Proposed Malewa dam in Kenya: Adequate adaptations to original design

Le projet de barrage de Malewa au Kenya : De nécessaires adaptations au projet initial

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Abstract. Malewa dam in Kenya was first studied in the 1990s at preliminary design stage, through a study funded by Japanese Government who entrusted JICA with it. At that time, its main purpose was water supply to Nakuru, Naivasha and Gilgil cities in the Rift Valley. Thirty years later, its design was reviewed within the frame of a feasibility study funded by World Bank to account for revised needs -now excluding Nakuru- also taking into account increased awareness of environmental impact on downstream Lake Naivasha (Ramsar zone), management of the water scarcity, climate change trends, reliability issue, quality of water, sedimentation, as well as growing concern with operation and maintenance costs. Among studied solutions, focused on supply by gravity for economic reasons, and as ground water poses a serious health problem in this area due to a high fluoride content detrimental to human consumption, the construction of Malewa dam was confirmed to be the best solution after a decision making process, subject to some changes to the basic design, such as using the compensation flow to generate hydro-power to pump water to a WTP nearby the dam, mixing water with groundwater, building check dams and implementing water management and compensation measures.

Résumé. Le barrage de Malewa au Kenya a fait l'objet d'une étude préliminaire dans les années 1990 financée par le Gouvernement Japonais et confiée à JICA. Sa principale fonction était l'alimentation en eau potable des villes de Nakuru, Naivasha et Gilgil dans la « Rift Valley ». Trente ans après, sa conception a été révisée par une étude de faisabilité financée par la Banque Mondiale pour considérer des besoins revus – excluant désormais Nakuru – une prise de conscience accrue de l'impact environnemental sur le lac Naivsaha (zone Ramsar), la gestion de la pénurie d'eau, le changement climatique, la fiabilité du projet, la qualité des eaux, la sédimentation ainsi qu'une préoccupation grandissante relative

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aux coûts d'exploitation et de maintenance. Parmi les solutions retenues d'alimentation gravitaire, et comme les eaux souterraines posent un grave problème de santé dû à un taux élevé de fluor préjudiciable à la consommation humaine, il s'avère à l'issue d'un processus décisionnel que la construction du barrage de Malewa est la meilleure solution, moyennant quelques modifications au projet d'origine telles que l'utilisation du débit réservé pour générer de l'hydro-électricité pour pomper l'eau à la station de traitement, le mélange de l'eau de la retenue avec des eaux souterraines, ou la construction de barrages de retenue des sédiments, ainsi que l'amélioration de la gestion de la ressource, sans oublier des mesures compensatoires.

1 Scope of the feasibility study (Water supply to Naivasha, Gilgil and Ol Kalou)

Malewa dam in Kenya was first studied in the 1990s at preliminary design stage, through a study funded by Japanese Government who entrusted JICA with it. At that time, its main purpose was water supply to Nakuru, Naivasha and Gilgil cities in the Rift Valley.

Thirty years later, its design was reviewed within the frame of a Feasibility Study carried out by French Consultant Egis Eau funded by World Bank and implemented by PIU (Project Implementation Unit) under Kenya Water Security and Climate Resilience Project (KWSCRP).

This study accounted for revised needs – now excluding Nakuru for which another source of supply had been identified - also taking into account increased awareness of environmental impact on downstream Lake Naivasha (Ramsar zone) and water scarcity management, climate change trends, quality of water, sedimentation, as well as growing concern with operation and maintenance costs.

Proposed Malewa dam is located in Nyandarua County, north-east of Lake Naivasha, in Kenya.

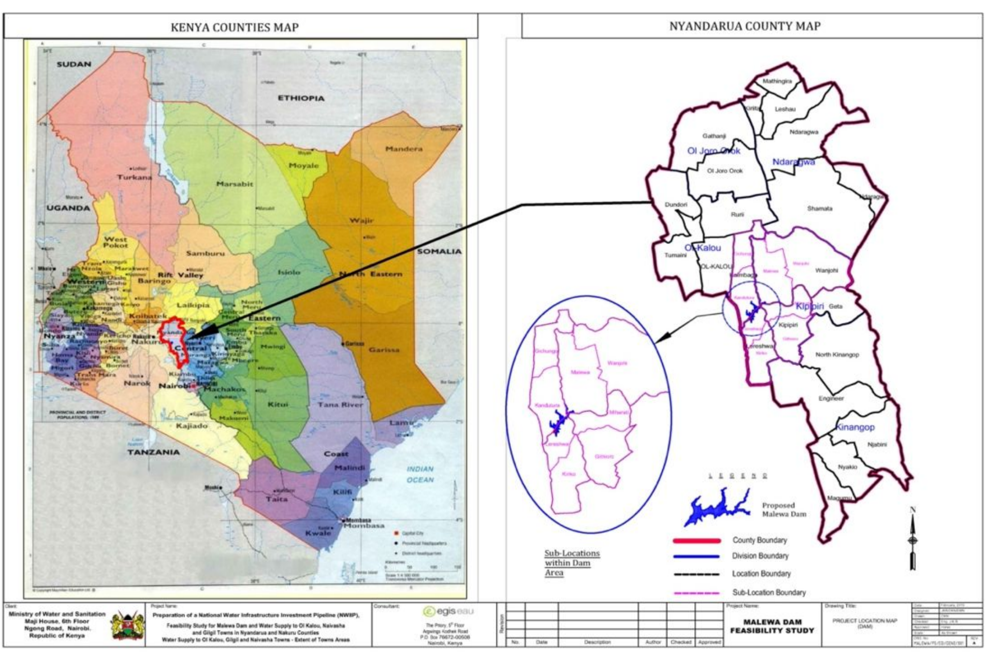

Fig. 1. Project location map.

2 Revised needs

2.1 Kenya legislation and policy

Kenya's national legislation and policy contains the same aspirations as the Sustainable Development Goals. Under Article 43(1) (d) of the Constitution of Kenya, every person has the right to clean and safe water in adequate quantities.

Vision 2030 states that the country should provide water and modern sanitation facilities to its citizens. According to the Government, this will be realized through specific strategies, such as:

i) raising the standards of the country's overall water, resource management, storage and harvesting capability;
ii) rehabilitating the hydro-meteorological data gathering network;
iii) constructing **multipurpose dams** across the country;
iv) and constructing water and sanitation facilities to support a growing urban and industrial population.

2.2 Change in scope

Water supply to Nakuru was no more required as it was decided since JICA study to build Itare dam which should supply Nakuru with water. Therefore, Malewa dam would now supply only Gilgil and Naivasha, thus reducing interbasin transfer from which problems arise frequently, especially in case of different counties.

The initially contemplated (by JICA study) transfer from Malewa river to Turasha river to take benefit of existing weir was therefore no more necessary.

2.3 Water supply demand

2.3.1 Increase in population and water demand

Future trend in population growth was adopted from the Kenya National Bureau of Statistics which gives population projections for the Naivasha Administrative Unit. The growth rate of the projection has been checked with available data from 2019 and 2009 Census.

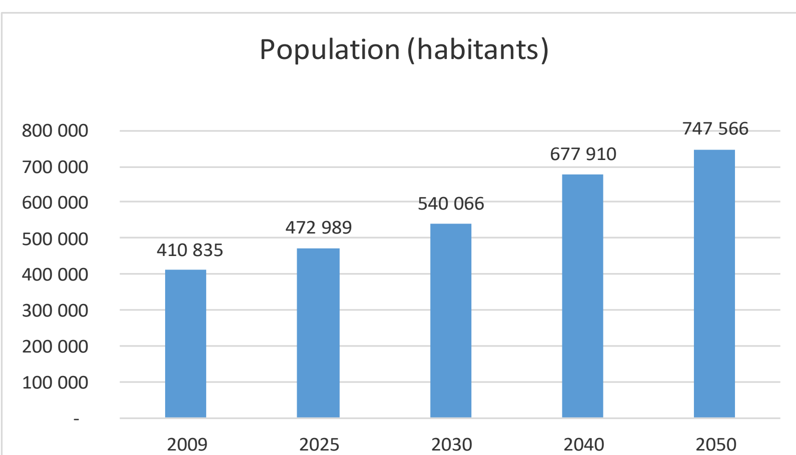

Fig. 2. Future trend in population growth for the Naivasha Administrative Unit.

The consumer category and per capita water demand was considered based on Kenya Water Supply Design Manual.

The breakdown of the total water demand is given in chart here below.

The ratio of water demand is close to 100 l/d/head for the domestic demand. The domestic demand represents 87% of the total water demand. The other 13% are for schools, tertiary institutions, health institutions, administrative offices and commercial areas.

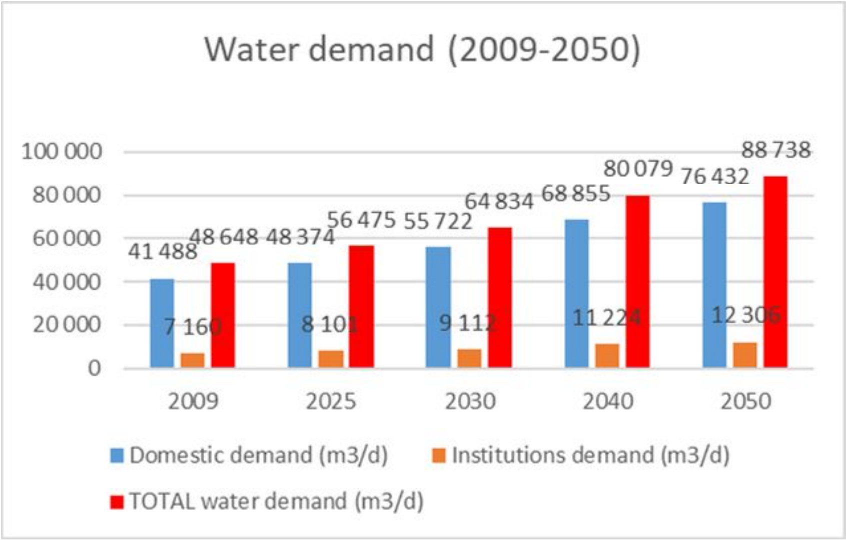

Fig. 3. Breakdown of the total water evolution for the Naivasha Administrative Unit.

2.3.2 The present water supply and quality of water

The Naivasha Water and Sewerage Company (NAIVAWASS) is mandated to supply Naivasha with water. To meet the present demand, NAIVAWASS abstracts water from 5 sites in Naivasha using 12 boreholes with a capability of producing 8 000 m^3/d.

Gilgil is mainly supplied with water by a part of the water from the Turasha weir (4 100 m^3/d), by Malewa weir (1 900 m^3/d) and by Morenda weir (360 m^3/d) for a total of 6 360 m^3/d.

The total present water supply for Naivasha and Gilgil is 14 360 m^3/d.

Most of the ground water abstracted water has fluoride levels above the recommended requisite of 1.5 ppm (KEBS 1, 2014) for public drinking water quality. The quality of water is affected by underlying aquifer conditions and characteristics of aquifer material. Despite NAIVAWASS has initiated efforts to treat water, the process are expensive and unsustainable, and therefore, only a fraction of population served receives treated water.

2.3.3 Water supply deficit and scenarios

Compared to the water demand, the deficit of water will increase from 70% in 2025, to 78% in 2035 and to 84% in 2050.

To provide drinking water, 3 scenarios had been studied and compared:

- Scenario 1 : Existing sources are retained and expanded
- Scenario 2 : Malewa Dam provides water to Gilgil and Naivasha exclusively

- Scenario 3 : A mix between existing sources and Malewa Dam are used to provide water to Gilgil and Naivasha

It came out from the comparison that Scenario 3 was the only one able to meet the demand as well as control the construction and maintenance cost, provide a quality water and control the impact on the water resource.

The good quality of water from Malewa dam reservoir – especially fluoride wise - makes it possible to blend it with water from boreholes, thus reducing at no cost (just by dilution) the fluoride content.

The storage into Malewa reservoir provides water resources during dry periods with a reliability of 95% whereas the level of the ground water during the dry session with a significant pumping of water is impossible to control, thus lowering the reliability.

Furthermore, the dam construction will help to control sedimentation flow into the lake Naivasha and flood downstream the dam.

This scenario must however be resilient and be part of an environmental and societal context presenting very important issues.

3 Taking account increased awareness of environmental impact

3.1 Lake Naivasha : Water scarcity and unique wetland

Lake Naivasha Basin takes huge socio-economic and conservational benefits, which concern over five hundred thousand people. Within this basin is the internationally renowned Lake Naivasha, a Ramsar site and a unique wetland.

The basin is however under serious threat from a wide rang of rapidly intensifying pressures, which include:

- Increasing reduction of lake level
- Deterioration of lake and river water quality
- Increased lake sedimentation
- Increasing population and water demand
- Poor waste management

Fig. 4. Photo of the Lake Naivasha, a Ramsar site.

Many conflicting demands put on the basin natural resources, and increasing human population, economic demands and urbanization has also resulted in increased water abstraction in the Lake Basin. This presents a huge challenge in the management of the lake so that the lake and its associated scarcity water resources are used in a sustainable and fair way.

The Water Allocation Plan – Naivasha Basin 2010-2012 underlines the following points:

- **The Water resources are finite and valuable**. This implies that there are insufficient resources to meet ever-increasing demands and therefore choices will have to be made on who should be allocated the resources and on what conditions.

- **Equity**. This is difficult to define precisely as it can often have different meanings for different stakeholders. Essentially equity implies that there should be a fair balance between environmental, livelihood and commercial benefits.

3.2 Water scarcity management

Present water abstraction and allocation in the lake Naivasha basin is based on “Lake Naivasha Basin Water Abstraction Survey Results Workshop Report – WRMA & WWF – July 2010”.

The repartition between irrigation and water supply is given in the figure on the right:

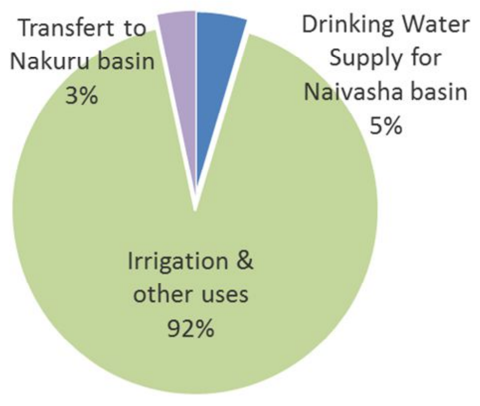

Fig. 5. Present water abstraction and allocation in the lake Naivasha basin.

There are three main responses towards water scarcity, as can be seen in (Molle, Research Institute for Development - 2003):

- The first is development, the reaction to augment the existing resources as well as tapping from new sources.
- The second response is about conserving the water. Improving the efficiency of already operational water resources without increasing the quantity.
- The third and last strategy is reallocation of water within or across sectors and basins.

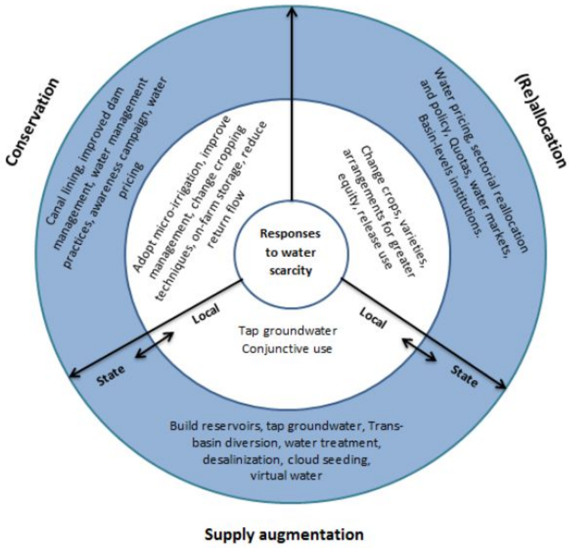

Fig. 6. Response to water scarcity – Molle, IRD – 2003.

This model of responses to water scarcity is helpful in classifying the awareness of increasing water shortage and in investigating in which manner the authorities and the stakeholders are concerned and responsive towards the increasing demand of water in the Lake Naivasha Basin and results in terms of water scarcity.

So, to compensate the additional needs of drinking water without any impacts on the Lake Naivasha, it was necessary to propose a new distribution of the water abstractions. The solutions thus proposed were:

- A partial return inter basin water from the present Nakuru transfert,
- A waste treatment plant to improve the water quality of the lake with at least a 50 %return flow,
- A water management of the present lake and rivers abstractions relying on the Water Allocation Plan – Naivasha Basin 2010-2012 which proposed options of water use charges to reduce wastage, water efficient technology in irrigation application systems, and crop selection with a lower water demand.

The new distribution of water abstraction will be:

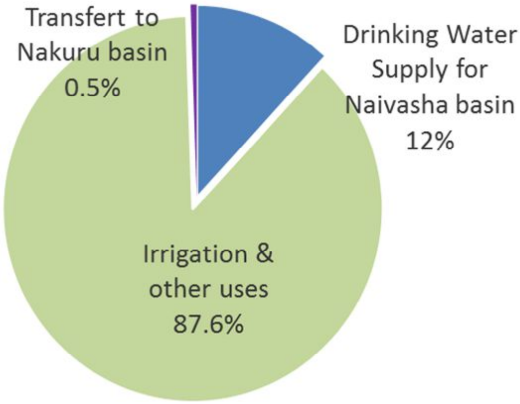

Fig. 7. Proposal of a new water abstraction and allocation in the lake Naivasha basin.

3.3 Climate change trends

3.3.1 Impact from climate change on hydrology

The impact of climate change on hydrology was studied in a specific Hydrology Report which was part of the Feasibility Study carried out by Egis-Eau by adjusting the streamflow time series with a factor.

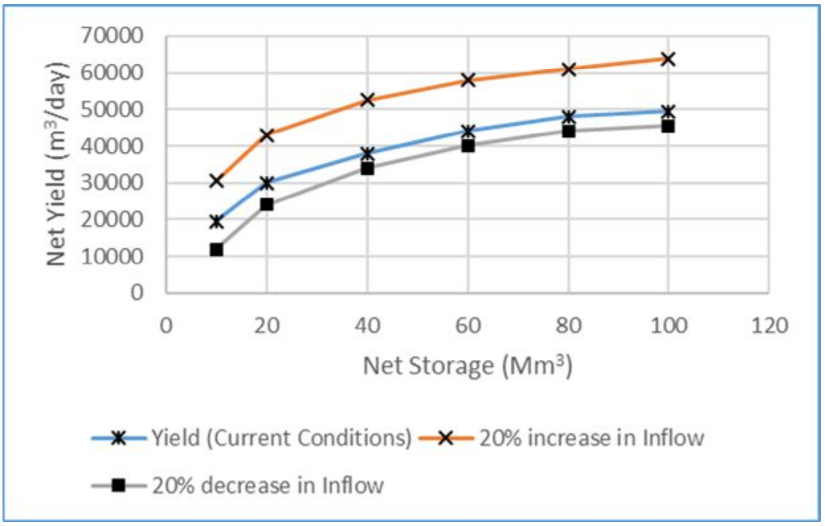

Fig. 8. Impact of Change in Inflow to Dam on Net Yield.

Figure above reveals the behaviour of net yield to changes in inflow to the dam. As expected, increased inflow results in higher yields and vice versa. However, an interesting observation is the magnitude of the increase/ decrease in the yield. The increase in yield is significantly higher than that of the current scenario whereas slightly lower for the converse. This can be attributed to the principle of the capture of flows equal to or larger than Q80. Therefore, an increase in higher flows results in a significant increase in yield. Since the dam will release all flows up to Q80, a reduction inflow mainly targets the lower frequency flows above Q80, hence its impact is much lower.

3.3.2 Contribution of the project to climate change adaptation

Malewa Dam appears to be a key infrastructure to improve resilience toward climate change for the growing population of Gilgil and Naivasha for the following main reasons:

- Malewa Dam is designed to improve water supply system of the 2 towns until 2050. Its capacity to store water from wet seasons increases the inhabitants capacity to face climate stresses.
- The gravity transfer line is more sustainable since it limits the use of electrical pumping. Electricity is proposed to be produced at the dam through a small hydropower scheme using (revised) compensation flow.
- Water abstracted upstream of the 2 towns will be less affected by human activities. Treated costs will be lower and water supply will meet the standard for drinking water, especially fluoride wise.
- Last but not least, the storage into Malewa reservoir would provide water resources during dry periods with a reliability of 95%. (Reliability can be defined

using the time-based concept where the number of time steps experiencing deficit in supply is expressed as a percentage of the total number of time steps). Such high reliability is a key point and a major asset when designing long-term infrastructure project.

3.4 Dam design with respect to the environment: needs for innovative solutions.

Malewa dam was designed in order to minimize as much as possible adverse environmental and social impacts. Several meetings have been held with the Consultant in charge of the ESIA (Environmental and Social Impact Assessment) and other stakeholders to share everyone thoughts.

In addition to previously identified key assets of Malewa dam project, which are recalled first, some innovative solutions brought some additional assets which should lead to the decision to finally build Malewa dam by making it even more sustainable.

3.4.1 Project Area

The project area has been chosen because of its relatively sparse population. The draft ESIA states that 514 land parcel owners will be affected, including 34 persons who will require physical relocation.

3.4.2 Environnemental flow

The location of Malewa dam, 10 km upstream to the next tributary called Turasha, reduces the impact on Malewa River downstream of the tributary.

The Environmental Flow Requirement (EFR) is the water required to meet the ecosystem needs of a river basin. After consulting and as recommended by the Water Ressource Authority the EFR has been set as Q_{80} instead of Q_{95}.

A simple way to implement the EFR is to use a long term Q_{80} flow as a constant release throughout the reservoir simulation period. However, this causes significant changes to the natural flow regime of the river downstream and particulary on the seasonal variation which is a key feature for the ecosystem. Therefore, a variable EFR has been adopted to simulate dry and wet season.

3.4.3 Hydropower to operate pumping from the reservoir to the water treatment plant

In fact, this increase in flow has made it possible to reconsider a hydroelectric production solution. The possibility to produce electricity from the environmental flow is a sustainable solution to pump water from the reservoir to the water treatment plant. The flow will not be a constant one, varying from 0.3 to 1.2 m3/s according to the season. The nominal electrical power will be around 320 to 450 kW.

Considering the fact that the investment costs are much minimized due to existing equipment for the water project that can be used for the power project, but also the high costs of electrical consumption for pumping, turbining the compensation flow is very interesting, on a technical level as well as on an economical level.
The investment return period is less than 5 years.

3.4.4 Dam materials : clay core replaced by geomembrane

The dam design has been updated to enable maximum use of materials that can be extracted around the project, avoiding as much as possible long hauling distance. The initial design relying on an earthfill dam with a clay core was altered to an earthfill dam with upstream membrane. During the site survey, adequate borrow area for impervious clayey material haven't been found after further field investigation within a reasonable distance. Soils on top of the bedrock are thin, implying huge area of inefficient scrapping with a very low yield if it was chosen to stick to the initial design.

So, the design was altered to an homogenous earthfill with upstream geomembrane commonly referred as Geomembrane Face Earthfill Dam, GFED. This key design change was discussed and explained to the stakeholder. This design as already been successfully used elsewhere in Africa under similar climatic conditions. The new design conforms to the recommendations and design requirements reported in ICOLD Bulletin 135 "Geomembrane Sealing System for Dams".

The updated design also includes a continuous grouting gallery at the upstream toe of the dam which will provide easy access to the geomembrane drainage layer and leakage monitoring, and will enable repairs in the grouting courtain if necessary. This is consistent with the increase in the design life from 50 to 100 years.

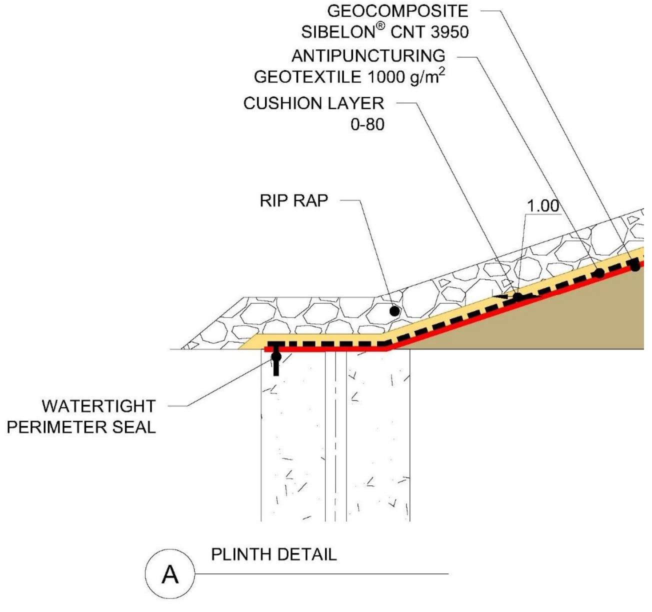

Fig. 9. Detail of the geomembrane waterproofing complex.

3.4.5 Check dams to alleviate sedimentation

The design life was increased from 50 to 100 years implying that the 61 Mm^3 active storage cannot be guaranteed without an active sedimentation control. In fact, the morphology of the Malewa dam site is favourable due to the relative ease of the implementation of the spillway on the left bank plateau, but on the other hand, the maximum dam height is limited. The maximum gross storage capacity is around 80 Mm^3.

Reanalysis of the sediment flow more than double the sediment volume trapped in the dam, from 16 Mm^3 in 50 years to almost 43 Mm^3 in 100 years. Without active sedimentation control, it will not be possible to guarantee a 100 years design life.

Active sedimentation control is provided by two check dams that control more than 70% of the catchment area. They are designed for 5 years of sediment storage to be dredged every 3 years. Excess capacity provides an additional safety margin for the storage of the sedimentation generated by severe flooding.

Both check dams share the same storage height but different storage capacity:

Table 1. Characteristics of the check dams.

Check Dam storage capacity	Rumathi checkdam	Kiambaga checkdam
Catchment area	423 km^2	431 km^2
Storage height	14 m	14 m
Average 5 year sedimentation storage	670 000 m^3	228 000 m^3
Area at normal pool	163 000 m^2	46 000 m^2
Efficiency from year 1 to year 5	77 – 45 %	50 – 25%

Check dams are an integrate part of the whole project and account for almost 8% of the building costs.

They would be made of concrete and have dedicated access roads for dredging operations. Typical cross section is gravity dam in non-overflowing sections, and ogee spillway in overflowing sections.

It is noted that some sediments will pass away from the check dam and from the catchment area from the other two contributing rivers that are not checked. They will contribute to depositing sediments directly into the dam reservoir. That is why a dead storage volume has still been taken into consideration.

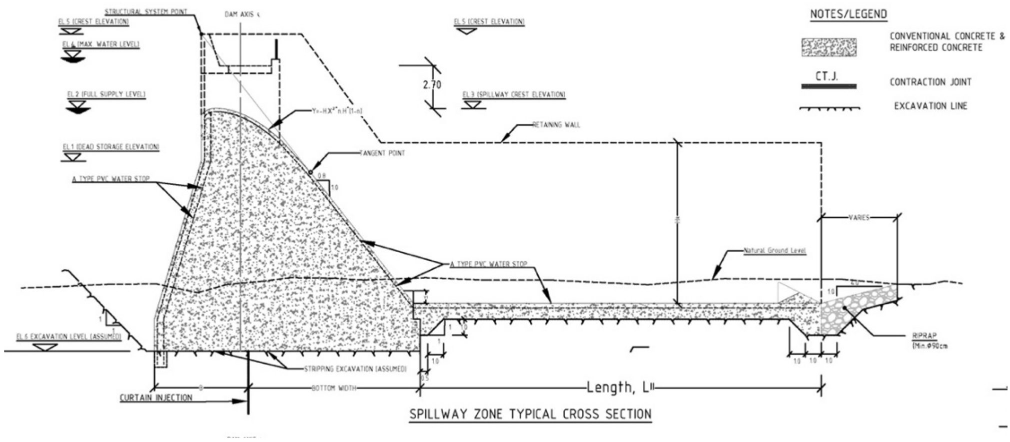

Fig. 10. Typical cross section of the check dam's spillway.

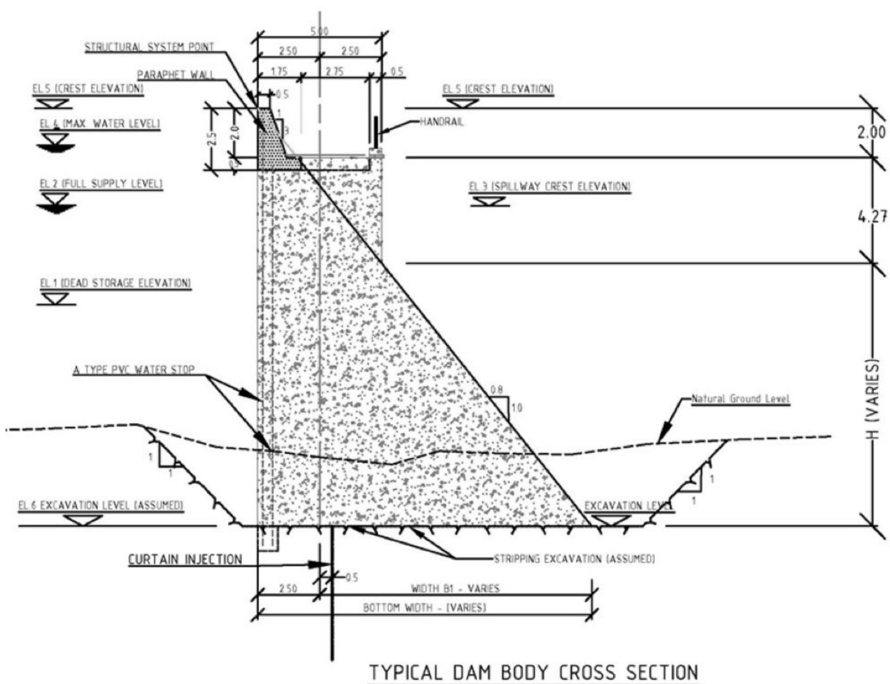

Fig. 11. Typical check dam cross sections.

4 Conclusion: Towards a sustainable project.

4.1 Assessment of the performance

Proposed changes to the basic design were scrutinised and challenged to ensure their fitness for purpose. As examples, referring to above mentioned changes and innovative aspects:

- With reference to 3.4.2 (Environnemental flow) proposed Q80 environmental flow was substantiated and a specific study was carried out to ensure the feasibility of small hydropower scheme using this environmental flow.

- With reference to 3.4.5 (Check dams to alleviate sedimentation): Check dams were designed in details and a maintenance plan was elaborated and proposed.

Some additional benefits such as cattle drinking points or re-use of sediments for agricultural or construction purpose were also pointed out.

- With reference to 2.3.3 (Water supply deficit and scenarios): As quantity of water from proposed Malewa dam far exceeds the quantity pumped from boreholes, and as fluoride content of surface water is low, dilution will greatly improve the quality of water provided an adequate distribution network is designed to properly mix groundwater and surface water.

- With reference to 3.3 Climate change trends, the issue of reliability is a key issue which should be considered, especially when designing long-term infrastructure projects such as a dam project.
  Reliability issue affects key design parameters such as dam and reservoir elevation level, dead water level during reservoir life, and will also have a significant impact on operation and maintenance procedures.
  Performance of the system in terms of reliability has been estimated accordingly (after considering several simulations) and can be easily measured later on.

4.2 Problems encountered

Two specific presentation meetings of the Feasibility Study were held with stakeholders: despite some opponents opposed the project, this was the opportunity to clarify some aspects of the project and to enhance its benefit for the people in Naivasha area.

Political issues in relation with intercounties transfer of water should not be underestimated: as proposed Malew a dam is located in Nyandarua County and will supply water mostly to another county (Naivasha), some compensations have to be given.

Hence, one specific component of the Feasibility Study dealing with Ol Kalou city located in Nyandarua county, as Malewa dam cannot supply Ol Kalou by gravity due to inadequate elevation.

Beyond technical considerations, access to drinking water and the fair distribution of abstractions must still be the subject of a consensus.

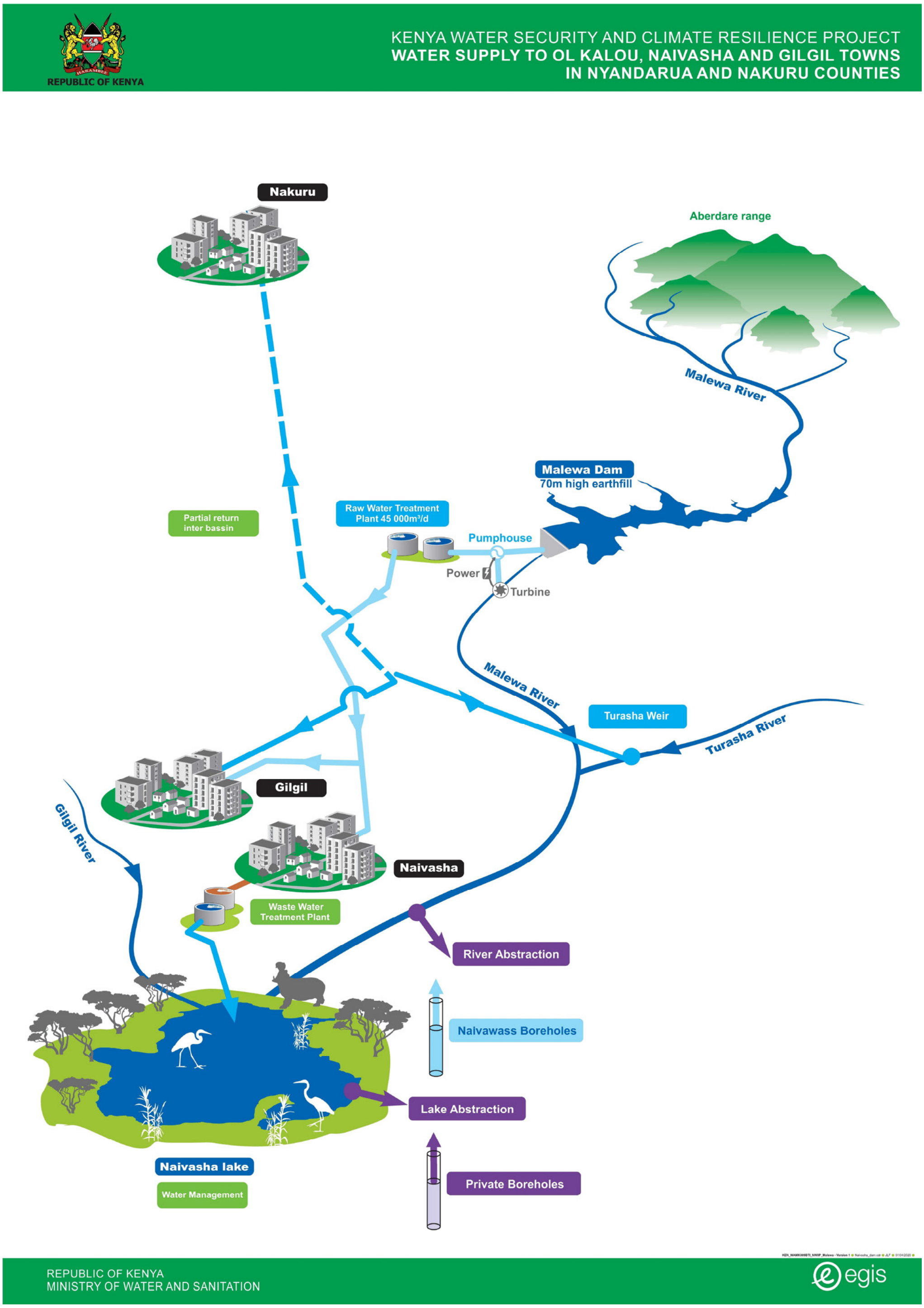

Fig. 12. Synthesis of the water supply project with Malewa Dam.