the d/s environment. This corresponds to the lowest monthly average dry season flow.

3. Design considerations - Recession agriculture:

An artificial flood will be released during July – Sept. The flood will be of 7-10 days duration, and the flow quantity will be 1,250 – 1,600 m3/sec.

4. Design considerations - Flood regulation and sustainable flow to Lake Turkana.

a. The lake is characterized by high rate of fluctuations which is currently reducing at an alarming rate due to climate changes

b. The lake gets its water from different sources, the largest contribution being from the Omo River.

c. During the dry season these rivers contribute an average monthly flow of 120 to 162 m3/sec while at the dam site the flow is only 61 to 76 m3/sec in the same period.

d. In addition to the proposed 25-50 m^3/sec ecological flow, the contribution of the small rivers shall maintain the inflow to the Lake during the dry season.

e. Thus the presence of the dam allows continuous and regulated flow into the Lake that help maintain its level.

5. Benefits of the dam to the d/s ecosystem:

a. Regulated flow to the flood prone areas

b. Reliable and timely water supply for the recession agriculture

c. Reduction of evaporation losses in the flood plains

d. Sustainable flow and positive hydrological balance to Lake Turkana

e. Reduction of extended drought periods

f. Long term sustainable development schemes that can positively change the lives of the d/s population

g. Beyond maintaining the existing natural environment (ecosystem), several developmental interventions that guarantee improvements in the livelihood of the indigenous population are recommended in the Environmental Management & Monitoring Plan.

h. These include irrigation schemes, infrastructures, Social services, Improved Fishing, Tourism and other benefits.

i. A total budget of more than 400 M Birr is estimated for the implementation of the mitigation measures. Out of this ≈ 250 M Birr is earmarked for the downstream interventions.

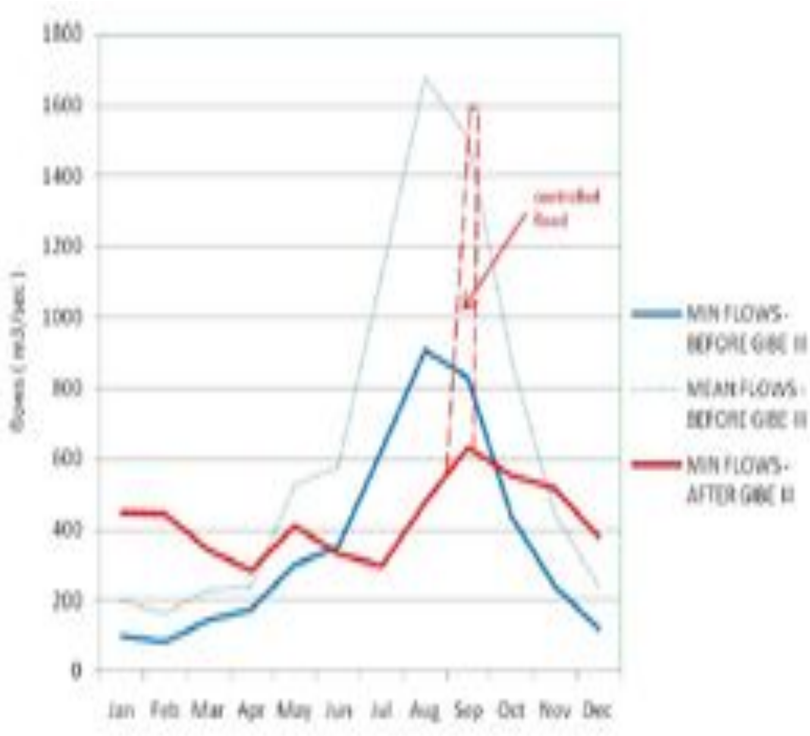

Figure 7.5: Monthly flows at Lake Turkana: dry year 1987 (min flows)

Annex 6: Satellite-based lake products

The Global Reservoir and Lake Monitoring program - Additional satellite-based lake level products (Birkett, Pers. Comm.)

The US Dept. of Agriculture, Foreign Agricultural Service (USDA-FAS) together with the National Aeronautics and Space Administration (NASA) are funding a program that aims to monitor in near real time the changing water levels of the world's largest lakes. The database currently contains around 75 lakes with products based on the NASA/CNES Topex/Poseidon and Jason-1 satellite missions (1992-2008), and the Naval Research Lab's (NRL) GFO mission (2000-2008).

The Jason-2 (or OSTM The Ocean Surface Topography Mission) satellite was launched in June 2008 and is the follow on mission to Topex/Poseidon and Jason-1. It is a joint venture between NASA, CNES, NOAA and EUMETSAT with science objectives that focus on the ocean, coastal regions and inland waters.

Utilizing radar altimetry the Jason-2/OSTM mission will continue the lake and reservoir water level observations through the 2008-2014 timeframe. The first preliminary OSTM products for the largest of the lakes were uploaded on October 1st, 2009 and operational procedures will update these weekly. Product revisions and additional lakes will continue to be uploaded through 2009 and 2010, as research and additional satellite data sets are incorporated into the program.

The GRLM Reservoir/Lake web site can be found at:
http://www.pecad.fas.usda.gov/cropexplorer/global_reservoir/index.cfm

Additional information on the Jason-2/OSTM mission can be found at:
http://sealevel.jpl.nasa.gov/mission/ostm.html
http://smsc.cnes.fr/JASON2/index.htm
http://www.osd.noaa.gov/ostm/
http://www.eumetsat.int/HOME/Main/What_We_Do/Satellites/Jason/index.htm

Funding Sources:
USDA/FAS Office of Global Analysis for implementation and operational tasks
NASA research grants NNS06AA15G, NNX08AM72G, NNX08AT88G and NASA/JPL sub-award 4-33637(UMD) for radar altimetry and product validation.

Data Sources:
NASA/PODAAC, CNES/AVISO, F-PAC, and LEGOS, and NOAA/NODC for provision of the TOPEX/Poseidon, Jason-1, Jason-2/OSTM and GFO satellite data sets.

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Annex 7: KMFRI monthly lake water level data

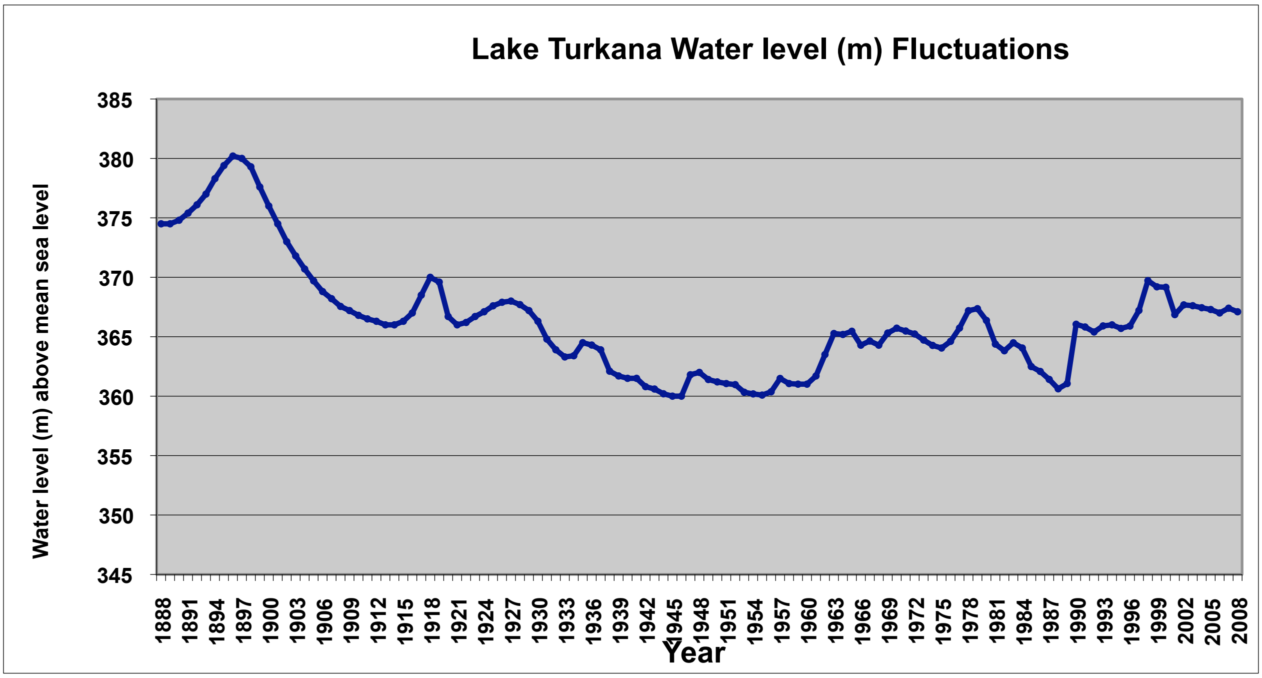
Levels above mean sea level at Mombasa are regarded as positive while water level measurements recorded below this value are regarded as positive.

For our monthly measurement, this level is located at 5.1 m below the concrete floor of the Lake Turkana Angling Lodge or 2.4 metres below the floor of KMFRI field station at Nataba (Communication from Dr. Ojwang, KMFRI, August 2009).

Lake level flactuations from 1988-2009

Month	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Jan	-4.75	-3.5	-3.54	1.27	0.98	0.71	1.55	0.83	1.01	1.72	4.69
Feb	-4.81	-3.68	-3.12	1.19	0.52	0.68	1.42	0.73	0.92	1.6	4.65
March	-4.85	-3.85	-2.87	0.96	0.47	0.55	1.36	0.71	0.77	1.52	4.61
April	-4.9	-4.01	-2.41	0.83	0.31	0.51	1.12	0.6	0.7	1.44	4.57
May	-4.98	-4.11	-1.92	0.79	0.14	0.47	0.62	0.52	0.61	1.31	4.52
June	-5.16	-4.16	-1.71	0.65	0.03	0.51	0.53	0.43	0.56	1.31	4.57
July	-5.49	-4.16	-0.68	0.43	0.11	0.67	0.65	0.51	0.51	1.42	4.61
August	-5.19	-4.15	-0.24	0.46	0.21	0.92	0.8	0.61	0.58	1.82	4.7
September	-4.98	-4.03	0.5	0.52	0.34	1.25	0.89	0.7	0.72	2.34	4.75
October	-3.87	-3.99	0.67	0.62	0.43	1.44	0.91	0.81	1.16	3.12	4.85
November	-3.73	-3.82	1.28	0.86	0.51	1.57	1.03	0.89	1.56	4.21	4.98
December	-3.45	-3.77	1.32	1.26	0.75	1.64	1.12	1.21	1.74	4.71	5.17

Month	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Jan	4.42	4.94	3.4	1.72	3.31	2.74	2.61	2.22	2.53	2.27	2.26
Feb	4.32	4.85	3.01	1.65	2.76	2.66	2.55	2.17	2.47	2.2	2.05
March	4.21	4.7	2.41	1.66	2.59	2.4	2.43	2.1	2.4	1.99	1.86
April	4.15	4.63	1.92	1.77	2.33	2.16	2.39	1.71	2.36	1.95	1.72
May	4.1	3.95	1.37	1.94	2.12	2.11	1.99	1.69	2.35	1.9	1.57
June	4.01	3.68	1.3	1.9	1.89	1.86	1.72	1.6	2.29	1.7	1.45
July	4.05	3.75	1.32	2.82	2.2	2.02	1.82	1.75	2.19	1.9	1.61
August	4.12	3.82	1.36	3.6	2.62	2.46	2.01	1.8	2.25	2.05	2.08
September	4.22	3.84	1.42	3.69	2.69	2.51	2.33	2.08	2.36	2.25	2.11
October	4.3	3.93	1.52	3.78	2.86	2.67	2.44	2.11	2.46	2.29	
November	4.41	3.95	1.61	3.78	2.93	2.76	2.51	2.25	2.51	2.31	
December	4.6	3.92	1.71	3.85	3.02	2.87	2.65	2.55	2.63	2.39	


Lake Turkana Water level (m) Fluctuations
Water level (m) above mean sea level
385
380
375
370
365
360
355
350
345
1888
1891
1894
1897
1900
1903
1906
1909
1912
1915
1918
1921
1924
1927
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2008
Year