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

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Dr. Sean Avery, BSc, PhD, C.Eng, C.Env
Consultant's e-mail: sean@watres.com Web: www.watres.com

EXECUTIVE SUMMARY

1. This report was undertaken for the African Studies Centre of the University of Oxford, England, and carries forward the Consultant's previous work on the impacts of Gibe III dam on Lake Turkana's hydrology and fisheries, for the African Development Bank (AFDB) (Avery, 2009; & 2010). This study extends research into the background to development in the Omo Basin, and the Lower Omo in particular, and extends studies on climate, traditional water sources surrounding Lake Turkana, and irrigation water requirements in the Lower Omo.
2. Lake Turkana is located within northern Kenyan, within the arid and semi-arid lands that comprise 80% of Kenya's land area. Lake Turkana's surrounding areas border Ethiopia, South Sudan, and Uganda. The Omo River and Lake Turkana are the major part of a major trans-boundary basin whose large catchment breaches three of Kenya's five international borders.
3. The Lake Turkana region's people traditionally subsisted through pastoralism, an appropriate arid zone livelihood, with agro-pastoralism in the Lower Omo, and along the Turkwel and Kerio rivers, and fishing in the Lake and Omo River.
4. Although annual rainfall has increased since records began in 1921 (Figure 42 p.128), the increase is insignificant in volumetric terms, and rainfall is increasingly variable with climate change. Arid zones have always been prone to drought during which livestock can perish in large numbers. These droughts lead to destitution and conflict, with pressure increasing with dramatic population increase (4-fold in 40 years). Since the 1970s the area has been a regular recipient of humanitarian relief food. Due to Government neglect, "food aid" is practically an "institutionalised drought coping mechanism" (Snyder, 2006), dominated by international aid agencies. The consequences include dependance and loss of self-esteem, increasing sedentarisation, and exacerbating tension through in-migration of people attracted by the food relief (Avery, 2010).
5. The northern areas have thus been long been "marginalised", with a history of tension caused by colonial border constraints and insecurity, with livestock losses through drought and rustling. The Kenya Government reacted by forming a Ministry of State for Development of Northern Kenya And Other Arid Lands, within the Office of the President (Vision 2030, GoK; cited in Avery, 2010).
6. Pastoral livelihoods are today increasingly challenged by the constraints to mobility caused by increasing population coupled with reducing rangeland areas through land excisions for alternative uses (such as wildlife conservation, tourism, infrastructure, and agriculture).
7. The effective surface water drainage area contributing to Lake Turkana covers 130,860 square kilometres (Table 26, p107). Turkana is notably Kenya's largest lake, Africa's fourth largest lake, and the world's largest desert lake.
8. Lake Turkana is located in Kenya but is sustained by the inflows of Ethiopia's Omo River, which alone provides about 90% of the lake inflow (Avery, 2010). The Omo Basin is Ethiopia's second largest river system, accounting for 14% of Ethiopia's annual runoff, and being second only to the Blue Nile in annual runoff volume from Ethiopia (ibid). Lake Turkana is a closed basin, hence the inflows are totally evaporated over time, and hence the lake waters are becoming increasingly saline, being already unfit for consumption, and unsuitable for agriculture. However the lake sustains its thriving fisheries ecology, though this is less diverse than exists in other African Great Lakes.
9. The population in the Omo Basin in Ethiopia was estimated to reach 13.429 million in 2009 (Woodroofe et al, 1996), distributed as follows:
    a. 900,000 people within South Omo (ibid).
    b. 175,000 out of 900,000 people are within Lower Omo (Sogreah, 2010) (only 1.3% of the total basin population).

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

1 INTRODUCTION

1.1 The Context

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

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

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

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

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

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

The 175,000 hectares Kuraz sugar plantations and factories in Lower Omo are being established largely on areas recently de-gazetted from the Omo and Mago National Parks, and the Tama Wildlife Reserve. Utilisation of protected areas for commercial agriculture was not foreseen in the Omo-Gibe Basin's Master Plan. As well as hosting interesting diverse fauna and flora, the national parks and wildlife reserve were also contributing to the livelihood of indigenous peoples through traditional agro-pastoral practices co-existing within the parks, although these activities were not encouraged. There are claims that local people are being displaced to accommodate the Government developments, claims which are denied by the Government. There are disturbing reports that these population displacements are being achieved through coercion amounting to human rights abuses (Human Rights Watch, 2012).

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

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

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

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

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

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

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

1.2 The Assignment

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

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

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

1.3 Methodology

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

The methodology was simple:

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

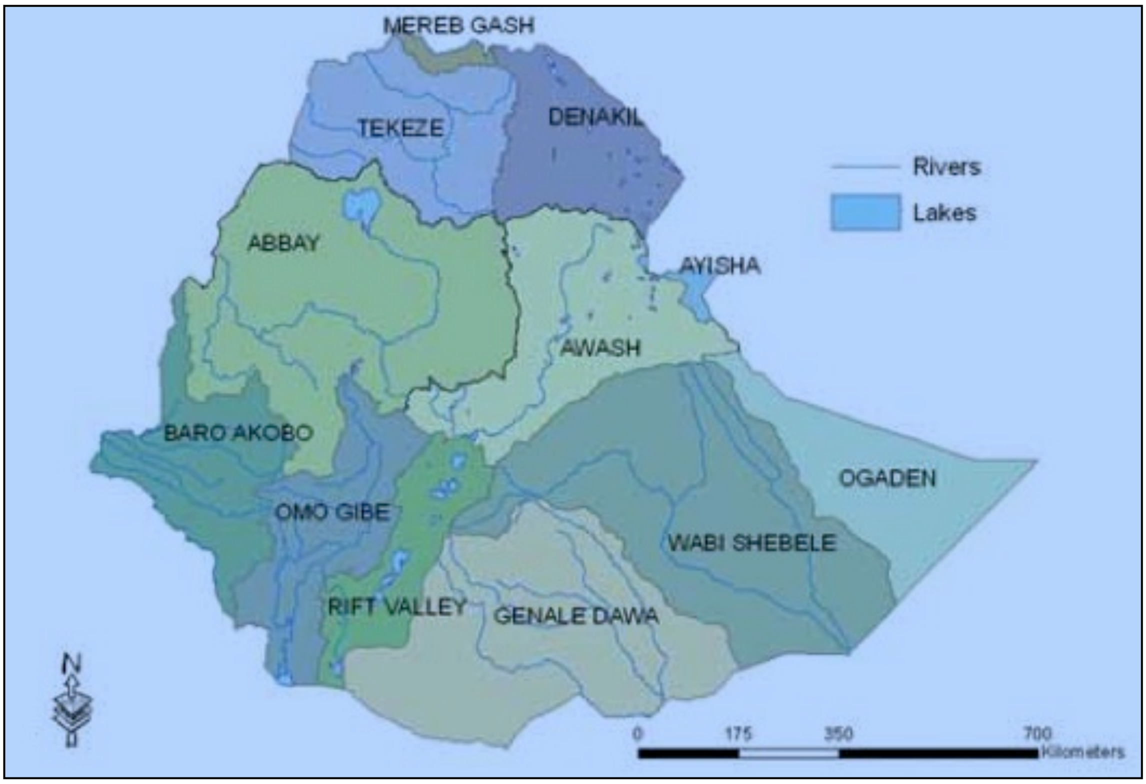

Figure 1: The river basins of Ethiopia
Source: IWMI 2007.

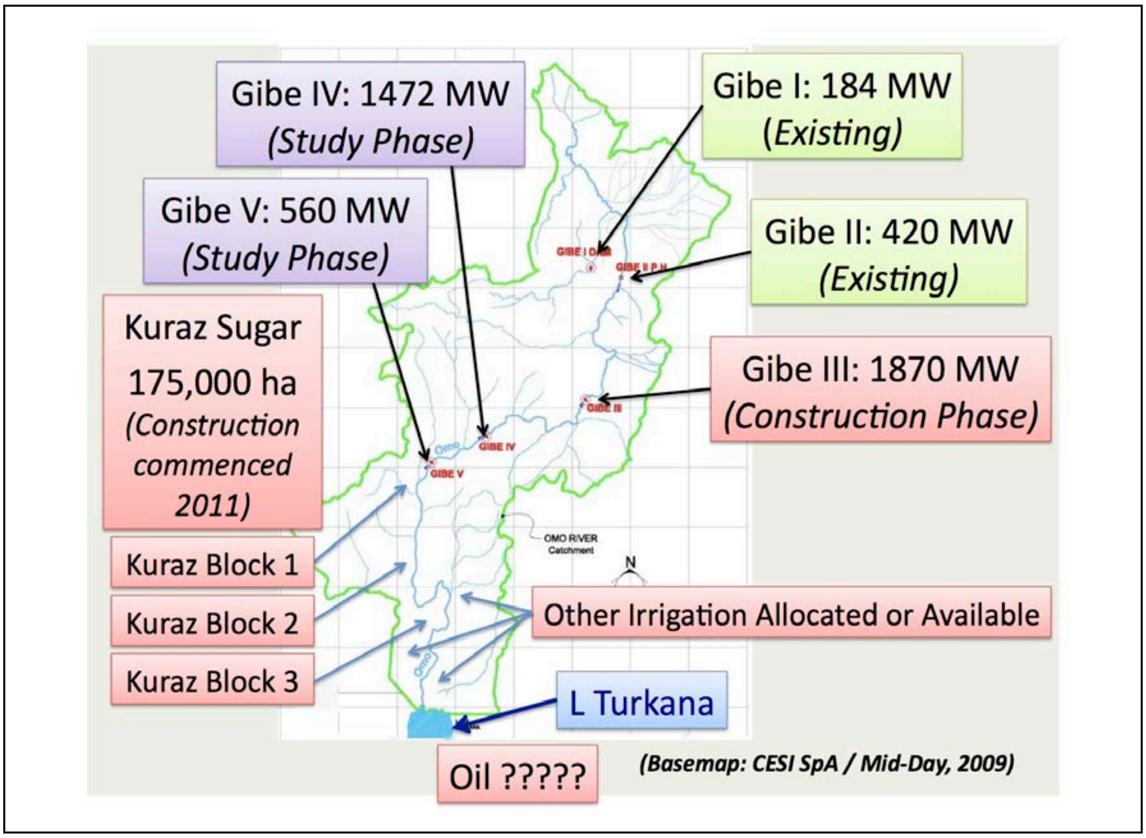

Figure 2: The Omo River's cascade of major schemes

Figure 3: Gibe III's catchment within Ethiopia

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