ENTRO
EASTERN NILE TECHNICAL REGIONAL OFFICE

BARO-AKOBO-SOBAT MULTIPURPOSE WATER RESOURCES DEVELOPMENT STUDY PROJECT

Feasibility study for the Kinyeti River multipurpose development project

Vfin July 2017

LIST OF DELIVERABLES

The Baro-Akobo-Sobat Multipurpose Water Resources Development Study Project has generated a set of deliverables which are summarised in the table below. This deliverable is highlighted in grey below.

THE BARO-AKOBO-SOBAT MULTIPURPOSE WATER RESOURCES DEVELOPMENT STUDY PROJECT	
A. The Integrated Water Resources Development and Management Plan	
A.1	Inception report
A.2	Consultation and Communication Plan
A.3	Scoping report
A.4	Baseline, Development Potentials, Key issues and Objectives report
A.5	Strategic Social and Environmental Assessment
A.6	Integrated Water Resources Development and Management Plan
B. Medium and Long Term Projects: Terms of references for feasibility studies	
B.1	The Integrated BAS Hydropower, Irrigation and Multipurpose Development Programme - Phase 1. Baro-Sobat component
B.2	The Akobo-Pibor Transboundary Multipurpose Development Project
B.3	Livelihood-based Watershed Management - Taking to Scale for a Basin Wide Impact
C. Short Term Project: Feasibility studies	
C.1	**Feasibility Study for the Kinyeti River Multipurpose Development Project**
C.2	Feasibility Study for the Majang Multipurpose Project
C.3	Design Details for the Akobo-Gambella floodplains Transboundary Development Programme
D. Project brochure	
D.1	The Baro-Akobo-Sobat Multipurpose Water Resources Development Study Project: General overview
D.2	The Baro-Akobo-Sobat Multipurpose Water Resources Development Study Project: Medium and Long Term Projects

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BARO-AKOBO-SOBAT MULTIPURPOSE WATER RESOURCES DEVELOPMENT STUDY PROJECT

Feasibility study for the Kinyeti River multipurpose development project

TABLES AND FIGURES

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ACRONYMS AND ABREVIATIONS

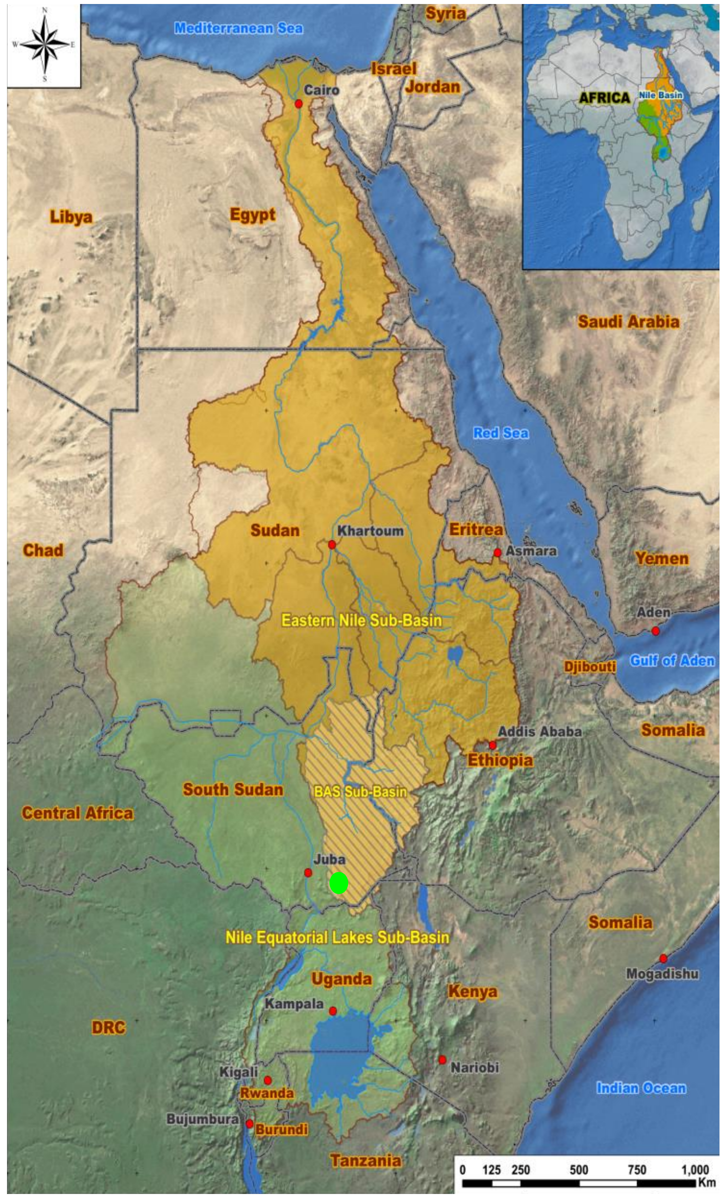
BAS	Baro Akobo Sobat
CAMP	Comprehensive Agriculture Development Master Plan
CBA	Cost Benefit Analysis
CRA	Cooperative Regional Assessment
DEM	Digital Elevation Model
EIA	Environmental Impact Assessment
ENSAP	Eastern Nile Subsidiary Action Plan
ENTRO	Eastern Nile Technical Regional Office (NBI)
FAO	Food and Agriculture Organization
GDEM	Global Digital Elevation Model
GIS	Geographic Information System
GWh/y	GigaWatt hour/year
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal Rate of Return
IUCN	International Union for Conservation of Nature and Natural Resources
IWMI	International Water Management Institute
IWRDMP	Integrated Water Resources Development and Management Plan
IWRM	Integrated Water Resource Management
MAFCRD	Ministry of Agriculture, Forestry, Cooperatives and Rural Development
MASL	Meters Above Sea Level
MEDIWR	Ministry of Electricity, Dams, Irrigation and Water Resources
MLFI	Ministry of Livestock and Fisheries
MoA	Ministry of Agriculture
MoEN	Ministry of Environment
NBI	Nile Basin Initiative
NELSAP	Nile Equatorial Lakes Subsidiary Action Program
NGO	Non-Governmental Organization
NPV	Net Present Value
SRFE	Satellite Rainfall Estimates
SRTM	Shuttle Radar Topographic Mission
SSEA	Strategic Social and Environmental Assessment
UNDP	United Nations Development Program
WaSH	Water Sanitation and Hygiene
WFP	World Food Program
WM	Watershed Management
WSS	Water Supply and Sanitation
WUA	Water Users Association

EXECUTIVE SUMMARY

The Kinyeti River multipurpose development project is one of the three short term projects proposed as part of the Baro-Akobo-Sobat multipurpose water resources development study project. The three short term projects are based on the sustainable development of water resources. They aim at providing inter-sectoral benefits and improving people's livelihoods in the sub-basin.

The Kinyeti project is centered around the construction of a **multipurpose dam** in Eastern Equatoria, South Sudan, upstream of the city of Torit. The project has been designed to provide the following benefits:

- The dam will support hydropower generation (production of **8 GWHrs/annum**) which could supply up to 80,000 people. It will play an important role in reducing deforestation in the catchment area.
- The 45 million m^3 reservoir will secure water access for the city of Torit (**100,000 inhabitants projected in 2041**). It will also support capture fisheries and recreational activities
- The regulation of the flow will provide water for the development of irrigation (**1,000 ha**) and aquaculture (**100 ponds of 200 m²**) downstream of the dam. It will also provide water for the livestock all year round and satisfy an environmental flow during the dry season. Irrigation and aquaculture will be introduced in this area and there would be room for further expansion of these activities in the future.



Location of the Kinyeti multipurpose development project (green dot)

In addition to these direct benefits, there will be positive externalities associated to the development of the project, among others:

- The production of hydropower and water supply will create a favorable environment for the development of ecotourism in this area which has many natural attractions such as the Badingillo floodplains, the Imatong Mountains and the Kidepo game reserve.
- Potable water supply to Torit will have many benefits, especially on people's health and on the reduction of waterborne diseases. It will also be the opportunity to reduce gender inequalities as women will no longer have to collect water every day.

Landscape in Torit County

- Finally, the dam will mitigate against the effects of climate change as it will secure an access to water in case of extreme drought events. It will also be highly valuable for crop production as climate projections in the area indicate a possible raise of the mean temperature from 0 to 2 degrees.

The total cost of the project would be around 92 million USD (around 56 million for the multipurpose dam). This is a very conservative estimate which takes into account that it would be the first major infrastructure project in the area. This project would bring significant benefits socio-economic and livelihood benefits. This is demonstrated in the cost-benefit analysis which indicates that the project is robust: the internal rate of Return is estimated to be around 10% and the net present value 11 million USD (over the next 25 years).

1. INTRODUCTION

1.1 CONTEXT OF THE SHORT-TERM PROJECTS WITHIN THE BAS STUDY

1.1.1 General Context

Work on the Baro-Akobo-Sobat (BAS) multipurpose water resources development study project commenced in March 2015. The overall objective of the study is to assist ENTRO in preparing an Integrated Water Resources Development and Management Plan (IWRDMP) based on a Strategic Social and Environmental Assessment (SSEA), and further develop investment packages for cooperative development in the Baro-Akobo-Sobat sub-basin. The study comprises 4 components:

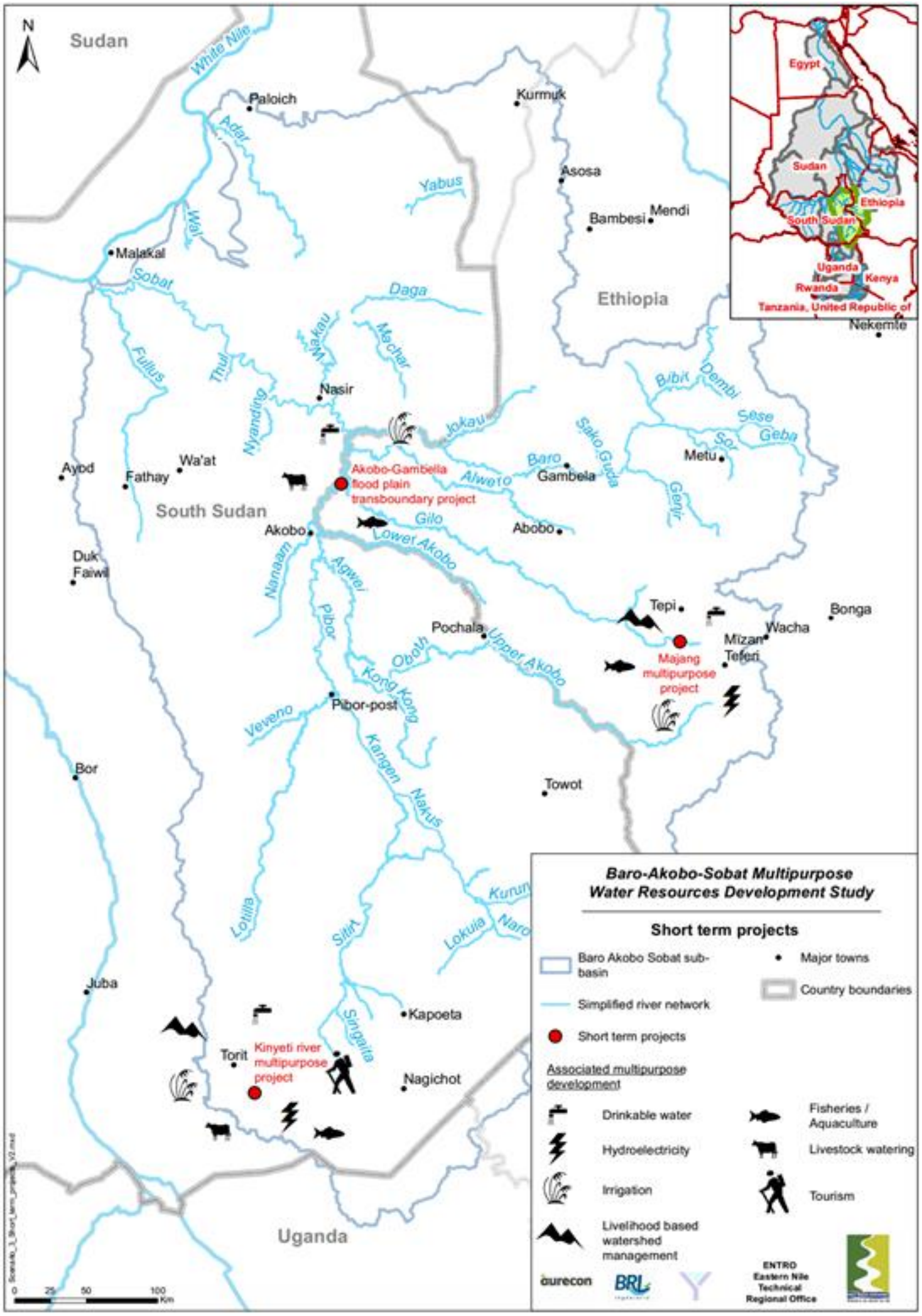
- **Component 1: Strategic Social Environmental Assessment (SSEA) and Integrated Water Resources Development and Management Plan (IWRDMP)**
- **Component 2: Identification and preparation of short term projects**
- **Component 3: Identification and profiling of medium and long-term projects**
- **Component 4: Project implementation support**

The Kinyeti river multipurpose development project is one of the three feasibility studies included in Component 2. The two other feasibility studies are the following:

- The Majang multipurpose development project (located in Ethiopia)
- The Akobo-Gambella floodplains transboundary development programme (shared between Ethiopia and South Sudan)

The three short term projects are shown on Figure 1-1. They were selected by key stakeholders during the baseline workshop held in Adama in April 2016. Seven short term projects were initially proposed in a concept note for discussion and selection during the workshop.

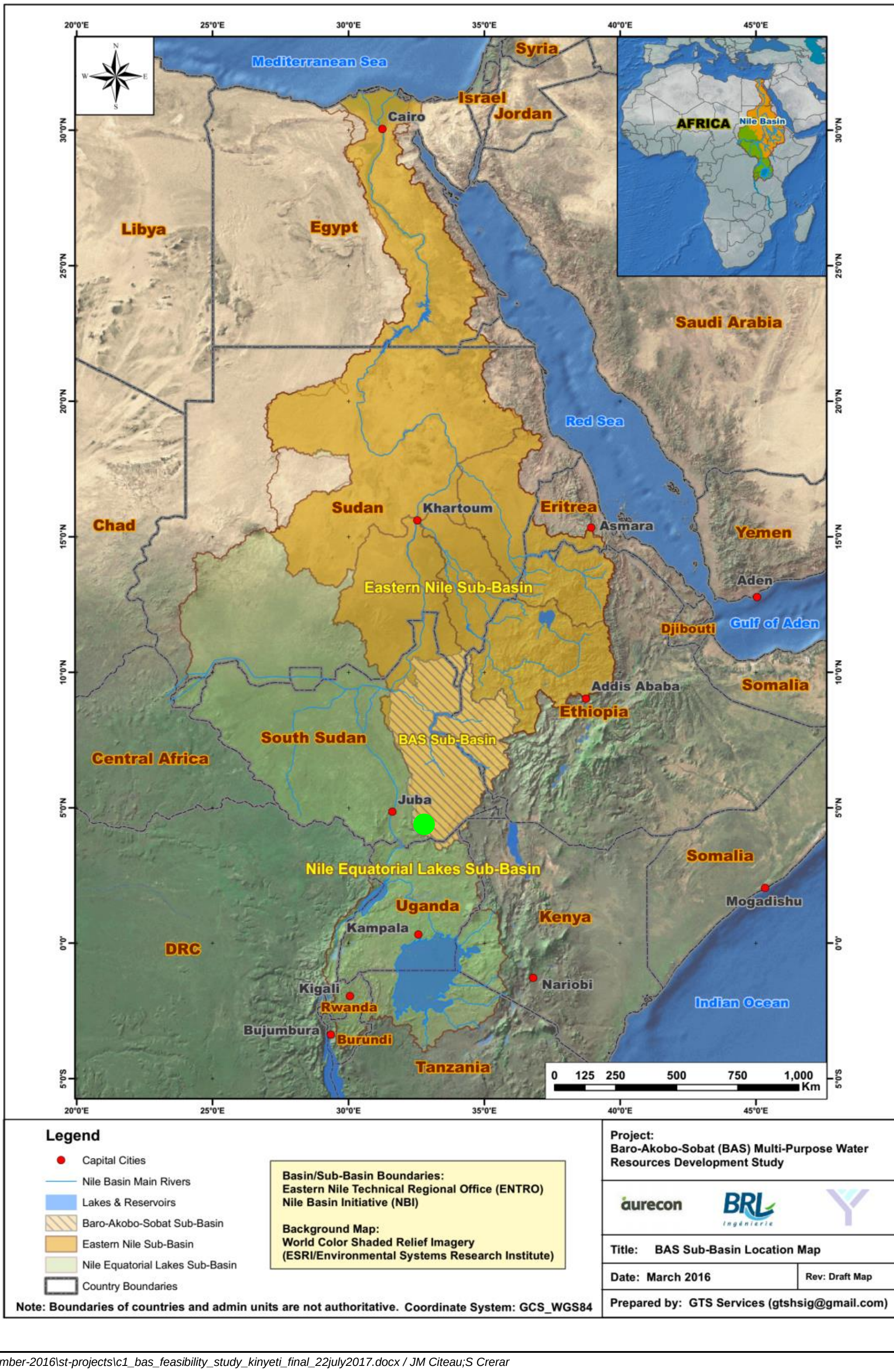
Figure 1-1: Location of the three short term projects



1.1.2 The BAS sub-basin

The BAS sub-basin is part of the Eastern Nile as shown in the location map hereafter. The multipurpose dam is indicated with a green dot on the map. This sub-basin is characterised by distinct wet and dry seasons and the spatial variation of precipitation across the basin is considerable.

Figure 1-2: Location of the Baro-Akobo-Sobat sub-basin within the Eastern Nile sub-basin



1.2 OBJECTIVES OF THE SHORT TERM PROJECTS

1.2.1 Objectives and principles of the short-term projects

OBJECTIVES OF THE SHORT-TERM PROJECTS

As stated in the general context, the feasibility studies for the short-term projects form Component 2 of the BAS multipurpose water resources development study project. The objectives of the short-term projects have been defined in accordance with the environmental and social work carried out in the baseline study and follow the guiding principles provided by the terms of references for the study. The main considerations of the short term projects are the following:

- Strategies to improve livelihoods and reduce poverty;
- Strategies to reduce conflicts over the resource (especially regarding livestock watering);
- Strategies to implement an enabling environment, favourable for moving towards the vision of the basin in the future, especially when supported by the implementation of medium and long-term projects and the taking of short-term demonstration type projects to scale.

Furthermore, it should be noted that these short-term projects have been designated in accordance with the sustainable development goals and more particularly with the following goals:

- Goal 1. End poverty in all its forms everywhere
- Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture
- Goal 3. Ensure healthy lives and promote well-being for all at all ages
- Goal 5. Achieve gender equality and empower all women and girls
- Goal 6. Ensure availability and sustainable management of water and sanitation for all
- Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all
- Goal 13. Take urgent action to combat climate change and its impacts

PRINCIPLES BEHIND THE SELECTION OF THE SHORT-TERM PROJECTS

<u>The perspective of IWRM principles is critical to ensure the sustainable use and management of water and associated resources</u>

IWRM principles have been central in the definition of these projects:

- Water resources development must be sustainable and integrate environmental, social and economic issues/potentials of the area.
- Water resources development must be based on local needs and include the consultation of key stakeholders.
- Water resources development must be coherent at the scale of the basin. Development upstream must not have harmful impacts on downstream water users and on the environment.
- Water resources development must provide shared benefits at basin scale.

The project must be designed in accordance with the vision defined for the basin as part of the IWRDM Plan

The vision represents the desired future state for the Baro-Akobo-Sobat sub-basin to be achieved by implementation of the IWRDM Plan. This vision was defined by key stakeholders from Ethiopia, Sudan, South Sudan and ENTRO during the baseline workshop held in Adama, Ethiopia on April 16th, 17th and 18th 2016. The three short term projects must contribute to reaching the vision which is as follow:

"A sustainably managed and developed BAS river sub-basin with prosperous, connected, peacefully and mutually co-existing societies."

The projects must provide inter-sectoral benefits

The three selected short-term projects are multipurpose projects: the proposed infrastructure can be shared by a number of development sectors (potable water supply, livestock watering, small scale irrigation, fisheries, hydropower, tourism etc.).

The services provided by water resources depend on the well-being of the related ecosystems

Emphasis has been put on **ecosystem services** and the need to sustainably develop water-related projects. The definition of ecosystem services by the Millennium Ecosystem Assessment is the following: "*Ecosystem services are the benefits people obtain from ecosystems. These include provisioning of services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services, such as nutrient cycling, that maintain the conditions for life on Earth."* The livelihood conditions of people in the basin depend directly or indirectly on the services provided by the ecosystems for potable water, sanitation, fisheries activities, agriculture, etc. In order to develop the livelihoods in the basin, it is thus essential to develop, optimize and ensure the sustainability of these ecosystem services. It should be stressed, therefore, that the concept of sustainability places emphasis on the economic self-sufficiency of the proposed project, since the environmental sustainability that the project should bring, can only be achieved if the economic sustainability is assured through the improved livelihoods of the beneficiaries.

1.2.2 Origin and justification for the project

The city of Torit, located in Eastern Equatoria depends on the Kinyeti River for potable water supply. This city has a population of arund 50,000 inhabitants and experiences frequent water shortages during the dry season. Moreover, there is no access to the electric grid in the county.

A field mission was carried out in Torit County in May 2015 and an area was preliminarily identified for the construction of a multipurpose dam. The potential dam area is located in Homodong Payam (Torit County, Eastern Equatoria State). The feasibility study found this area suitable for the development of a multipurpose dam.

The two main purposes of the proposed dam are the production of hydropower and provision of potable water for the population of Torit. In addition, the dam will allow the development of 1,000 of irrigated scheme (as a first phase), the development of fisheries in the reservoir, aquaculture downstream the dam and will create a favorable environment for the development of ecotourism. The promotion of these various uses associated with the development of the dam is highly encouraged to ensure the following factors of success for the project (EDF & World Water Council, 2015):

- Equitable access to water amongst the various sectors using water will ensure the acceptability of the project. This acceptability will be strengthened by the involvement of the local population in the implementation and operationalization of the project.
- Adaptability of the project: depending on the needs, the allocation of water amongst the different sectors can be adapted.

- River basin approach to ensure the proper management of the resources.

On the other hand, the development of this multipurpose dam is challenging as the sectoral benefits do not provide sufficient financial rates of return to ensure the repayment of the dam and generate private sector interest to build the infrastructure.

However, the dam will provide multiple public benefits which are difficult to measure such as a reliable access to a safe source of water for the city of Torit, mitigation of droughts and floods, reduction of water related conflicts which are commonly experienced in that area. As such, the dam can be seen as a public interest. The dam will also create opportunities for private sector investments (for hydropower, irrigation, aquaculture, tourism, etc.). This is often the case for multipurpose dams and public investments allow to overcome low financial rates of returns. For instance, the Lom Pangar dam in Cameroun and Kandadji dam in Niger are financed as public goods (EDF & World Water Council, 2015).

1.2.3 Specific objectives of the Kinyeti River multipurpose development project

The Kinyeti development project is located within the South Sudan part of the Baro-Akobo-Sobat (BAS) sub-basin. The primary purpose of the project is the production of hydropower together with the supply of potable water for Torit and its surroundings. A dam with a reservoir will be located 15 km upstream of Torit city. The multipurpose project will allow the parallel development of irrigation, fisheries (capture and aquaculture), livestock watering, tourism and recreation.

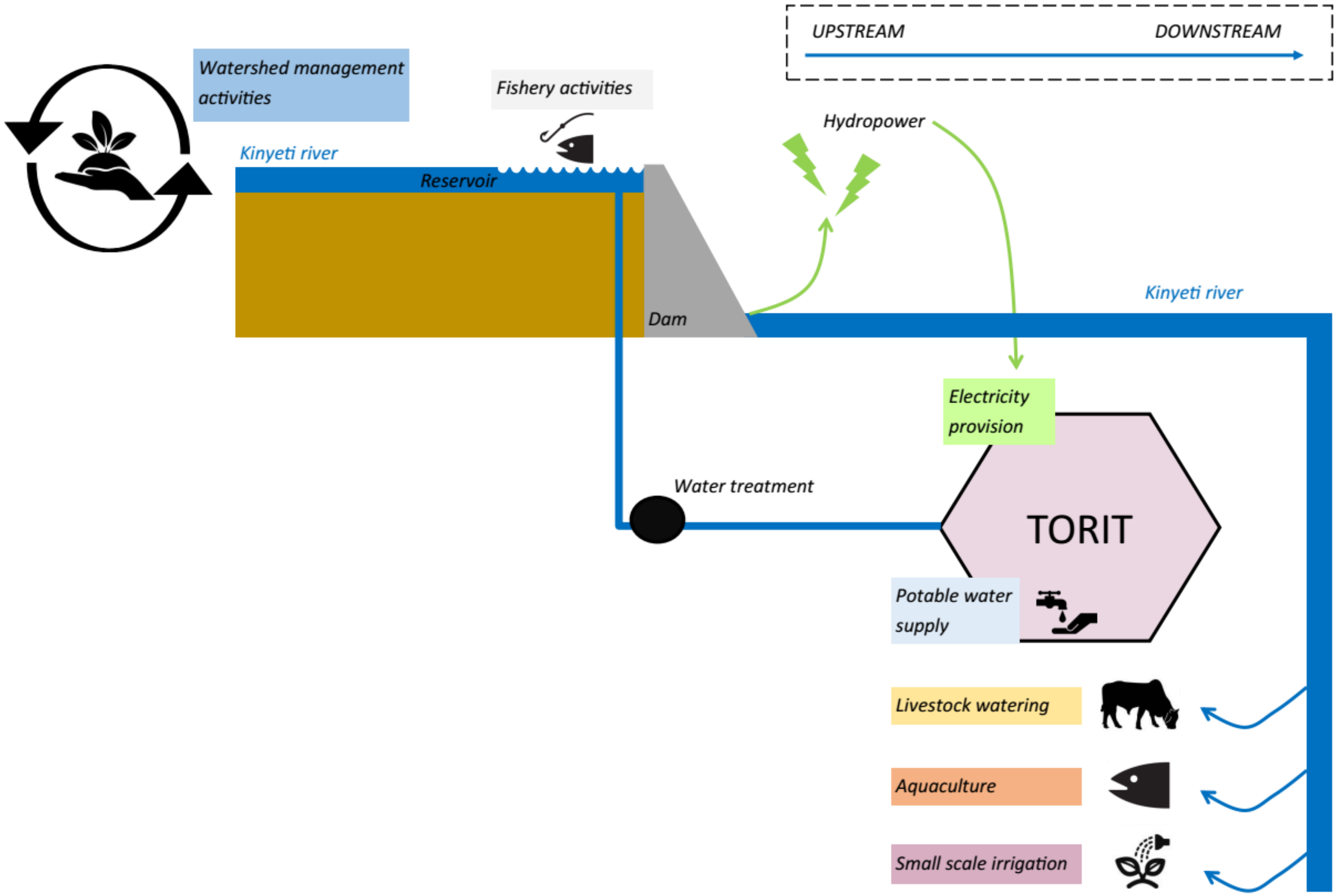
Finally, an essential component of the project will be focused on watershed management in the catchment area of the Upper Kinyeti River.

The beneficiaries of the project will be people living in Torit County:

- In the bomas located around the dam for fisheries activities,
- In Torit for access to potable water and hydropower,
- Downstream of Torit city for irrigation, livestock watering and aquaculture.

The overall principle of this short-term project is presented in the figure hereafter which underlines the multipurpose nature of the project.

Figure 1-3: Overall principle of the Kinyeti River multipurpose development project



1.2.4 Objective of this report

This report is the feasibility study for the Kinyeti River multipurpose development project, it will be presented to donors identified by ENTRO during a round table in 2017. It includes the following elements:

- Baseline analysis of the area where the project will be implemented (Chapter 2)
- Project design with implementation modalities (Chapter 3)
- Environmental and Social Impact Analysis of the proposed project (Chapter 4)
- Cost benefit analysis to help decision making (Chapter 5)

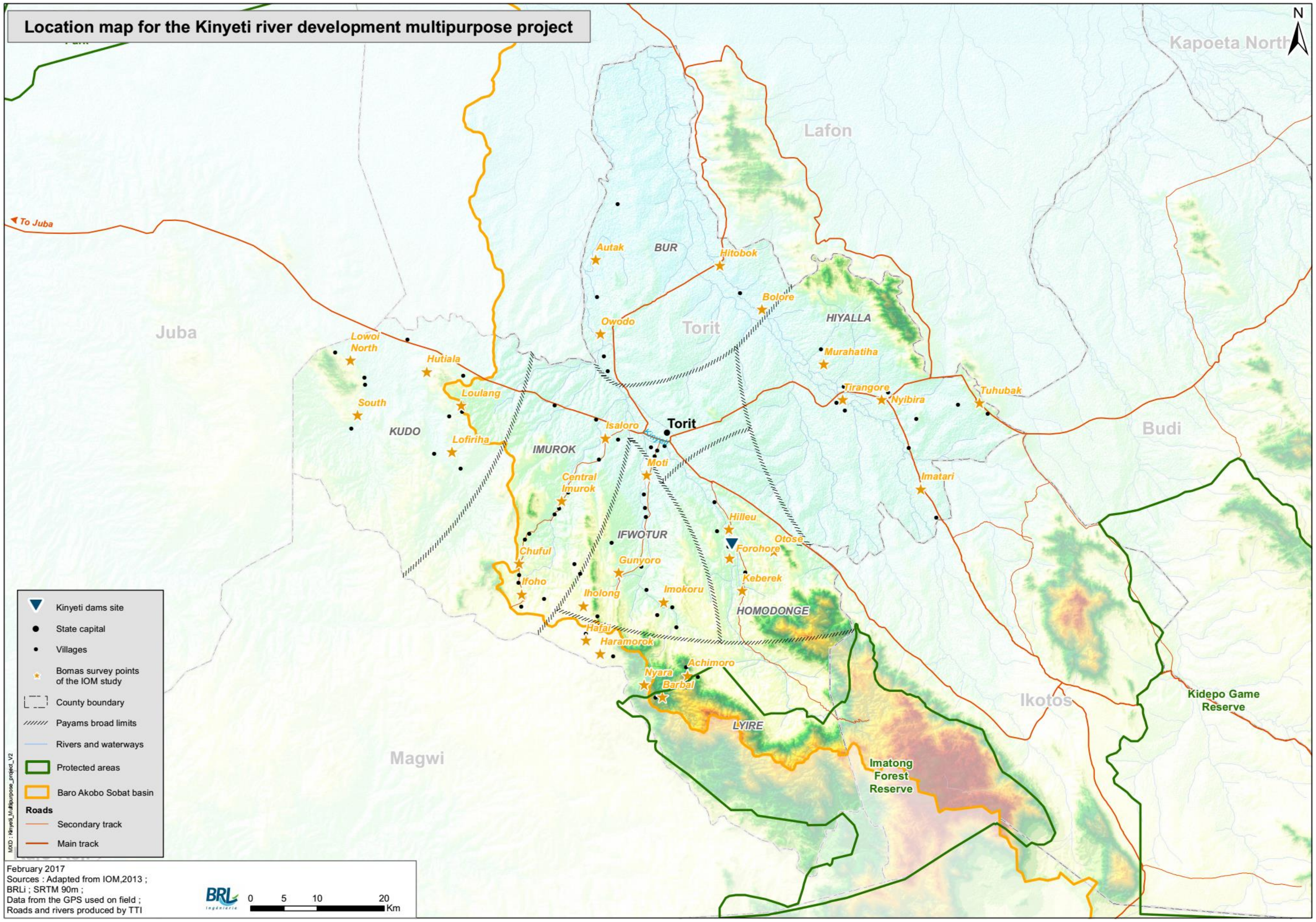
1.3 PROJECT AREA

The proposed dam and reservoir and the related activities are located in Torit County, on the Kinyeti river. Torit County is one of the 8 counties of Eastern Equatoria State in South Sudan. This County comprises 7 Payams (plus Torit city). The area of Torit County is 5,835 km².

Figure 1-4: The Kinyeti River close to the proposed damsite (May 2015)

A location map is provided in Figure 1-5.

Figure 1-5: location map for the Kinyeti River development multipurpose project



Adapted from IOM, 2013

2. PROJECT AREA - BASELINE

2.1 INTRODUCTION

The baseline information provided in this section relates to environmental, socio-economic and institutional information to understand the situation in Torit County, Eastern Equatoria State, South Sudan. Having a clear picture of the current situation enables identification of the needs and potentials of the area and to justify the proposed multipurpose project.

2.2 BIO-PHYSICAL ENVIRONMENT

2.2.1 Baseline situation

2.2.1.1 Physical environment

INTROCUCTION

The Kinyeti River is located in the Pibor sub-basin, with the river taking its source in the Imatong Mountains (see Figure 2-1; the location of the project area is indicated with a black circle).

The elevation in Torit County varies greatly, from more than 2,000 masl in the Imatong mountains down to 500 masl in the northern part of the County (in Bur Payam). The identified site for the proposed Kinyeti Dam is located at an altitude of 670 masl and the city of Torit at an altitude of around 620 masl.

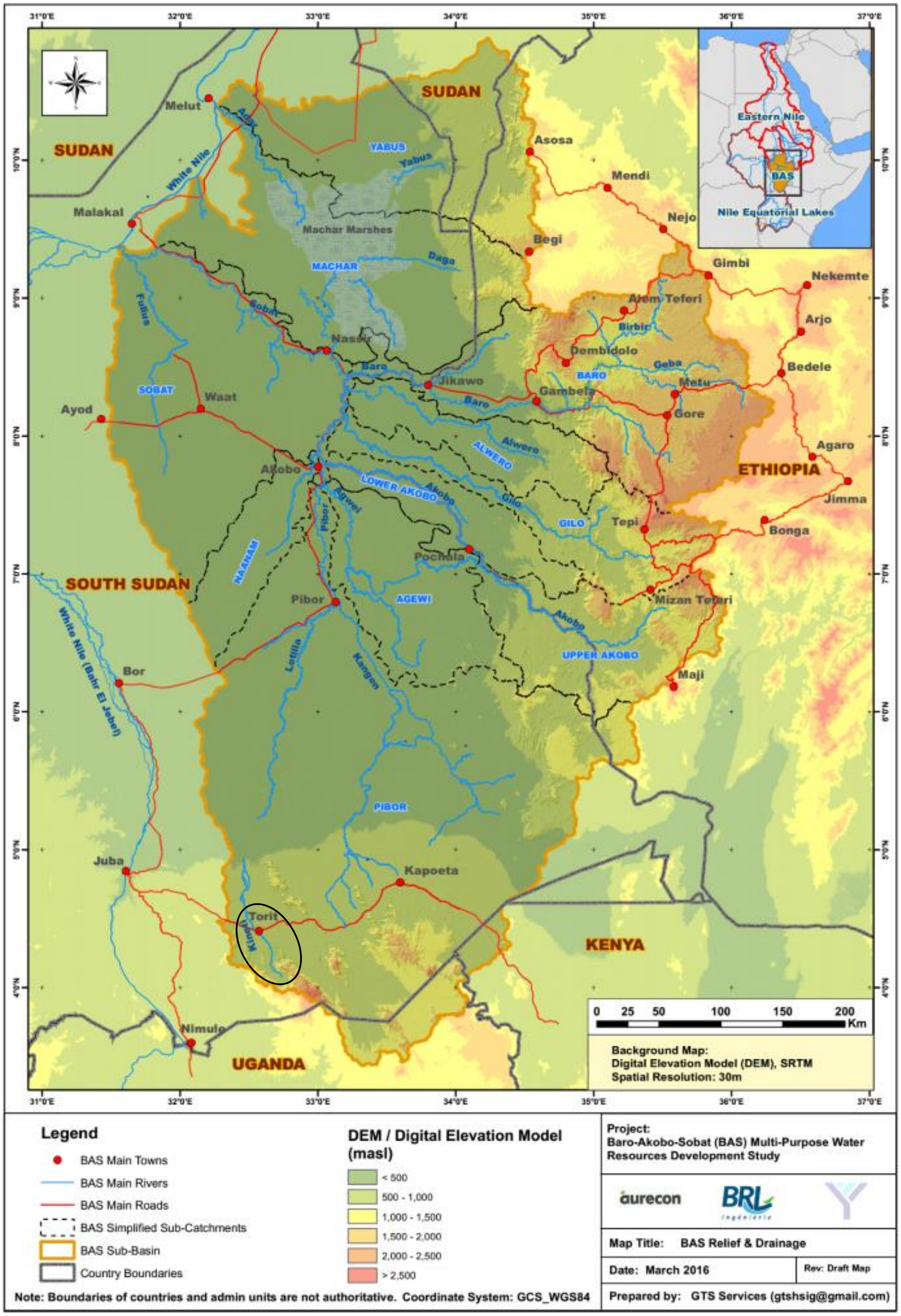
CLIMATE AND HYDROLOGY

This catchment receives around 750 to 1,000 mm of rainfall per year, the wettest months being July and August and the driest months December, January and February. The minimum temperature varies from 15°C in the highland to 17°C in the plains around Torit and the maximum temperature from 24°C in the highlands up to 30°C in the plain.

A detailed analyis of catchment rainfall has been carried out as part of the rainfall-runoff modelling carried out as part of the storage-draft analysis for the proposed Kinyetti Dam and reservoir (see Section 4.3). Mean annual precipitation (MAP) for the catchment (as defined by the proposed dam site) is calculated at 965mm. The annual potential evapotranspiration around the area of the proposed dam site has been calculated by means of the Thornwaite equation at 1054 mm

Various observations in literature and during field missions, have noted that springs contribute to the flow in the Kinyeti River. As part of a Hydrology Mission to the Kinyeti River Basin (Sep, 2014), daily flow measurements were recorded in the Kinyeti River at Torit from September 2015 to October 2016. There are very few other reliable data. Based on a combination of observed data and rainfall-runoff modelling, the mean annual runoff of the Kinyeti River is estimated at 154 Mm^3, which corresponds to a mean discharge of 4.88m^3/s. More detail on the hydrology and peak floods are provided in the analysis included as part of Section 4.3 later in this report.

Figure 2-1: BAS sub-basin: relief and drainage



2.2.1.2 Biological environment

FLORA

According to the WWF (World Wildlife Fund) classification of ecoregions, Torit County includes three main ecoregions:

- **East African Montane Forest ecoregion with Tropical and Subtropical Moist Broadleaf Forests: Mt. Kinyeti in the Imatong Mountains**

  The vegetation of the Imatong mountains is described by Bussman (2006) and varies greatly according to the altitude. The lower slopes are covered with lush evergreen submontane forest and the common species are *Ocotea usambarensis*, *Olea welwitschii a*nd *Chrysophyllum fulvum* (from Jackson 1956). Above 2,000 masl, the forests form an evergreen montane xeromorphic forest with *Podocarpus latifolius* and *Olea capensis*.

- **Northern Accacia Commiphora Bushland and Thickets ecoregion with Tropical and Subtropical Grasslands, Savannas and Shrublands: between 700 and 1,100 masl**

  Typical trees found in these areas are: *Combretum* and *Terminalia* species, *anogeissus leiocarpus*, *Boswellia papyrifera*, *Lanea schimperi*, and *Stereospermum kunthianum*. The solid-stemmed bamboo *Oxytenanthera abyssinica* is prominent in the western river valleys of Ethiopia. Dominant grasses include tall species of *Hyparrhenia*, *Cymbopogon*, *Echinochloa*, *Sorghum*, and *Pennisetum* (Tilahun et al., 1996 in Burgess et al., 2004).

- **East Sudanian Savanna with Tropical and Subtropical Grasslands, Savannas and Shrublands: between 700 and 1,100 masl**

These ecoregions were defined based on numerous references which can be found with a complete description of the ecoregions on the website of the WWF.
(http://wwf.panda.org/about_our_earth/ecoregions/ecoregion_list/).

FAUNA

The avifauna in the **East African Montane forest ecoregion** is quite diverse, and hosts eight endemic bird species (Stattersfield et al., 1998). Among these species, there are the Aberdare cisticola (*Cisticola aberdare*), Abbotts starling (*Cinnyricinclus femoralis*), Kenrick's starling (*Poeoptera kenricki*), Hunter's cisticola (*Cisticola hunteri*), Jackson's francolin (*Francolinus jacksoni*), and Sharpe's longclaw (*Macronyx sharpei*). Some of these species are typical of the montane forest, while others are found only in the montane grasslands within the ecoregion (Stattersfield et al. 1998).

Mammal endemism is more pronounced, even though there are no endemic large mammals. In the small mammals there are eight strictly endemic species, mainly shrews (*Crocidura gracilipes* (CR), *Crocidura raineyi*, *Crocidura ultima*, *Surdisorex norae* and *Surdisorex polulus*), and in rodents (*Grammomys gigas*, *Tachyoryctes annectens*, *Tachyoryctes audax*). Near-endemic mammals include Jackson's mongoose (*Bdeogale jacksoni*), Abbot's duiker (*Cephalophus* spadix), sun squirrel (Heliosciurus undulatus), and the eastern tree hyrax (*Dendrohyrax validus*).

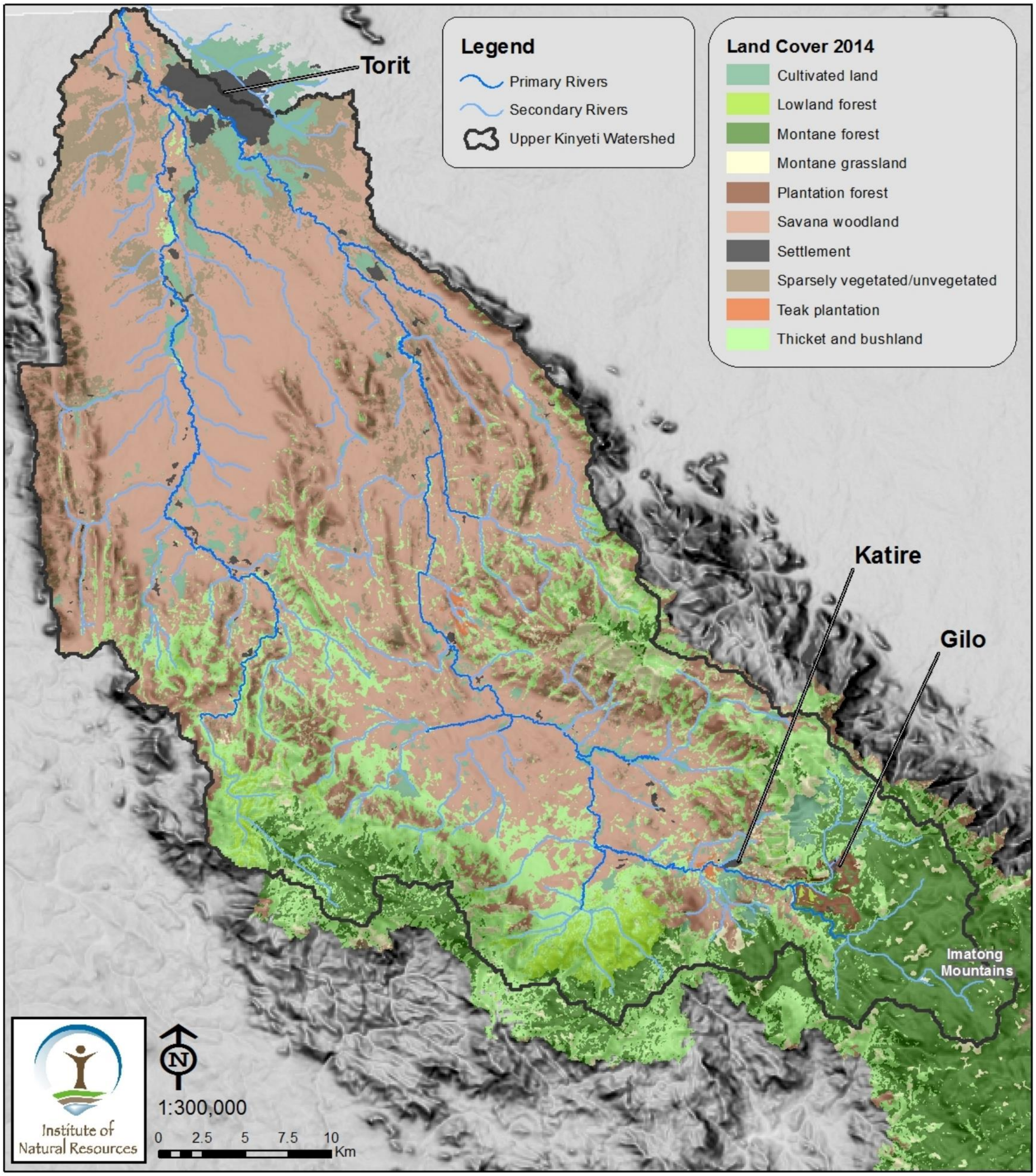
The **East Sudanian Savanna** and **Northern Accacia Commiphora Bushland and Thickets ecoregions** have low rates of faunal endemism, with only one strictly endemic mammal, two strictly endemic reptiles and five bird species for the East Sudanian Savana ecoregion. However, this is an important area for endemic plants. Threatened mammal species include elephants (*Loxodonta Africana*), wild dog (*Lycaon pictus*), cheetah (*Acinonyc jubatus*), and lion (*Panthera leo*). The roan antelope's (*Hippotradus equinus*) can also be found.

Figure 2-2: Typical landscape in Torit County with bush and thickets in the foreground and mountains at the background

2.2.1.3 Land use and land cover

The African Wildlife Foundation (AWF) produced a consultancy report on water resources in the Imatong Mountains. The document describes the land cover and land use of the Upper Kinyeti watershed and the map, extracted from the AWF report is presented hereafter in Figure 2-3. The land use is dominated by small scale subsistence agriculture, mainly around Torit city and along the river, within the different payams.

Figure 2-3: Land cover of the Upper Kinyeti Watershed



Source: AWF, 2014a

2.2.1.4 Areas with special status

Part of the Imatong Mountains is designated as a “forest reserve”. According to the South Sudan National Wildlife Service (SSWS) and the Wildlife Conservation Society (WCS), the reserve was designated in 1952. The implication of this designation is not clear although the governance is done at national level. Outside Torit County, there is the 1,200 km² Kidepo game reserve which was designated in 1975.

2.2.2 Key issues and challenges

The key environmental issues, as described by the WCS in the document *Sustaining Wildlife, and Community Livelihoods in the Southern Sudan-Northern Uganda Transboundary Landscape* (WCS-USAID, 2011) are the following:

- Depletion of wildlife populations due to:
  - Conflicts between livestock and wildlife for access to grazing lands and water
  - Poaching: the armed conflict in South Sudan has led to the proliferation of firearms and unsustainable hunting of wildlife in large numbers. This practice has been reinforced by the large movements of refugees in the area. It should be noted that a moratorium on wildlife hunting has been declared in 2011 by the Ministry of Wildlife Conservation, but little information is available on the level of compliance to this ruling.
- Deforestation and unsustainable use of charcoal and timber: deforestation is not well documented but could be a serious threat in the area. Moreover, unsustainable deforestation practices could increase erosion and sedimentation of the streams.
- Many endangered species are found (such as chimpanzees) in the Imatong Mountains.

2.3 SOCIO-ECONOMIC CONTEXT

2.3.1 Baseline situation

Information provided in this section relies mostly on data found in the *Village Assessment Study for Torit County* published in 2013 by the IOM (International Organization for Migration), from the *South Sudan Statistical Yearbook* published in 2011 by the South Sudan National Bureau of Statistics and, from the *Socio-Economic baseline survey of Imatong mountains water tower and Kinyeti river watershed* published by the AWF in 2014.

2.3.1.1 Population demographics

In 2013, the population of Torit County was about 115,184 people. Applying a 4.5% growth rate between 2013 and 2020, the population could reach 156,750 people in 2020 (and 263,274 people in 2041 with a 2.5% growth rate between 2020 and 2041). More information is given in Table 2-1 hereafter.

Table 2-1: Demography for Torit County, per Payam

		2016			**2020 (4.5% growth rate per year)**			**2041 (2.5% growth rate per year)**		
		Total	**Males**	**Females**	**Total**	**Males**	**Females**	**Total**	**Males**	**Females**
Torit County: population in 2013 per payam	Bur	19,797	10,007	9,970	23,508	11,816	11,692	39,484	19,846	19,638
	Homodonge	11,878	6,004	5,874	14,105	7,090	7,015	23,691	11,908	11,782
	Hiyalla	31,088	15,714	15,374	36,917	18,556	18,361	62,005	31,166	30,839
	Ifwotur	11,438	5,782	5,657	13,583	6,827	6,755	22,814	11,467	11,346
	Imurok	9,092	4,596	4,496	10,796	5,427	5,370	18,133	9,115	9,019
	Kudo	14,078	7,116	6,962	16,717	8,403	8,314	28,078	14,114	13,964
	Torit	49,419	24,980	24,439	58,684	29,497	29,187	98,565	49,543	49,022
	Lyire	-	-	-	-	-	-	-	-	-
	TOTAL Torit County	**146,790**	**74,199**	**72,772**	**174,310**	**87,616**	**86,694**	**292,768**	**147,158**	**145,610**

Source: South Sudan National Bureau of Statistics, 2011

2.3.1.2 Education

As can be seen in Table 2-2, the literacy rate in Eastern Equatoria is very low, 19% for people aged over 15. (27% at national level). It is likely that there are significant disparities between males and females even if the information is not available at state level (at national level, 40% of males are literate over 15 years old compared to 16% of females).

More information on primary school pupil enrolment rate is provided in Table 2-3.

Table 2-2: Literacy rate for South Sudan and Eastern Equatoria

			Can read and write (6+)	**Can read and write (15+)**	**Can read and write (15-24)**
Literacy rate in 2009	South Sudan	Male	38%	40%	55%
		Female	19%	16%	28%
		Total	28%	27%	40%
	Eastern Equatoria	Total	18%	19%	26%

Source: South Sudan National Bureau of Statistics, 2011

Table 2-3: Primary school pupil enrolment rate

			Total	**Male**	**Female**
Primary school pupil enrolment rate in 2010	Torit County	Children of primary school age	47,087	-	-
		Number of pupils in primary school	24,956	15,196	9,760
		Pupil enrolment rate	53%	60.9%	39.1%
	Eastern Equatoria	Pupil enrolment rate	50%	60.2%	39.8%

Source: South Sudan National Bureau of Statistics, 2011

2.3.1.3 Sources of livelihood

As shown in Table 2-4, 85% of the households in Torit County are farmers, mostly for subsistence. In 2010, it represented 17,622 households. The average cereal area per household was 0.8 ha with a yield of 1.05 T/ha. The cereal deficit in 2011 was estimated to be around 1,998 T for the County.

More information on food consumption for Eastern Equatoria and at national level is presented in Table 2-5.

Table 2-4: Livelihood information for Torit County in 2010

Livelihood information for Torit County in 2010		Households mid-2010	Percentage of farming households	No. of farming households	Average Cereal area (ha/hh²)	Total Cereal area (ha)	Yield (T/ha)	Estimated cereal deficit in 2011 (T)
	Torit County	20,732	85%	17,622	0.8	14,098	1.05	1,998
	Eastern Equatoria	163,930	74%	121,252	0.9	103,362	0.96	42,778

Source: South Sudan National Bureau of Statistics, 2011

Table 2-5: Information on food consumption in Eastern Equatoria

Information on food consumption in Eastern Equatoria		Average food consumption in dietary energy value (kcal/person/day)	Minimum dietary energy requirement (kcal/person/day)	Proportion of food deprivation in total population (%)	DEC* coming from proteins (%)	DEC* coming from fats (%)	DEC* coming from carbohydrates, fiber and alcohol (%)
	Eastern Equatoria	2,400	1,701	47%	14.7%	25.1%	60.2%
	South Sudan	1,890	1,717	27%	13.3%	21.3%	65.3%

Source: South Sudan National Bureau of Statistics, 2011

*DEC: Dietary Energy Consumption

FOOD CROP PRODUCTION

According to the village assessment survey carried out by the IOM (IOM, 2013), the major food crops grown in the county are the following:

- Maize, sorghum, sesame, groundnuts and vegetables are grown in most of the bomas which were visited during the survey
- Millet and cassava are also grown to a lesser extent while there is no rice plantation.

LIVESTOCK AND FISHERIES

Livestock husbandry activity is widespread in South Sudan. According to the IOM survey, it is practised in all the bomas visited. Fishery activity is far less significant in the county although practised in few bomas such as Owodo and Autak in Bur Payam and Hilleu in Homodonge Payam (close to the proposed reservoir).

WATER MANAGEMENT

Access to water can be a source of conflict, especially for livestock watering during the dry season. As can be seen in Table 2-6 hereafter, most of the bomas surveyed by the IOM experienced water related conflicts in 2013 despite the organization of water user committees in most of them.

However, the following should be noted:

- The 4 bomas which did not report water related conflicts have water user committees
- All the bomas which did not have water user committees reported water related conflicts

Table 2-6: Water management and related conflicts for Torit County, at Boma level

			Water user committee	water fee	conflict for water
Water management and related conflicts at Boma level in 2013	Bur	Hitobok	✓	×	✓
		Owodo	—	—	—
		Autak	✓	×	✓
		Bolore	✓	×	✓
	Hiyalla	Nyibira	×	×	✓
		Imatari	—	—	—
		Tirangore	✓	×	×
		Tuhubak	—	—	—
		Murahatiha	—	—	—
	Homodong	Otose	✓	×	✓
		Forohore	×	×	✓
		Hilleu	×	×	✓
		Keberek	—	—	—
	Ifwotur	Iholong	—	—	—
		Gunyoro	—	—	—
		Moti	✓	×	✓
		Imokoru	✓	×	✓
	Imurok	Isaloro	—	—	—
		Central Imurok	✓	×	×
		Ifoho	✓	×	×
		Chuful	✓	×	×
	Lyire	Nyara	—	—	—
		Barbal	—	—	—
		Achimoro	—	—	—
		Haramorok	—	—	—
		Hafai	—	—	—
	Kudo	Lowoi North	✓	×	✓
		Lowoi South	✓	✓	✓
		Hutiala	✓	×	✓
		Lofiriha	✓	×	✓
		Loulang	✓	×	✓

Source: IOM, 2013

2.3.1.4 Health status

According to the socio-economic baseline survey carried out by the AWF in Torit, Ikotos and Magwi counties (AWF, 2014), most of the diseases found in the area are waterborne, the three most common being malaria, typhoid and diarrhoea (refer to Table 2-7). Other diseases include Schistosomiasis, Helminthiasis, Leshimaniasis, and Onch ocerchiasis.

As emphasized during the survey, even though people are aware of health hazards associated with water and sanitation, 64% of the households reported that at least one member of the family was sick during the past year (AWF, 2014). This can be explained by the fact that the main source of drinking water is provided by public boreholes and unprotected wells and springs. Moreover, 60% of the households surveyed reported the practice of open defecation and the remaining 40% essentially use traditional pit latrine that they share between different households. These poor hygiene conditions are the main factor explaining Typhoid, Cholera and other diarrhoea diseases.

Table 2-7: Water related diseases reported in the surveyed households

Disease / sickness	%
Malaria	35.1
Typhoid	23.9
Diarrhoea	21.9
Eye disease	9.5
Respiratory disease	4.5
Bilharzia	3.3
Cholera	0.83

Source: AWF, 2014

Except in the town of Torit, there is no hospital in the County. In rural bomas, people mostly go to primary health care units and drug dispensaries as shown in Table 2-8.

Table 2-8: Access to health facilities in Torit County in 2013

		Primary Health Care Unit	Primary Health Care Centre	Hospital	Drug dispensary	Immunization	Health education
Torit County: Access to health facilities and services offered per payam (number of facilities and centres offering the service) in 2013	Bur	6	2	0	5	8	0
	Homodonge	0	1	0	1	1	1
	Hiyalla	2	0	0	2	1	1
	Ifwotur	2	0	0	2	2	0
	Imurok	3	0	0	2	3	2
	Kudo	2	1	0	1	2	1
	Lyire	3	1	0	1	4	2

Source: Source: IOM, 2013

2.3.1.5 Gender relations

As emphasized in the AWF study (AWF, 2014), there is a need for detailed surveys and studies on gender roles in this area. The responsibilities and decision-making power attributed to women are not known. A few key facts can, however, be pointed out:

- Access to education is lower for females than for males;
- Women are almost always in charge of collecting water and have a heavy workload in domestic duties and raising the children.

Furthermore, in some bomas during the IOM survey, women reported facing Sexual and Gender Based Violence (SGBV).

2.3.1.6 Ethnic groups

The main ethnic groups and languages spoken in Torit County, per payam are presented in Table 2-9.

Table 2-9: Tribes and spoken languages in Torit County

		Main tribe	Main language
Torit County: main tribes and languages spoken per payam in 2013	Bur	Lotuko/Otuho	Otuho
	Homodonge	Lotuko	Otuho
	Hiyalla	Lotuko/Otuho	Lotuko/Otuho
	Ifwotur	Lotuko	Otuho
	Imurok	Lotuko	Otuho
	Kudo	Lokoya/Lotuko	Lokoya/Otuho
	Lyire	Lotuko/Otuho	Lotuko/Otuho

Source: Source: IOM, 2013

2.3.1.7 Agricultural markets and infrastructure

According to the IOM survey (IOM, 2013), there are roads in most bomas. However, their condition, especially during the rainy season is not known. It is thus difficult to assess the accessibility of the bomas throughout the year.

Apart from Torit city, there are small markets in 5 bomas: Lowoi, Central Imurok, Hyara, Barbal, and Nyibira.

2.3.2 Key issues and challenges

Key socio-economic issues in Torit County relate to access to safe water throughout the year, high prevalence of waterborne diseases, food security, gender inequality and water related conflicts.

- Access to safe water throughout the year and sanitation: as already emphasized, the low level of access to a safe water source and the poor conditions of hygiene lead to a high prevalence of waterborne diseases.
- Food security: this issue was raised in most of the bomas surveyed by the IOM. According to the South Sudan national bureau of statistics, the cereal deficit was around 1,998 T for Torit County in 2011. It is likely that this figure was higher in the last few years due to the significant number of displaced people who arrived in the area. In some local communities, food insecurity has created conflicts between members of the community and between different communities.
- Gender inequality is an issue raised for the following reasons:
  - There is an unequal access to education between males and females.
  - Women have heavy workload in domestic duties (including collecting water and raising the children)
  - Sexual and Gender Based Violence were reported to the IOM during their survey in 2013.
- Water related conflicts are mainly related to livestock watering during the dry season. Farmers migrate with the livestock in search of grazing areas and water. This is the cause of many conflicts between the different communities.

2.4 INSTITUTIONAL BASELINE

ADMINISTRATIVE ORGANIZATION

In South Sudan, there are four main sub-national administrative levels which are the following (from the largest to the smallest):

- States
- County
- Payam
- Boma

The project is centered around Torit County (the administrative center of the County being Torit city). The different Payams and Bomas included in Torit County are presented in Figure 1-5.

LAND TENURE SYSTEM

In Torit County, the land tenure system is mostly “free communal” which means that each member of the community has a right to use the lands of the community. In some Bomas, there is also an “ancestral” land ownership type where people can inherit land.

2.5 NEEDS AND POTENTIALS

Needs can be deduced from the identified key social and environmental issues/challenges in the County. They are the following:

- Provide a safe and perennial access to water: this need is the priority of the short term project and will be addressed through the provision of water to the city of Torit from a reservoir built upstream of the city, on the Kinyeti river (water needs were defined for a growing population with 2041 as reference).
- Improve food security: this need will be addressed through the development of fisheries, aquaculture, irrigation and livestock watering.
  - **Aquaculture** is both a need and a potential. The area downstream of Torit city is indeed favourable for the development of aquaculture with high production levels and it can be seen as an alternative to provide animal proteins and reduce conflicts related to animal husbandry.
  - **Irrigation** will be particularly important to secure crop production during dry spells and years with a delayed rainy season.
  - **Livestock watering** is a key component to reduce water-related conflicts among the communities.
  - As for aquaculture, **fisheries represent** both a need and a potential. Fishing is already practised in a few b omas in Torit County, especially in Hilleu Boma which is close to the planned reservoir where fisheries activities will be developed.
- Foster economic development: the above activities will also contribute to the economic development of the area.
- Protect the rich biodiversity of the Imatong mountains: poaching, deforestation and unsustainable use of charcoal are key issues in the county. There is the need to provide alternative sources of energy and livelihood opportunities. There is already an ongoing project of the AWF to “secure the Imatong Mountains Water Tower” and proposed actions in this feasibility study are formulated in line with this project. It should be noted that the Project manager of the AWF for this project was met in Torit in May and July 2015 in the course of this study.

One of the main **potentials** of the area is the **production of hydropower**. At the same time, only a few locations in Torit currently receive electricity and this is provided by diesel generator sets. The provision of affordable electricity to Torit and surroundings would meet a real need and support the reduction of poverty in many ways. A hydropower site has been identified (refer to Figure 1-4) and the production of electricity in the county will be a key element to reduce deforestation. It will also contribute to the improvement of food security, health and foster economic development (notably through the development of agro-processing activities and addition of value activities).

Finally, it should be noted that there is a great potential for developing ecotourism in the area. The supply of potable water and electricity and the increase in food production will be enabling factors in the development of tourism in the area. Ecotourism can be highly profitable for local communities. The Imatong mountains, the Kidepo game reserve and the Bandingilo national park could support the development of ecotourism. The Imatong mountains could be particularly interesting to develop accommodation given the cooler climate offered by the mountains and the proximity of Juba.

2.6 CONCLUSIONS

Chapters 1 and 2 have aimed at providing the elements for understanding the baseline situation in Torit County and show the relevance of this multipurpose project. The following sections present the technical details for implementing the project for the different sectors. As already emphasized, this project has been designed in such a way that it is highly replicable in other areas of the BAS basin.

3. ASSESSMENT OF WATER REQUIREMENTS AND JUSTIFICATION OF THE PROJECT

3.1 WATER REQUIREMENTS PER SECTOR

3.1.1 Introduction

Major needs and potentials in the area are presented above. As emphasized in the introduction of the report, this project is based on the construction of a multipurpose dam. Water requirements for the different sectors that will beneficiate from the dam and reservoir are presented here after.

3.1.2 Hydropower generation

In order to maximize hydropower potential, water for the different uses will be abstracted downstream of the dam and will be used for hydropower production. There is no minimum threshold to generate hydropower but the production is proportional to the flow going through the turbines. The maximum capacity of the turbine was determined as a result of the following parameters (refer to section 4.3):

- Water needs downstream of the dam must be satisfied 95% of the time
- Fisheries activities in the reservoir must be sustained all year round

3.1.3 Potable water supply for Torit Payam

Future water demands (for the year 2041) for Torit Payam have been determined as follows:

- The population projections to 2020 for Torit have been based on those for Torit County in the Torit Payam which are published in Table 470 of the South Sudan National Bureau of Statistics entitled 'Population Projections for South Sudan by Payam from 2015-2020. These population projections are provided in Table 2-1.

The projected demand for potable water supply is shown in Table 3-1 below. This table shows that the estimated average domestic water demand will be about 11,000 m^3/day in 2041.

Table 3-1: projected water demand for Torit

Year	Population	Average demand l/capita/day	Average Day		Maximum Day	
			m^3/day	l/s	m^3/day	l/s
2016	49,419	26	1,670	19.33	3,252.86	37.65
2017	51,667	26	1,746	20.21	3,400.83	39.36
2018	53,964	26	1,824	21.11	3,552.02	41.11
2019	56,290	26	1,903	22.02	3,705.13	42.88
2020	58,684	32	2,441	28.26	4,754.10	55.02
2021	60,151	32	2,502	28.96	4,872.94	56.40
2022	61,655	35	2,805	32.47	5,463.05	63.23

Year	Population	Average demand l/capita/day	Average Day		Maximum Day	
			m^3/day	l/s	m^3/day	l/s
2023	63,196	35	2,875	33.28	5,599.59	64.81
2024	64,776	35	2,947	34.11	5,739.59	66.43
2025	66,395	35	3,021	34.96	5,883.04	68.09
2026	68,055	35	3,097	35.84	6,030.13	69.79
2027	69,756	40	3,627	41.98	7,063.83	81.76
2028	71,500	40	3,718	43.03	7,240.43	83.80
2029	73,288	40	3,811	44.11	7,421.49	85.90
2030	75,120	40	3,906	45.21	7,607.01	88.04
2031	76,998	40	4,004	46.34	7,797.19	90.25
2032	78,923	44	4,514	52.25	8,791.33	101.75
2033	80,896	44	4,627	53.56	9,011.11	104.30
2034	82,918	44	4,743	54.89	9,236.34	106.90
2035	84,991	44	4,861	56.27	9,467.26	109.57
2036	87,116	44	4,983	57.67	9,703.96	112.31
2037	89,294	44	5,108	59.12	9,946.57	115.12
2038	91,526	44	5,235	60.59	10,195.20	118.00
2039	93,814	44	5,366	62.11	10,450.06	120.95
2040	96,159	44	5,500	63.66	10,711.27	123.97
2041	98,563	44	5,638	65.25	10,979.06	127.07

3.1.4 Environmental flows

The definition of an environmental flow to be released from the dam is essential to ensure that there is enough water to maintain the functions and the resilience of the river ecosystems.

A support to low water levels was chosen to define the environmental flow downstream of the dam. 1/10 of the mean daily discharge (m^3/s) is a value commonly used. The mean daily discharge at the hydrological station located downstream of the dam is 4.14 m^3/s so an **environmental flow of 0.4 m^3/s** is selected.

3.1.5 Irrigation

The main rainy season in the area is from mid-May to October (around three quarters of the annual rainfall occurs between May and October. During the dry season (from November to April), available soil moisture does not meet plant water requirements and irrigation is required to increase crop production.

Agro-ecologically and topographically, the area is suitable for irrigated agriculture with sufficient land and water resources. Crop production, which is supplemented by traditional livestock production, plays a leading role in food safety and local economy. Despite its leading role, crop production is constrained by low agricultural productivity causing high vulnerability to weather-induced shocks.

Water requirements for 1,000 ha under irrigation are presented in Annex 2. The main results are featured in the following table.

Table 3-2: Water requirements for irrigation development (50% efficiency, 10% flexibility factor)

Month	Area Under Cultivation		Water requirements			
	%	Ha	Volume / month (Mm^{3})	Flexibility Factor l/s/ha (+10%)	24 hr irrigation	
					l/s/ha @ 50% Efficiency	Total (m^3/s)
January	95	950	2.4631	0.48	0.97	**0.92**
February	70	700	0.1490	0.04	0.09	**0.06**
March	5	50	0.0029	0.01	0.02	**0.00**
April	80	800	0.1369	0.03	0.07	**0.05**
May	95	950	1.0636	0.21	0.42	**0.40**
Jun	95	950	1.7353	0.34	0.68	**0.65**
July	88	880	0.2593	0.06	0.11	**0.10**
August	5	50	0.0029	0.01	0.02	**0.00**
September	5	50	0.0057	0.02	0.04	**0.00**
October	95	950	0.3250	0.07	0.13	**0.13**
November	95	950	2.1669	0.44	0.88	**0.84**
December	90	900	3.2880	0.68	1.36	**1.23**
Total			11.5987			

3.1.6 Fisheries and Aquaculture

Fisheries activities will be developed in the reservoir. As such, there is no minimum water flow requirement in the river.

For aquaculture, the surface area of each pond is around 200 m^2 and the depth 1.5 m. 30,000 m^3 of water are thus required to fill in the 100 proposed ponds. The development of aquaculture is planned over 5 years (20 ponds per year), so 6,000 m^3 per year will be required to fill in the ponds. This can be done during the rainy season and does not represent a constraint.

Water needs during the dry season will be lower, just enough to maintain the level of water in the ponds. If a maximum evaporation of 7 mm/day is considered then, it means that 140 m^3/day will be required to maintain the level of water during the dry season. This volume is not significant and does not represent a constraint. By way of comparison, for example, the environmental flow is 0.4 m^3/s which represents 34,560 m^3/day.

3.2 JUSTIFICATION FOR THE MULTIPURPOSE DAM AND COMPARISON WITH A SIMILAR DAM

MULTIPURPOSE USES OF THE DAM/RESERVOIR

The dam/reservoir is multipurpose in nature and has three main objectives:

- Ensure access to water for the city of Torit
- Create head for the production of hydropower.
- Create a reservoir for the development of fisheries activities but also for recreational activities.
- Regulate the flow for other water needs downstream i.e for irrigation, aquaculture, livestock watering, etc.

COMPARISON WITH A SIMILAR DAM

The Agly dam was built in the early 90s in France on the Agly river. This dam was initially designed for the following uses: irrigation, potable water supply, low water-level support, flood peak reduction. In 2013, a hydropower plant was installed. The characteristics of this dam are quite similar with the proposed Kinyeti dam and its value comes for the multipurpose uses allowed by the dam.

It is thus interesting to compare the characteristics of the two dams to give an idea of what could be the Kinyeti dam.

Table 3-3: Comparison of the main characteristics of the Kinyeti and Agly dams

Characteristics	Agly dam	Kinyeti dam
Maximum storage (Mm3)	49	45
Maximum head (m)	57	40
Maximum surface area (ha)	450	300
Dam width (m)	260	340
Capacity of the turbines (kW)	2,300	1,800 (maximum 2,900 kW)

Some pictures of the Agly dam are given here after (i) during the construction of the dam in the 1990s and (ii) very recent pictures.

Figure 3-1: Agly dam during the construction (spillway on the right)

Figure 3-2: Agly dam recently

3.3 Potential of the dam to mitigate climate change

3.3.1 Climate change projections in the area

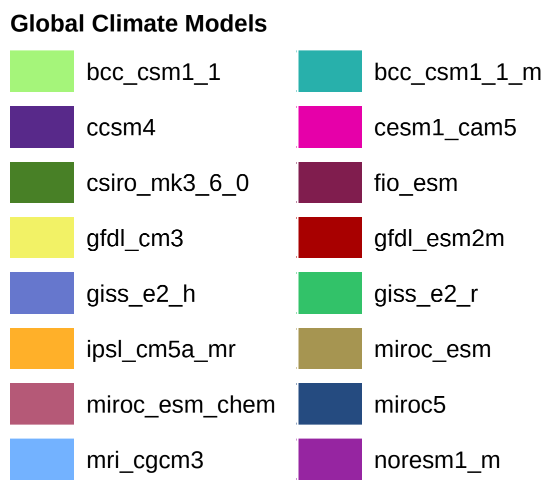
Source of information

Data from the "Climate Change Knowledge Portal" of the World Bank, available online on *http://sdwebx.worldbank.org/climateportal/* were used to study climate change projections in the Kinyeti area.

This portal was created to disseminate existing information regarding climate change in a user friendly manner and thus inform decision makers. The website uses a vast collection of models to outline projected future changes of temperature and precipitation across the globe and for major river basins. The collection analyzed is a representative subset of the full CMIP5[1] distribution (Taylor et al. 2012) used by the Intergovernmental Panel on Climate Change (IPCC) in the 5th Assessment Report released in 2009.

Climate change projections are presented as changes in 20-yr period of time (2080-2099) relative to a reference period 1986-2005. The different models used in the Climate Change Knowledge Portal are presented in Figure 3-3.

Figure 3-3: Global climate models used in the Climate Change Knowledge Portal



[1] CMIP5 is "the fifth iteration of a globally coordinated experiment collection which reflects different possible futures of distinct emissions, landuse change, and associated atmospheric radiative forcing."(Metadata of the Climate change knowledge portal)

PROJECTIONS IN THE DAM AREA

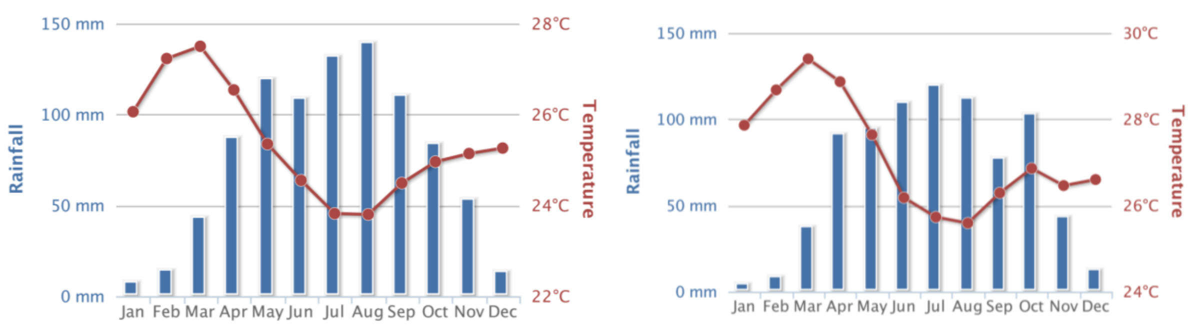
On the portal, the project location for which the information is required can be easily chosen. The location of the dam site was selected (latitude 4.26°, Longitude 32.66°) for the different queries.

Some key results are presented hereafter:

- Mean monthly temperature and rainfall from 1960 to 2012 (Figure 3-4).
- Mean Monthly Temperature – projection from 2080 to 2099 (Figure 3-5). An increase of 0 to 2°C is projected by the different models for the period 2080-2099 compared to the reference period 1986-2005.
- Maximum temperature – projection from 2080 to 2099 (Figure 3-6). An increase of 0 to 2°C is projected by the different models for the period 2080-2099 compared to the reference period 1986-2005.
- Minimum temperature – projection from 2080 to 2099 (Figure 3-7). An increase of 0 to 2°C is projected by the different models for the period 2080-2099 compared to the reference period 1986-2005.
- Rainfall - projection from 2080 to 2099 (Figure 3-8). There is no specific trend (increase or reduction of the mean rainfall) that can be drawn as the projected rainfall varies from - 50% to + 50% for the period 2080-2099 compared to the reference period 1986-2005.

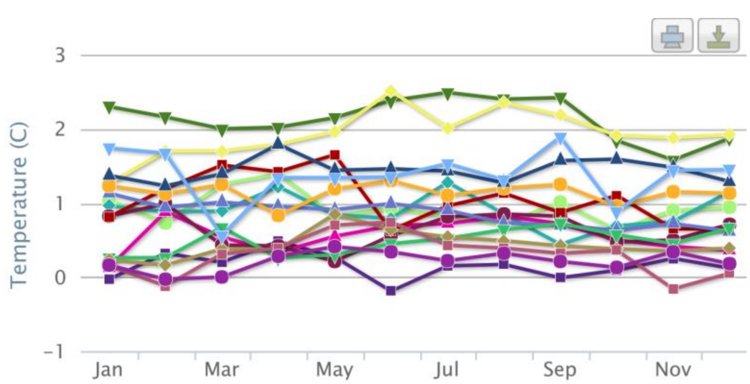
The different colors represent the 16 models that were used and which are presented in Figure 3-3.

Figure 3-4: Mean monthly temperature and rainfall (1960 to 1990 on the left and 1990 to 2012 on the right)



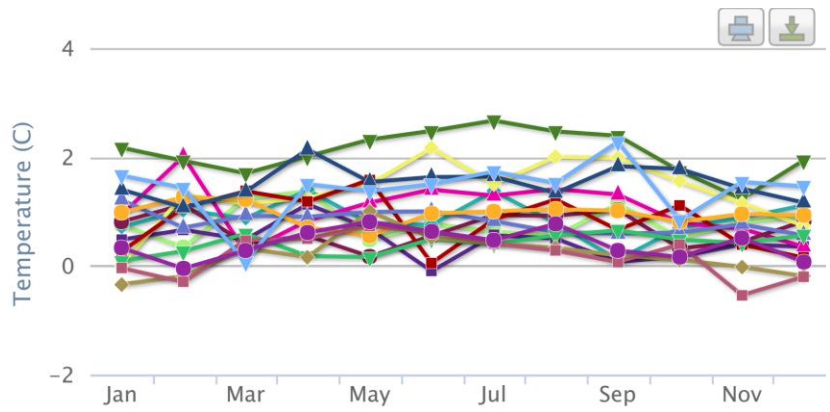
Dataset produced by the Climatic Research Unit of University of East Anglia

Figure 3-5: Projected change in mean monthly temperature (Projection 2080-2099)



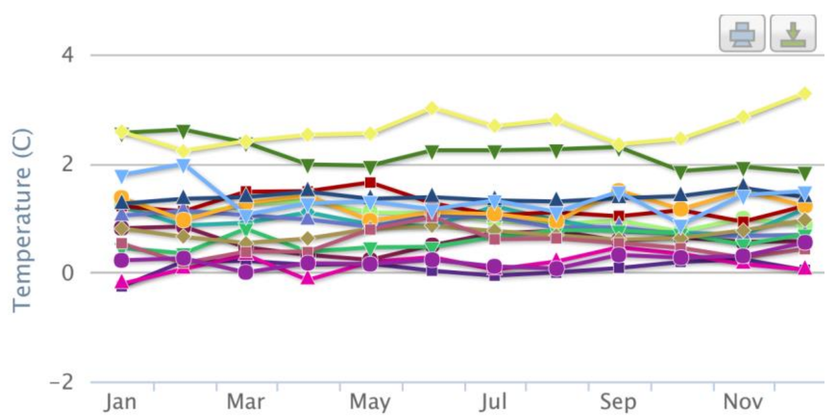
Source: computed on the WB Climate Change Knowledge Portal

Figure 3-6: Projected change in maximum monthly temperature (Projection 2080-2099)



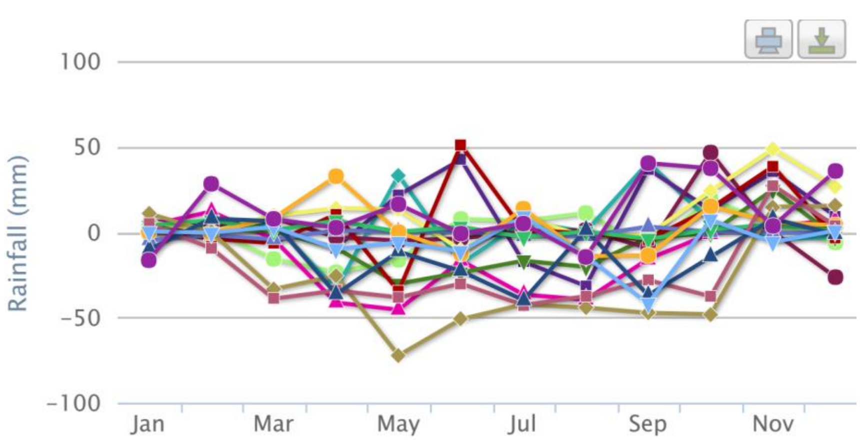
Source: computed on the WB Climate Change Knowledge Portal

Figure 3-7: Projected change in minimum monthly temperature (Projection 2080-2099)



Source: computed on the WB Climate Change Knowledge Portal

Figure 3-8: Projected change in mean rainfall (Projection 2080-2099)



Source: computed on the WB Climate Change Knowledge Portal

3.3.2 Possible impacts of climate change on water resources and water uses

There is a general trend for **temperature** projections. The mean, maximum and minimum temperatures could increase from 0 to 2°C for the period 2080-2099 compared to the reference period 1986-2005.

Temperature increase could lead to the following:

- Increase of evapotranspiration will impact especially rain fed agriculture and the production/yields could be reduced compared to the current situation.
- Increase of evaporation will impact especially the reservoir and the aquaculture ponds.

There is a very high level of uncertainty regarding **rainfall** as the results from the different models vary greatly. However, as the general trend for rainfall projections is not conclusive, according to the precautionary principle, the risk of a reduction of rainfall should be considered.

Reduction of rainfall could lead to the following:

- Reduction of annual and monthly flow will lead to an increased occurrence of water shortage in Torit for potable water.
- Direct impacts on rain fed agriculture and decrease of the production

Effects of climate change on **extreme events** are still uncertain but are likely to lead to an increased occurrence floods and droughts.

3.3.3 Possible benefits from the project

The multipurpose dam will probably have benefits to cope with climate change for the following reasons:

- The reservoir will store water that can be used in case of extreme drought events and ensure water access for vital needs such as potable water supply in Torit but also water access for the wildlife.
- The reservoir will provide water for irrigation. There is currently no irrigation around Torit where agriculture is highly dependent on rainfall and thus vulnerable to climate change.
- The production of hydropower could limit deforestation and reduce soil erosion. This will help mitigating heavy rainfalls.

It should be noted that the infrastructure may also be impacted by climate change:

- Major droughts could result in the drop of water level in the reservoir. This would affect water quality by increasing the concentration of pollutants and sediments.
- Extreme rainfall events may also result from climate change

In order to mitigate these risks, the following measures are recommended:

- The dam spillway must be adequately designed in case of extreme flood event.
- A measuring network (precipitation, flows, etc.) and an early warning system (for droughts and/or floods), should be implemented.
- The effective dam management can help limit adverse climate change impacts including ensuring minimum environmental flows.

4. PROJECT DESIGN

4.1 INTRODUCTION

As explained in the introduction, the multipurpose dam will benefit the following sectors:

- Hydropower
- Fisheries
- Irrigation
- Aquaculture
- Livestock watering
- Watershed management

The development of these sectors is presented in this section of the report.

4.2 DESIGN OF THE MULTIPURPOSE RESERVOIR

4.2.1 Description of the reservoir

4.2.1.1 Purpose of the reservoir

The primary purpose of the reservoir is to ensure a regulated flow that can guarantee a reliable year-round source of water for supply to Torit and for other development activities further downstream, including irrigation, aquaculture and livestock watering. At the same time the required environmental flows will be guaranteed and the configuration of the reservoir and its storage capacity allow for the production of hydropower and the development of fisheries activities and recreation (in support of tourism).

4.2.1.2 Reservoir characteristics

The location of the reservoir (potential of the area) was determined during a field mission in May 2015 in Homodong Payam with the assistance of satellite imagery. This payam is located in Torit County (refer to the location map of the project, Figure 1-5). It had been planned to make a return visit to the area in order i) to further investigate the dam site and possible alternative sites further upstream and ii) to meet with stakeholders. However, this return visit was not possible due to the deteriorated security situation.

The reservoir bathymetry was drawn using a 5m resolution Digital Elevation Model (DEM). This high definition DEM allowed the accurate construction of the contours in the area around the dam wall and down to Torit as shown on Figure 4-2. Additional explanations are presented in Annex 3.

The lowest point of the base of the proposed dam wall is at 647 masl. To maximise the capacity and hydropower a Full Supply Level (FSL) of 687.4 masl was selected. Different options for the spillway configuration were investigated with varying Non-Overspill Crest (NOC) levels. The selected site has a saddle on the right abutment just upstream of the centerline of the embankment, and has a low point of 685 masl. For the selected FSL saddle embankment of some sort would be required to provide the required freeboard in the saddle.

Figure 4-1: Storage Capacity Curve

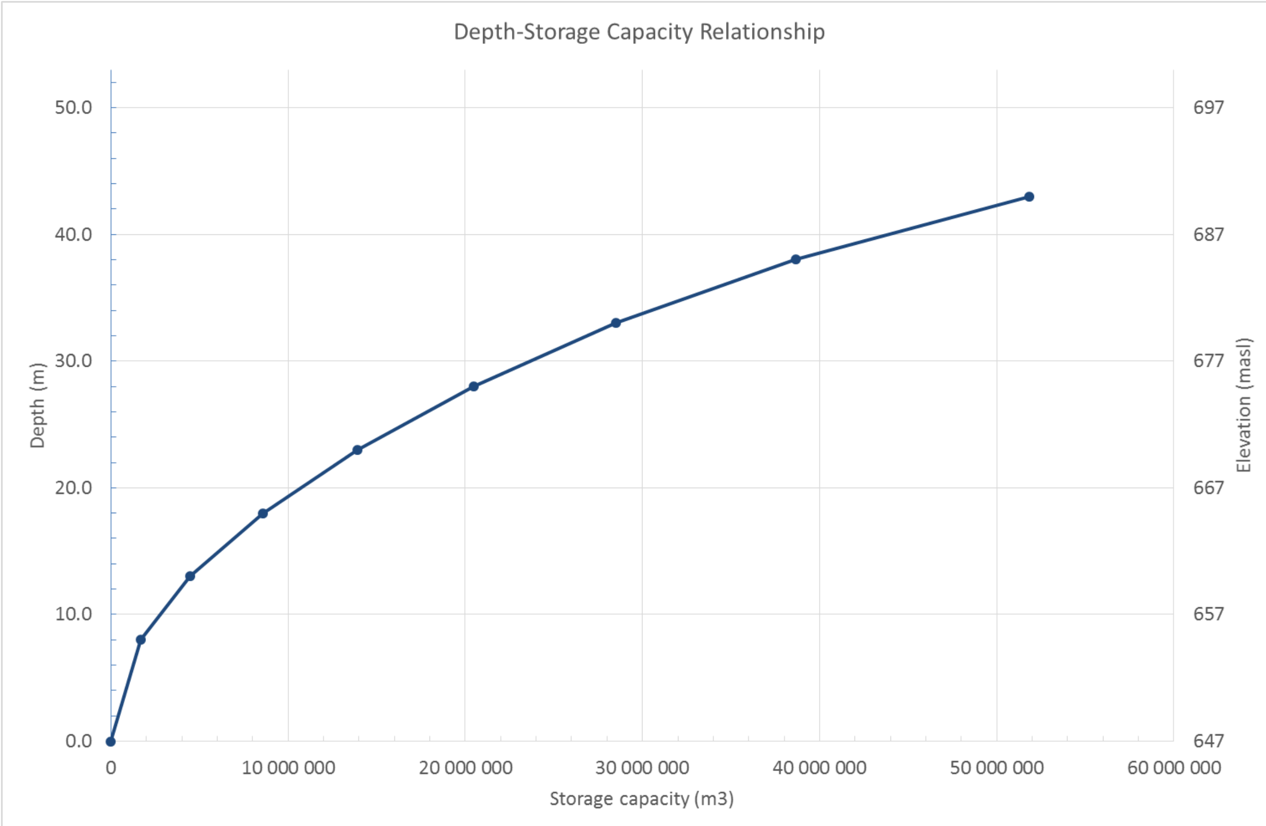
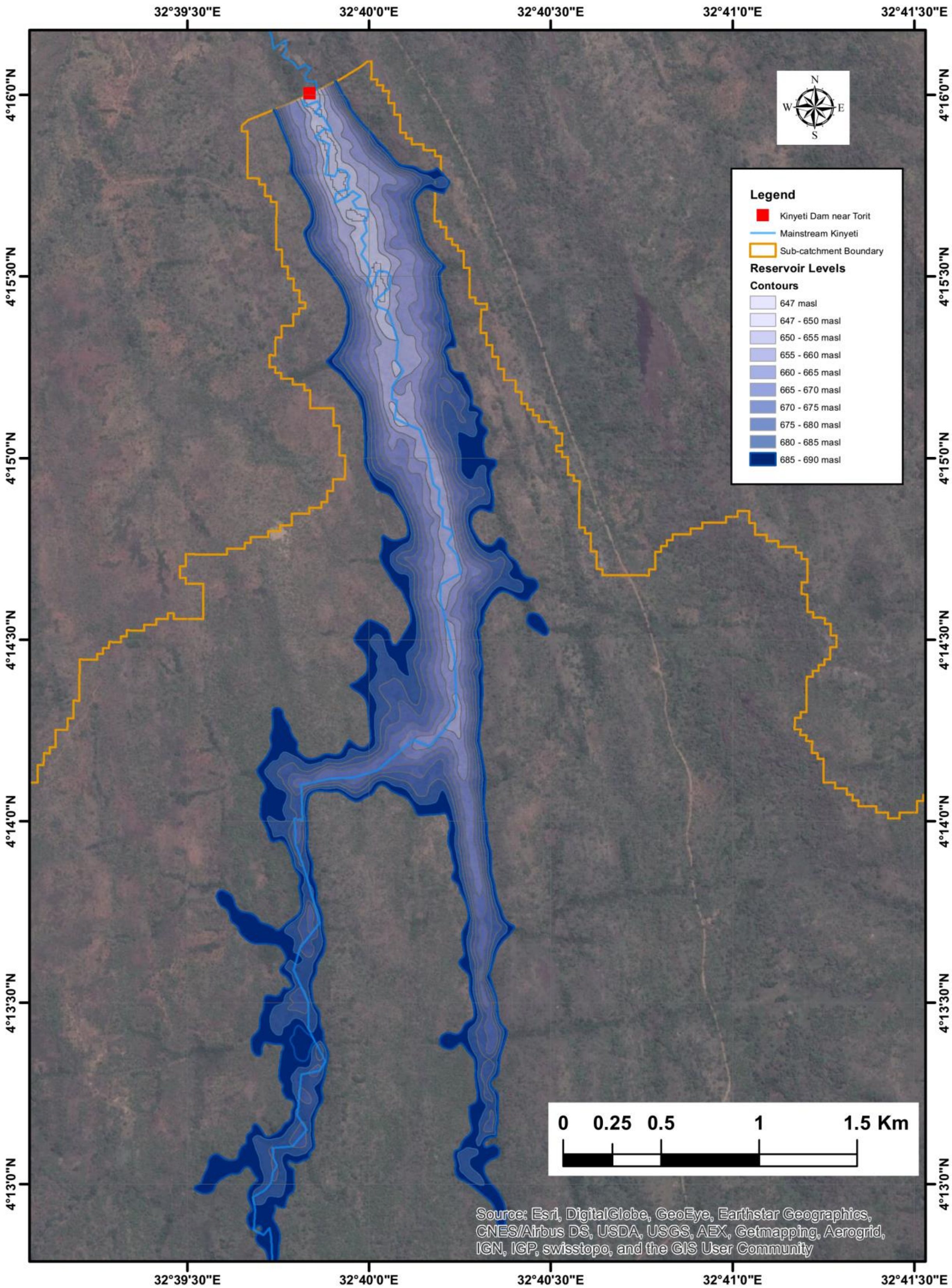


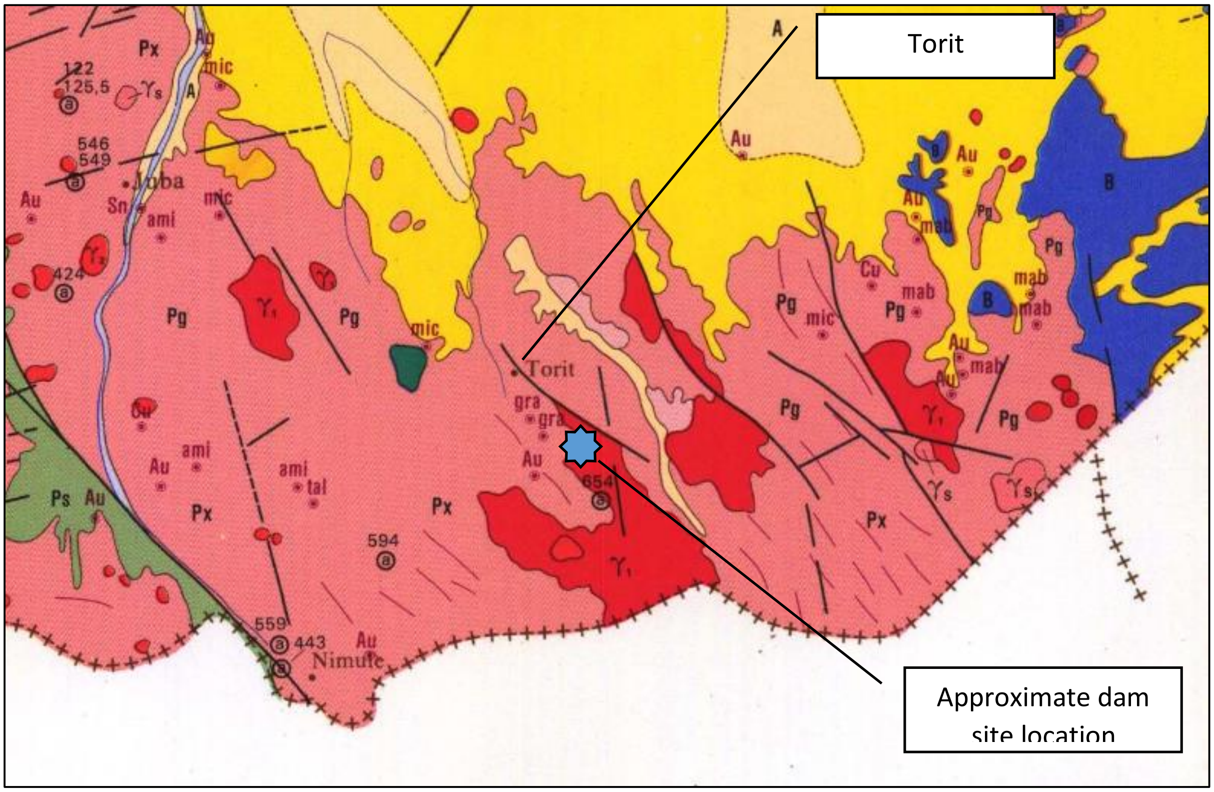
Figure 4-2: Reservoir area of the Kinyeti multipurpose dam



4.2.1.3 Regional geology

The Geological map of The Sudan (Geological & Mineral Resources Department, 1981) indicates that the site is located close to the boundary between *Undifferentiated Basement Complex* (Px on the map) and the intrusive formations classified as *Batholic granites, grey granites and pegmatites* (γ_1 on the map). It can also be seen on the above map that there is a fault zone running parallel/in the Kinyeti River valley.

Figure 4-3: Regional geology around Torit and the dam site



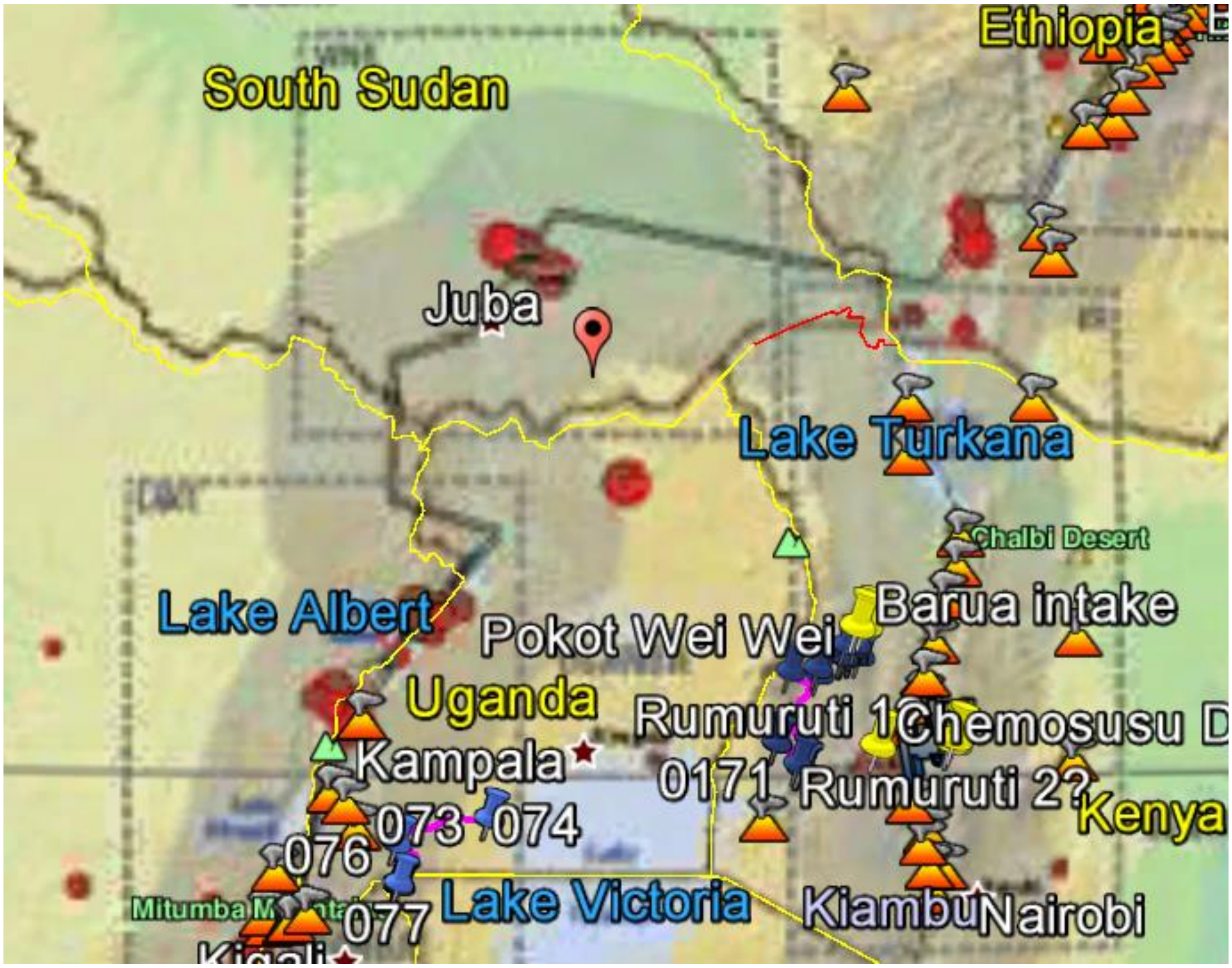
Source: Geological map of The Sudan, Geological & Mineral Resources Department, 1981

4.2.1.4 Seismic risk

It is noted that the dam is located in the Rift Valley and that the occurrence of significant seismic events are likely to occur during the dam's lifetime. These risk factors will need to be incorporated into the dam's design. Some fault lines, on a regional geological scale, have been noted in close proximity to the site. Since there is very little seismic information on the project area and little in the way of seismic records for South Sudan, use was made of information obtained from the data published on *Preliminary Determination of Epicenters*, the official website of USA Earthquake Administration. According to the data published by this organisation, there were several earthquakes affecting the general area between 1973-2009. Only on two occasions were earthquake magnitudes larger than 4.0 within 100km of the dam site. The largest earthquake (magnitude 7.2) occurred on May 20, 1990 with an earthquake centre around 150km from the dam site.

Note however that the two largest instrumentally recorded events in Africa occurred about 300 km north of Lake Albert, in an area of Mesozoic (250–65 Ma) rifting. These M7.1 earthquakes struck four days apart in May 1990, both at ~15 km depth. Importantly, these events would be close to the Kinyeti dam site.

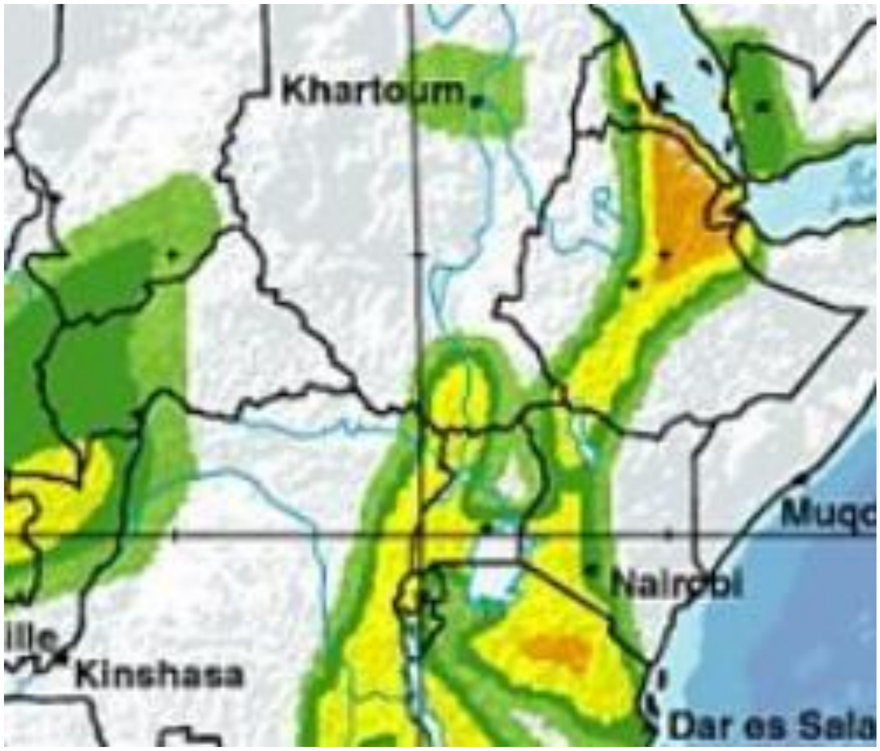
Figure 4-4: Excerpt from map of East African Rift System (EARS) showing site location and proximity to western branch of EARS which is shaded (USGS, 2014)[2]



The seismic hazards map for Africa below shows Peak Ground Acceleration (PGA) values for the area of interest between 0.8 and 1.6 m/s^2. This equates to a moderate seismic hazard.

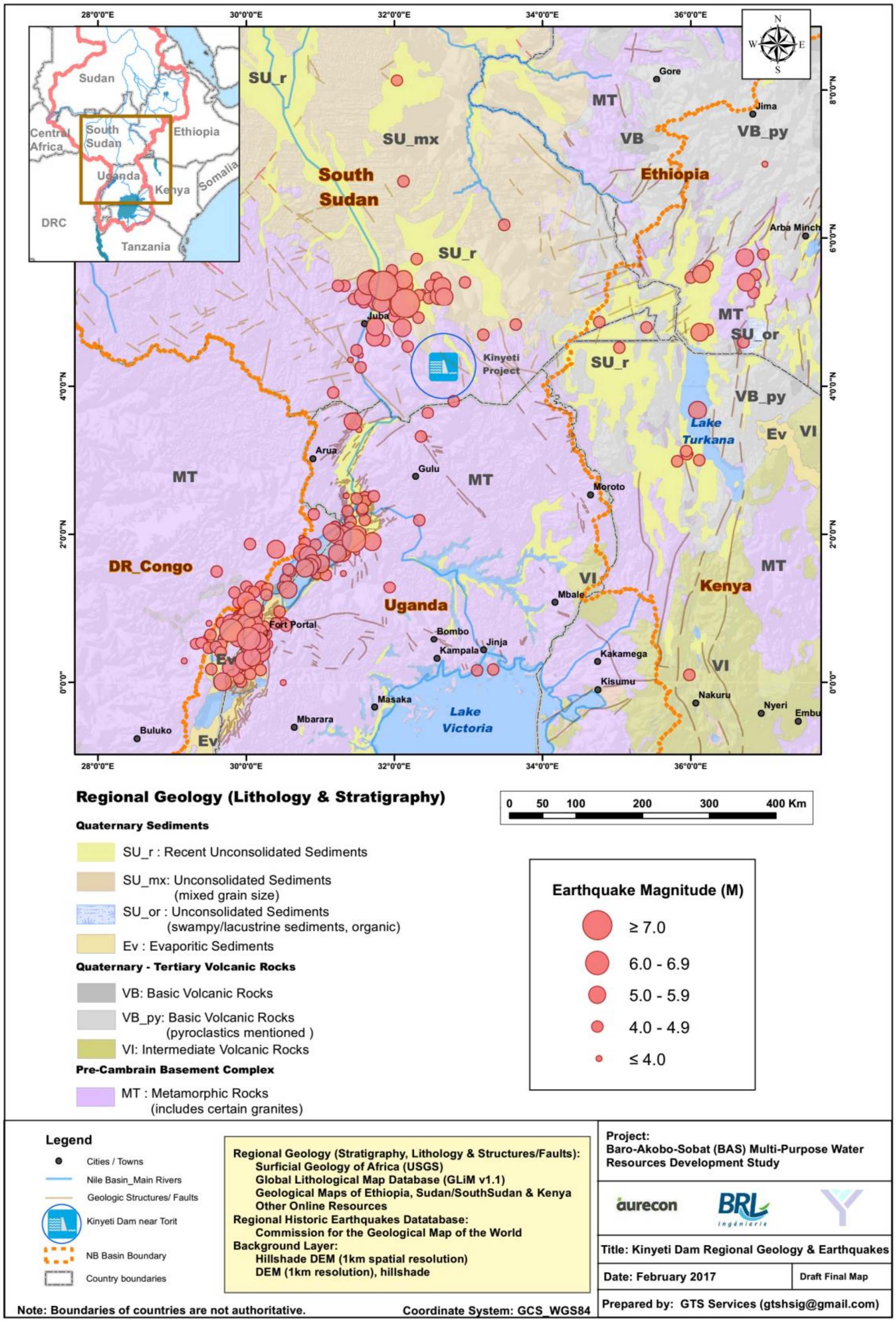
[2] U.S. Geological Survey. 2014. Seismicity of the Earth 1900 – 2013. East African.

Figure 4-5: Excerpt of the Seismic Hazard map for Africa



Geology and earthquakes in the region of the dam are presented in the map hereafter.

Figure 4-6: regional earthquakes and geology



4.2.1.5 Maximum and minimum volumes of the reservoir

The maximum volume of the reservoir is estimated through an elevation-surface area-volume relationship. This relationship is presented in section 4.3.1.1 “Set up of the model”.

The FSL of the dam is set at 687.4 masl which provides a storage volume of approximately **45 Mm^3**.

The minimum volume of the reservoir is an input in the model; it is the limit below which the water level should not fall during normal operation (minimum operating level). This limit was defined by looking at the following impacts:

- The mean area of the reservoir: the area of the reservoir is the determining factor for fisheries productivity.
- The potential hydropower production: The operating volume of water available for the generation of hydropower corresponds to the difference between the full supply volume and the minimum operating volume. The lower the minimum operating volume, the larger this difference and hence the larger the amount of hydropower that can be generated.

Three cases were considered:

a) Vmin = 0.7 x Vmax (maximization of fisheries activities)

b) Vmin = 0.6 x Vmax

c) Vmin = 0.5 x Vmax (maximization of power generation)

With a minimum volume of 22.5 Mm^3 (50% of Vmax), the mean area of the reservoir is 85% of the maximum area of the reservoir (at full supply level) and the minimum area of the reservoir represents 54% of the maximum area of the reservoir (at full supply level). As shown in section 3.4, the fishery productivity of the reservoir is not significantly impacted with this minimum volume and the production of hydropower is maximized. The minimum operating volume of the reservoir is set at **22.5 Mm^3**.

4.2.1.6 Reservoir sedimentation

CATCHMENT SOIL CHARACTERISTICS

Information on the soil and land cover characteristics of the catchment upstream of the proposed Kinyeti Dam was obtained from two main sources:

- Assessment of Soil Erosion, Run-off and Vegetation Cover Status in Relation to Land Management Practices in the Kinyeti River Catchment Area of Eastern Equatoria (Shah et al, 2015), which used existing publications, supplemented with field investigations, to asses soil erosion, run-off and vegetation cover in the study area.
- Water Resources Assessment Study, Torit, Eastern Equatoria State (SMEC, 2012), which involved desk studies and field surveys to provide surface water and groundwater resource assessments for the catchment upstream of Torit.

The soil texture within the catchment ranges from clay loam to sandy loam, with the dominant soil type being sandy loam. In general, the upper part of the catchment is dominated by clay loam whereas the lower part of the catchment is dominated by sandy loam. Around Torit town, where crop production is fairly intensive, the topsoils are medium textured and grey. From Kiliu to Katire, soils are clayey and dark.

In the absence of significant infrastructure or mining and industrial activity, agriculture is the main source of sheet erosion in the study area. The soils are invariably tilled down-up, while intensive intercropping is practiced with maize and/or sorghum as main crops. The crop production areas within the Imatong Mountain range can be divided into two broad categories. The first category is the agricultural fields directly south-east of Katire (up the eastern ridge of the Imatong) and west/south-west (up the Acholi range). These fields are intensively used without regular fallow periods, and the soils are reddish and clayey. The second category is at higher altitudes, in Gilo, where the land is used much less intensively and the soils are black and clayey.

Soil erosion in the study catchment is expected to increase because of an expansion of the cropping areas due to the anticipated doubling of the population by 2032 (SMEC, 2012), including the smallholder farming population, as well as increasing activities of commercial farmers. Soil losses will further increase when farmers intensify and expand crop production activities on steep slopes.

Estimation of sediment yield

No historical data on suspended sediment in the Kinyeti River is available. Consequently, an indirect assessment of potential sediment yield was performed by implementing an empirical model, the Revised Universal Soil Loss Equation (RUSLE) (Wischmeier and Smith, 1978; Renard *et al*, 1991). The RUSLE approach effectively integrates information on each of the generic causes of surface soil erosion through a set of factors that have been empirically derived through a number of runoff plot experiments in different parts of the world. The RUSLE equation is as follows:

$$A = R \times K \times LS \times C \times P$$

with:

A: long-term mean annual soil loss per unit area (t/ha/a)

R: an index of mean annual rainfall erosivity (MJ.mm/ha.h.a)

K: soil erodibility factor (t.h/MJ.mm)

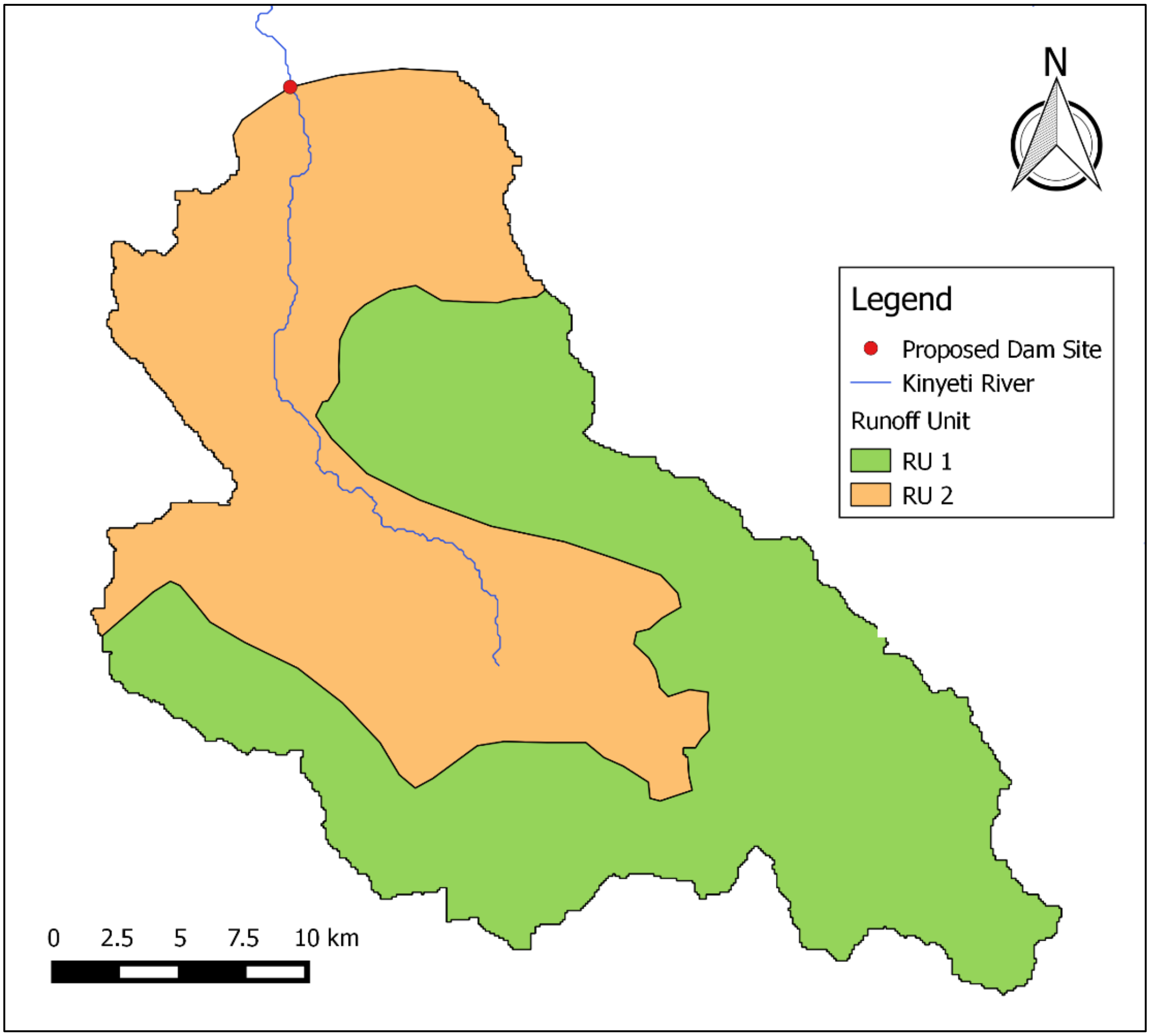
LS: slope length and gradient factors (dimensionless)

C: cover factor (dimensionless)

P: land management support practice factor (dimensionless).

For application of the RUSLE method, the Kinyeti catchment upstream of the proposed dam site was divided into two runoff units (RUs), as shown in Figure 4-7. RU1 represents the upper mountainous region which is covered mainly by forest vegetation and is characterized by altitudes ranging from approximately 1 500 to 2 800 masl. The second unit (RU2), represents the lower region between Katire and Torit towns which is characterized by flatter terrain and areas of herbaceous and barren land cover. The sediment yields for the two units were calculated separately and then weighted to obtain an average sediment yield estimate.

Figure 4-7: Division of runoff units for the RUSLE method



Rainfall erosivity (R)

The R-factor was estimated based on Mean Annual Precipitation (MAP) using an equation developed for the White Nile basin (Tamene & Bao Le, 2014):

$$R = 0.36 \times MAP + 47.6$$

Soil erodibility (K)

The K-factor was estimated for each RU based on the corresponding soil type, according to the soil erodibility classification by Schulze (Smithers et al, 1994).

Slope length (L)

The L-factor for the RUs was calculated according to the generally accepted L-factor equation by Renard et al (1991). This equation requires the slope length (λ), which is defined as the distance from the point where sheet flow begins to the point where the slope gradient decreases sufficiently so that deposition starts. The slope length can be estimated using the resolution of the DEM used to determine the catchment slope. The orthogonal resolution of the DEM used in this case was 90 m, which determines the incremental surface slopes that make up any particular catchment area. Given this resolution, the surface water flow length for each DEM pixel in the study area was limited to 60 m in the interest of conservativeness, while recognising that slope lengths might be notably shorter in many cases. The L-factor equation is shown below, where m is a variable slope length exponent, related to the ratio of rill to interrill:

$$L = \left(\frac{\lambda}{22.1}\right)^m$$

Surface slope (S)

All incremental catchment slopes were determined at a 90 m x 90 m resolution. The S-factors for the 90 m x 90 m pixels were calculated from the catchment slope according to the generally accepted S-factor equations (Renard *et al*, 1991):

$$S = 16.8 \times \sin s - 0.5 \qquad \text{for slope} < 9\%$$

$$S = 10.8 \times \sin s + 0.03 \qquad \text{otherwise}$$

Land-cover (C)

Representative C-factor values for the predominant vegetation class representative of each RU was determined according to guiding tables in Wischmeier and Smith (1978).

Land management and soil conservation (P)

The P-factor was estimated based on information in literature regarding farming practises in the study area.

The RUSLE input values for the study catchment runoff units are listed in Table 4-1.

Table 4-1: RUSLE parameters for the Kinyeti River catchment

Parameter	RU 1	RU 2
Area (km^2)	400	307
MAP (mm)	965	965
R-Factor	395	395
K-Factor	0.28	0.20
Length (m)	60	60
L-Factor	1.9	1.6
Slope (%)	29.5	8.5
Slope (degrees)	16.4	4.9
S-Factor	4.25	0.94
C-Factor	0.002	0.039
P-Factor	1	0.8

The sediment yield from each runoff unit was calculated as 181 t/km^2/a (RU1) and 381 t/km^2/a (RU2) respectively, which translates into a weighted annual sediment yield of 268 t/km^2 for the catchment upstream of the proposed dam site.

MEAN ANNUAL SEDIMENT LOAD

A large portion of the soil transported by sheet erosion never reaches any water stream. Instead, most of the soil is deposited in grassy, bushy or forested areas. For the wider White Nile basin, it was established that only 13% of the gross soil loss translates into a net soil loss (Tamene & Bao Le, 2014). In case of the Imatong Mountains, the ratio may be significantly smaller, since the distances between the crop lands to streams is generally considerable and the intersects are densely vegetated.

Assuming that 13% of the potential sediment yield reaches the dam site, the estimated mean annual sediment load into the dam, based on a sediment yield of 268 t/km^2/a/ is calculated as 34.8 t/km^2/a. This compares favourably with the WRAS study (SMEC, 2012), where the sediment load from the Kinyeti River catchment at the dam site was estimated as 21.2 t/km^2/a.

RESERVOIR SEDIMENTATION

Assuming a conservative 100% trap efficiency and an estimated density of 1 350 kg/m^3 for sediment after 50 years, the decrease of dam volume after 50 years due to sedimentation from the upstream catchment equates to only 0.91 million m^3, which corresponds to about 2% of the total dam storage volume.

4.2.2 Dam design

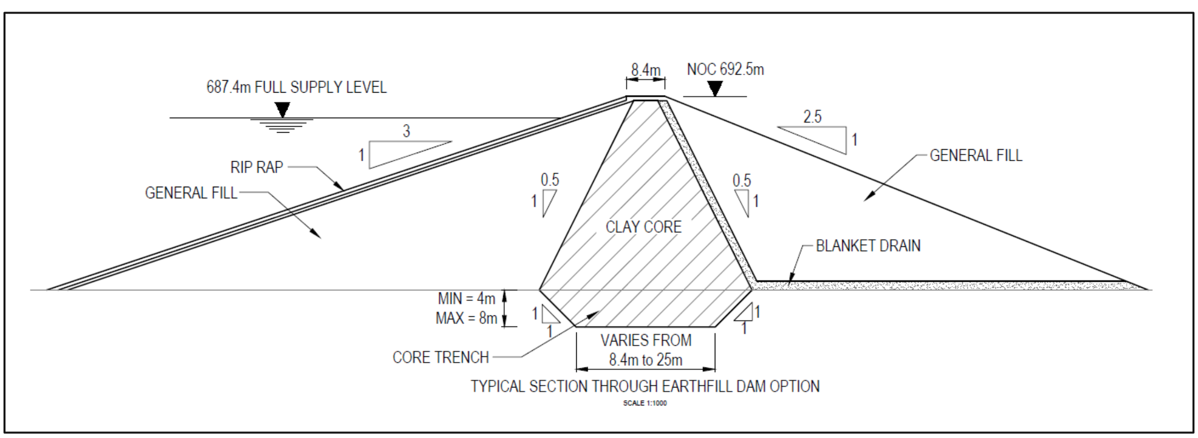
4.2.2.1 Dam type options

The dam site is located in a U-shape valley with an estimated base width of 115 m and a width of around 340 m at the NOC of 692.5 masl, for a 45 million m3 dam (FSL=687.4 masl). The abutment slopes of the valley cross section at this site are relatively steep which could make construction activities more onerous (particularly compaction); with average gradients of 1V:2.1H on the right slope and 1V:2.2H on the left slope.

A clay core earthfill embankment dam, as its name implies, consists of a central compacted clay core which renders the dam impervious. This core is supported on its upstream and downstream sides by compacted general fill which usually consists of unselected earthfill excavated from the dam's basin. In addition to these two material types, provision is also made for special zones comprising drainage and filter zones within the dam, and rip-rap for wave erosion protection along the upstream face.

Provided that local borrow areas can supply sufficient quantities of suitably impervious material for the clay core, an earthfill embankment is typically found to be the most cost effective embankment type. That being said, however, special arrangements have to be made for its spillway, which, depending on the size of floods that need to be accommodated, could impact significantly on the construction costs.

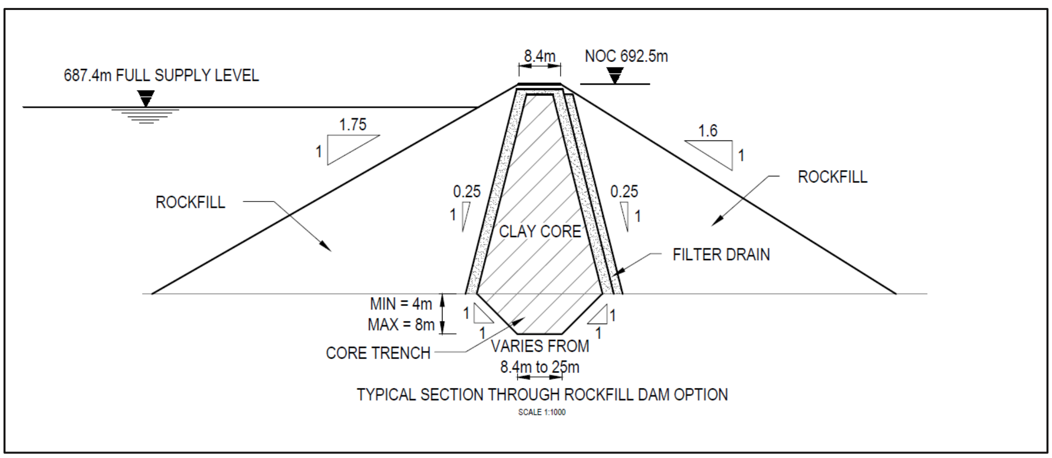
Figure 4-8: Typical section through the earth embankment dam



A clay core rockfill dam is very similar to its earthfill counterpart in that it has a central clay core supported by an upstream and downstream shell. In this instance, however, these shells consist of selected rockfill. Special filter zones are required between the clay core and the rockfill, while rockfill dams also have different foundation requirements compared to earthfill dams. Since rockfill has a much higher shear strength than does normal earthfill, the slopes of the embankment can be constructed with steeper gradients (approximately 1V:1.6H, as opposed to 1V:2H, or even 1V:3H for earthfill). This has the benefit that the total volume of fill that needs to be excavated, placed and compacted is much smaller, which can lead to potential cost savings and reduced construction time. The availability of suitable rockfill material is important factor to consider during further design and a quarry area would have to be established during construction, which should be identified during further geotechnical investigations. A possible site is the spillway excavation, the design and layout of which may be modified to provide sufficient cut-to-fill for a rockfill embankment.

As with earthfill embankment dams, special arrangements for a spillway for a rockfill dam must also be considered, which can impact significantly on the overall cost. A rockfill dam does have the further minor advantage over the earthfill embankment in that it can be designed (through the use of reinforced rockfill) to be overtopped by floodwater during construction. Consequently, the river diversion strategy can allow for smaller coffer dams and flow by-pass arrangements, thus decreasing their cost, but still within acceptable levels of risk.

Figure 4-9: Typical section through rockfill embankment.



A concrete faced rockfill dam (CFRD) would have a similar embankment to that of a rockfill embankment (as shown above) other than the absence of an impervious clay core and associated filters. The CFRD dam is rendered impervious by the provision of a relatively thin impervious concrete lining on the upstream face of the dam. The concrete facing requires a strong rock foundation for its upstream footing at the base of the embankment, and is thus dependent on the presence of such foundations. The placement of the upstream concrete lining requires a specialist contractor, hence this type of dam is usually only considered if sufficient quantities of clay are not available for an earthfill or conventional rockfill dam to be considered. Another valid reason for selecting a concrete faced rockfill dam is that it can be constructed in most climatic conditions, whereas the placement of clay generally requires relatively dry weather.

As for earthfill and clay core rockfill type dams described above, a CFRD is an embankment type dam and thus must be provided with a separate spillway to prevent flood water overtopping the embankment.

Various dam configurations for a dam with a FSL of 687.4 masl were considered. The options aimed to investigate different dam and spillway types. Two final options were eventually compared, namely a clay core earth embankment and a clay core rockfill embankment. Due to security concerns, the site specific geotechnical information was limited to a desktop level study and investigation of aerial photographs. These provided some indication as to the possible availability of clay material for an impermeable core, as well as visible rock outcrops, particularly on the right abutment ridge (eastern ridge), indicating possible foundations for a spillway and potential source of rock fill and/or filters from the spillway excavation. Due to the uncertainty of the depth and quality of good rock foundations along the centreline of the proposed dam, and relatively wide valley, concrete dam options (such as arch and mass concrete gravity) and CFRD were not considered further in this study. However, if good foundations are found during initial on site geotechnical investigations these options could be revisited during preliminary design phase.

The presence of a saddle on the right abutment provides the option for the siting of a main or auxiliary spillway. The adjacent valley to the east into which the saddle leads does not appear to have any major river channel in it and only returns to the Kinyeti River channel some 2 km downstream. It would thus appear as if the valley is not capable of accommodating the large design floods without sustaining significant erosion damage in the process. For it to be considered, some form erosion protection should be provided for the channel until it re-joins the Kinyeti River channel quite a distance downstream. For this reason, in this study, the saddle was not considered a practical and cost-effective option for a spillway.

The earthfill and rockfill dam types were compared on the basis of the same spillway design for each. The cut from the spillway excavation would be used in the fill of the embankment and would largely determine the construction of either an earthfill-, rockfill- or combination-fill embankment. See Figure 4-10 and Figure 4-11 for the option layouts.

The embankment slopes used in the design (refer to Table 4-17 and Figure 4-8 and Figure 4-9) are generally accepted safe slopes for embankment and rockfill dams of this size. The strength, friction angle, permeability, material zoning, dimensions and seismicity all play a role in the ultimate stability for the different load cases which should be investigated after the geotechnical investigations. The stability analysis should thus be based on actual test results of the relevant materials and is therefore not considered further at this stage in the optimisation of the embankment slopes volumes, as none of these parameters have yet been determined.

Figure 4-10: Plan layout of the Kinyeti Dam options

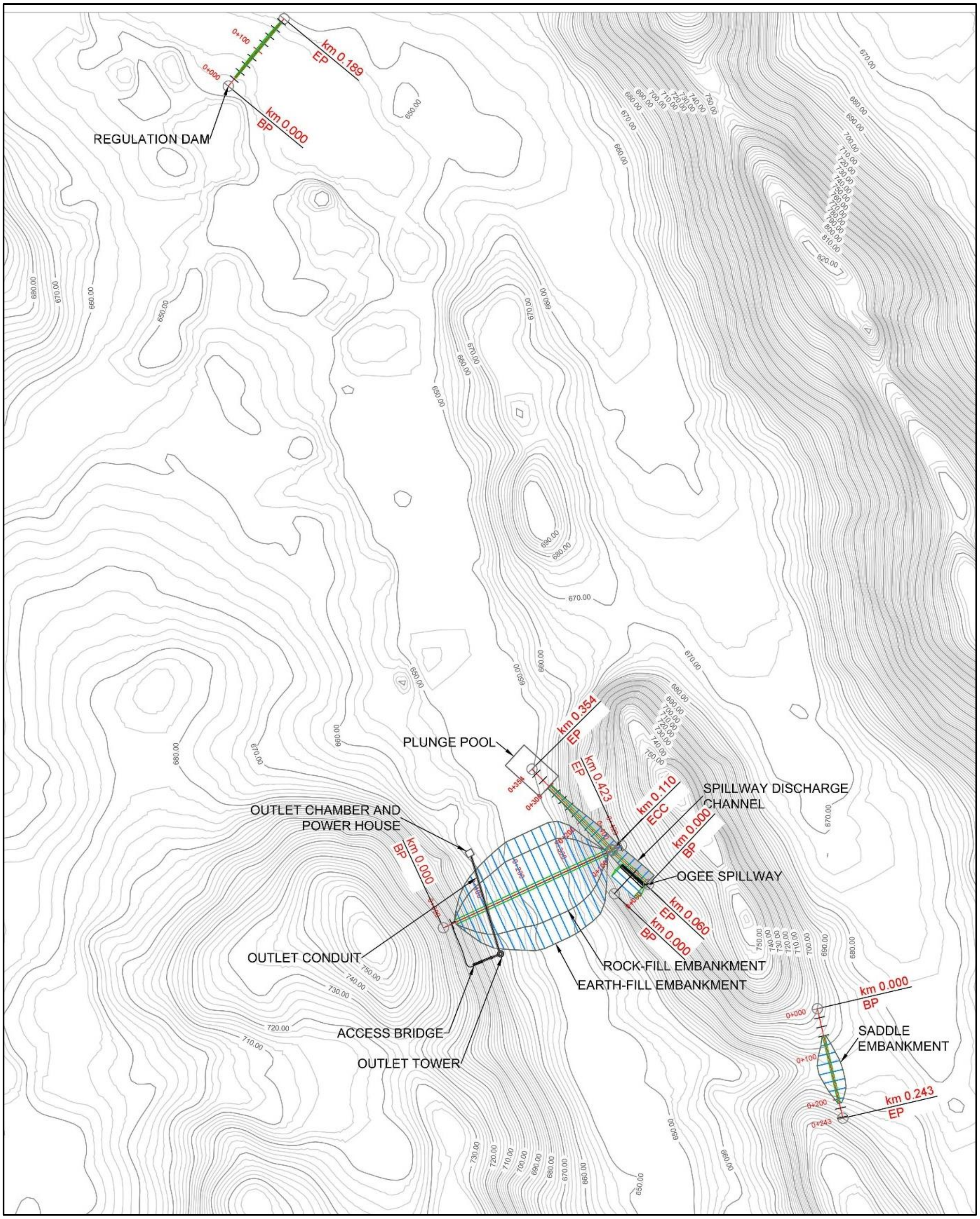
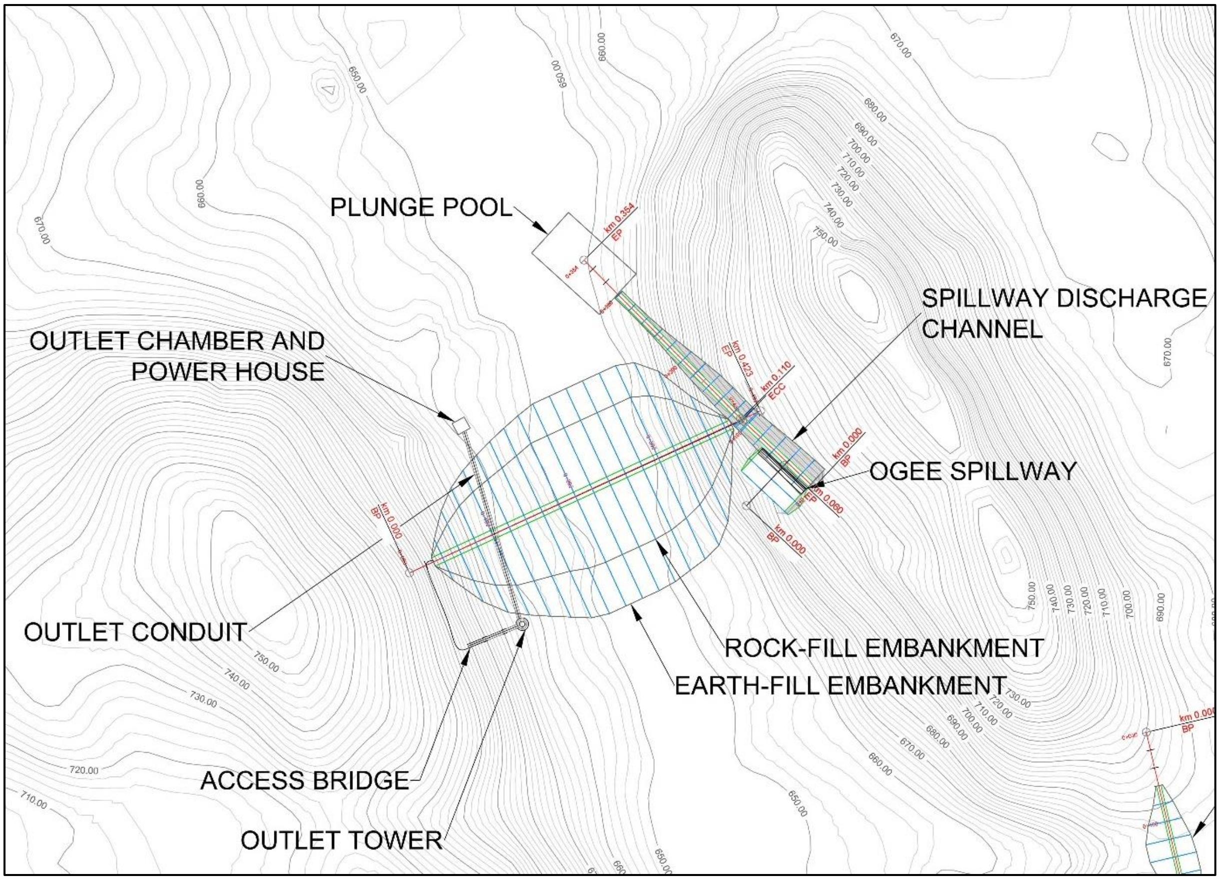


Figure 4-11: Proposed dam and associated infrastructure layout.



4.2.2.2 Geotechnical investigations

The geotechnical investigations should be approached in a two stage process. Firstly an initial site visit and "walk-over" assessment by a geotechnical engineer/engineering geologist so as to make a general on-site appraisal, along with shallow trial investigations (e.g. DCP and test pits) and limited laboratory testing programmes. This process will inform a more detailed second investigation which will assess the local geology in more detail and depth, with rotary core drilling likely to be necessary.

The initial investigation should include visual interpretation of the foundations on the abutments, within the river section, at the proposed locations of the spillway and discharge channel, as well as at the outlet tower location and along the outlet pipe route alignment. Any major geological features would be identified along with their related challenges. Furthermore, identification and visual interpretation of the available materials will be undertaken, with a focus on earthfill materials (particularly impervious clay core material), rock for aggregate and/or rockfill and sands and gravels for filter zones. With this information (from the first-order geotechnical assessment), a recommended detailed geotechnical investigation and schedule can then be scoped and specified.

The second phase (which is likely to involve rotary core drilling) is best undertaken in a step-wise approach. The first action would be a geophysical survey in order to identify the material distribution, and possible sub-surface anomalies, which will assist in determining borehole positions guided by onsite inputs from a geotechnical professional. This will obviously be informed by the results of the first phase. This detailed phase of the geotechnical investigation could include trial pitting, boreholes, sample analyses and geophysical investigations, culminating in an interpretation of the collated results, as briefly discussed below.

Trial pit investigations are done to assess the nature of the sub soils and to assess likely foundations for some of the smaller appurtenant structures. They are typically limited to depths of 3m (in the case of a wheel mounted excavator) and 5m (in the case of a track mounted machine). Sub surface samples are also taken to be assessed in terms of particle distribution, Atterberg limits, dispersivity, permeability and density. Trial pitting would thus be conducted on the proposed dam solum, at the spillway, outlet works as well as any identified potential fill material borrow areas.

The objective of the geophysical investigations is to provide information on the founding condition at the dam site in general. The results would identify the material distribution, and possible sub-surface anomalies, which will assist in determining borehole positions, i.e. it must precede the drilling investigations. Both seismic refraction and resistivity surveys shall be considered.

For borehole investigations (rotary core drilling) the objective is to confirm local geology, including conditions associated with the anomalies as mentioned, and to determine the founding conditions at depth. Typically the targeted areas would include: the dam centreline, spillway and along the discharge channel centreline, quarry (for rock fill/aggregate), and outlet tower location. The extent and suitability of clay and rockfill material would also be determined through core drilling investigations at the proposed quarry sites.

Approximate, 1st order cost estimates of the above studies are outlined in the table below.

Table 4-2: 1st order geotechnical investigation cost estimates

Task	**Cost (USD)**
Mobilization and demobilization	25 000
Trial pitting/augering	20 000
Core drilling	100 000
Geophysical	10 000
Testing of samples and materials	20 000
Geotechnical engineering services, reporting, appraisal	45 000
Total	**220 000**

4.2.2.3 Spillway and floods

DESIGN FLOOD ASSESSMENT

Current internationally-accepted norms as promulgated by the International Committee on Large Dams (ICOLD) and its national affiliates dictate that the Recommended Design Flood (RDF) and Safety Evaluation Floods (SEF) for the purpose of designing dams should take the height of the dam and the hazard rating (potential impact on life and property in the event of a failure) into account. In the case of Kinyeti Dam, which will be higher than 30 m and is located upstream of Torit, the dam can be classified as a high hazard, large dam. In this case, it is recommended that a RDF equivalent to the 1 in 200 year flood and a SEF equal to the 1 in 10,000 year flood (as prescribed by Ethiopian guidelines) be used in the design of the dam spillway.

Catchment Characteristics

Relevant parameters describing the physiographic catchment characteristics upstream of Kinyeti Dam that are required for design flood calculations were calculated using the SRTM 90m DEM. These characteristics are listed in Table 4-3.

Table 4-3: Kinyeti River catchment characteristics

Characteristic	Value
Catchment Area (km^2)	707
“10/85” Catchment Slope (m/m)	0.0231
“Equal-Areas” Catchment Slope (m/m)	0.0151
Longest Watercourse (km)	74.9
Centroidal Longest Flow Path (km)	37.5
Average Catchment Slope (%)	20.1
Time of concentration (h)	9.3
Lag time (h)	12.1

Design rainfall analysis

As described in this report, observed monthly rainfall at Torit, Agoro and Juba, in conjunction with rainfall data from the Climatic Research Unit (CRU) at the University of East Anglia and from the Swedish Meteorological and Hydrological Institute (SMHI) database, were used to derive time series of monthly and daily catchment rainfall representative of the Kinyeti River catchment. In order to determine design rainfall for different recurrence intervals, a probabilistic analysis was performed on annual maximum daily rainfall values extracted from this rainfall sequence. Only the period from 1957 to 1990 was considered in the analysis (see Table 4-3.), as this corresponds to that part of the Kinyeti rainfall sequence which was disaggregated using observed data from Juba station - whereas years which fall outside of this period were disaggregated to daily rainfall rainfall using modelled SMHI data, which introduced some uncertainty.

Table 4-4: Annual maximum daily rainfall values for the Kinyeti catchment

Year	Max Daily Rainfall (mm)	Year	Max Daily Rainfall (mm)
1957	132	1975	78
1958	60	1976	94
1959	64	1977	78
1960	40	1978	43
1961	88	1979	79
1962	85	1980	72
1963	68	1981	110
1964	54	1982	69
1965	53	1983	95
1966	81	1984	63
1967	42	1985	77
1968	45	1986	76
1969	69	1987	59
1972	47	1988	83
1973	93	1989	74
1974	72	1990	43

Different exceedance probability distributions were fitted to the annual maximum values and plotted against Cunane-ranked plotting positions. Three different probability distributions were considered for the probabilistic analysis: Log-Pearson Type III (LPIII), General Extreme Value using method of moments (GEVMM) and General Extreme Value using probability weighted moments (GEVPWM). The LPIII distribution was selected as it gave the best fit to the observed data. Table 4-4 shows the daily design point rainfall upstream of Torit for various return periods.

Table 4-5: Design point rainfall at Torit using statistical methods

Return Period (y)	Daily design point rainfall (mm)
2	69
5	88
10	99
20	110
50	122
100	131
200	140
1 000	160
10 000	186

The above daily design point rainfall values were converted to 24-hour design point rainfall using a conversion factor of 1.11 (Adamson, 1981). The values compare very well to estimates of point rainfall at Gulu station (X 62.11 15.85 Y) in northern Uganda (Potts, AS. 1971), which is situated approximately 150 km SW of Torit, and an estimate of the 100 year 24h rainfall using the TRRL method (Fiddes et al., 1974) as shown in Table 4-6. Although the values are very similar, Potts provide slightly more conservative values, especially for higher return periods and for this reason the Potts rainfall values were selected as the final design rainfall values. Note that the 200 year final design rainfall value was estimated using RI ratios derived from the results of the probabilistic analysis.

Table 4-6: Recommended 24-hour design point rainfall

Return Period (y)	24-hour design point rainfall (mm)			
	Statistical Analysis	Potts (1971)	Fiddes et al. (1974)	Final
100	146	150	150	**150**
200	156	-	-	**164**
10 000	206	231	-	**231**

Probable Maximum Precipitation

As a check on the order of magnitude of the 10:10,000 year design rainfall, the 24-hour PMP for Torit catchment, based on curves relating Probable Maximum Precipitation (PMP) to catchment elevation for catchments in East Africa (Lumb, 1971) was estimated at between 270 mm and 330 mm. As expected, this is higher than the 1:10,000 year value of 231 mm. However, it is of the same order of magnitude and therefore substantiates the 1:10,000 year design rainfall value of 231 mm.

Due to the relatively short length (32 years) of the Amax rainfall record (Table 4-3), the Hershfield statistical method was not deemed appropriate for determining the PMP in this case

Design floods

To ameliorate uncertainty associated with flood determination, three alternative approaches were employed viz. empirical, deterministic and probabilistic techniques.

Creager's empirical formula

In order to evaluate extreme flood peak flows at the Torit dam site, the Creager empirical formula was applied to estimate the 1:10,000 year flood at the dam site:

$$Q_p = 46 \times C \times A^n$$

$$n = 0.894 \times A^{-0.048-1}$$

with:

- C: Creager's coefficient
- A: catchment area (mi2)
- Qp: specific flow (ft3/s/mi2).

As part of the Tams Hydropower Feasibility Project (ELC & Water Works Design and Supervision Enterprise, 2014), design floods from existing dam projects in Ethiopia were reviewed in order to calibrate Creager's equation. The calibrated C-values were transferred to the Kinyeti River catchment. The results of Creager's method applied to the Kinyeti catchment are shown in Table 4-7.

Table 4-7: Results of Creager's empirical flood analysis or the 1:10,000 year flood

Parameter	Value
C	35
n	-0.3170
Q_p ($ft^3/s/mi^2$)	272
Q (ft^3/s)	74239
Q (m^3/s)	2102

Unit hydrograph

Due to the absence of concurrent storm rainfall and sub-daily flow information in the Kinyeti River, it was not possible to derive site-specific unit hydrographs for the Kinyeti catchment. Consequently, the synthetic Snyder unit hydrograph (UH) was applied in order to derive design flood hydrographs at the proposed dam site. Three different storm durations ranging from 6h (½ TL) to 24h (2TL) were evaluated.

To convert the 24-hour point rainfall values to areal rainfall for the catchment, an Areal Reduction Factor (ARF) was applied, based on curves developed for Eastern Africa by Fiddes et al. (1974). The ARF curve is based on the following relationship between ARF and catchment area, A:

$$ARF = 1 - 0.044A^{0.275}$$

From this equation, the ARF for the Kinyeti River catchment was calculated at 73%.

Similarly, to convert 24h areal rainfall to sub-24h storm durations, ratios from Fiddes et al. (1974) were used, while hyetographs were based on temporal storm distributions for intermediate storms (HRU, 1972)- see Table 4-8.

Table 4-8: Hyetographs showing the hourly distribution of storm rainfall for 6, 12 and 24 hour durations

Time (h)	6 h	12 h	24 h
1	6%	2%	2%
2	6%	2%	2%
3	10%	3%	2%
4	22%	5%	2%
5	28%	9%	2%
6	28%	13%	5%
7		14%	7%
8		15%	8%
9		12%	8%
10		10%	8%
11		8%	9%
12		7%	9%
13			9%
14			6%
15			5%
16			4%
17			3%
18			3%
19			1%
20			1%
21			1%
22			1%
23			1%
24			1%

Typical storm losses for the region were derived from the Feasibility Study for the Baro 1 and 2 Hydropower Projects (Norplan, 2006) as well as envelope curves of maximum storm runoff (HRU, 1972), and were found to range between 61% (100 year RI) and 20% (10,000 year RI).

As it was not possible to calibrate the Snyder coefficients due to the lack of hydrograph data in the Kinyeti catchment, a sensitivity analysis was conducted in order to identify the combination of coefficients which result in the most conservative flood peaks. Coefficients of 0.69 (Cp) and 1.3 (Ct) were eventually used.

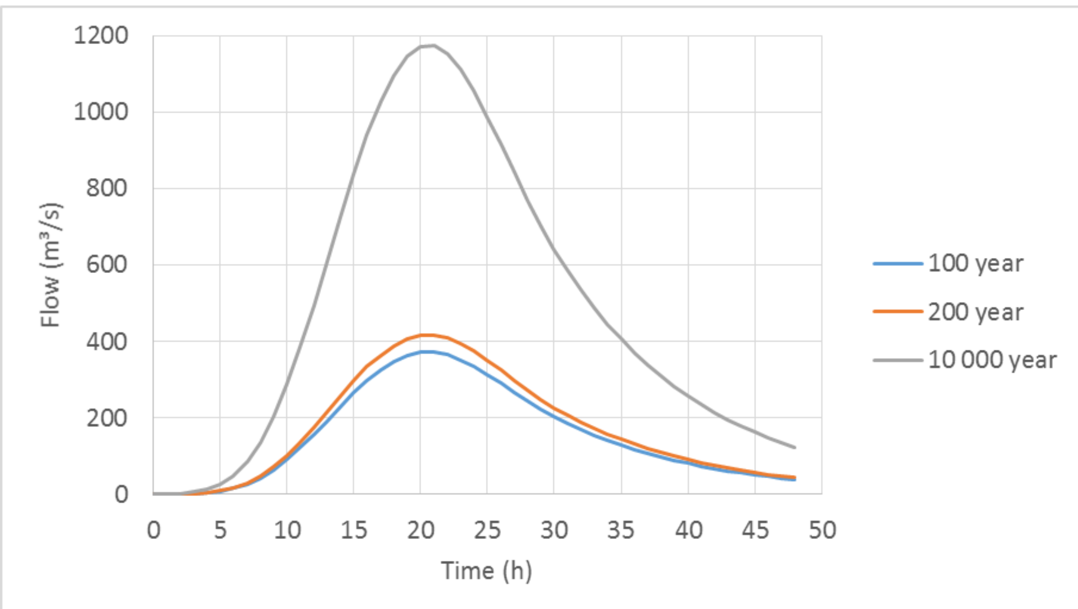
For each return period, hydrographs were simulated using 6, 12 and 24 hour storm durations in order to determine the critical storm duration corresponding to the maximum flood peak.

The final peak flows calculated using Snyder's method are listed Table 4-10, while the hydrographs for the various return periods are shown in Figure 4-12. No allowance was made for baseflow in the river as this was deemed negligible compared to flood peaks - based on observations during the Hydrology Mission to the Kinyeti River Basin (Sep, 2014).

Table 4-9: Results of Snyder's deterministic method (12h storm)

T	100	200	10 000
Q (m^3/s)	372	416	1 173

Figure 4-12: Snyder's design hydrographs for various return periods



Regional flood frequency analysis (FFA)

A site-specific probabilistic analysis of observed annual maximum daily flows on the Kinyeti River was not possible due to a lack of daily and/or instantaneous flow records of a significant length in the study area. Using a total of 47 observed annual maximum daily flood values from Ethiopia at Sor nr. Metu (and Baro nr. Masha (Norplan, 2006), regional growth curves were developed using probabilistic analysis. Details of the stations which were used are provided in Table 4-10.

Table 4-10: Details of stations used for regional FFA analysis

Station	Catchment area (km2)	Record Period	Amax mean (m3/s)
Sor nr. Metu	1,622	1967-2003	235
Baro nr. Masha	1,653	1989-2003	234

The growth factors calculated for different return periods are listed in Table 4-11.

Table 4-11: Regional growth factors

Return Period (years)	Growth Factor
2	0.938
5	1.178
10	1.352
20	1.531
50	1.782
100	1.985
200	2.202
500	2.512
1000	2.768
2000	3.043
5000	3.438
10000	3.765

A regional relationship between catchment area and mean annual flood peak was developed as part of the Baro Hydropower Feasibility Study (Norplan, 2006), which was then used to derive a representative mean annual flood at the Kinyeti dam site as follows:

$$Q_{Site} = Q_{Masha} \times \left(\frac{A_{Site}}{A_{Masha}}\right)^{0.8348}$$

QSite: mean annual flood peak at the point of interest (m3/s)

QMasha: mean annual flood peak at Masha station (m3/s)

ASite: catchment area at the point of interest (km2)

AMasha: catchment area at Masha station (km2)

Finally, as the regional analysis was based on daily average flood values, a scaling factor of 1.6 was applied in order to convert the average values to instantaneous flood peaks. This was based on the Norplan (2006) study, which calculated a ratio of 1.3 based on analysis of data at the Sor river station. However, as the Kinyeti dam catchment is significantly smaller and characterised by a very steep upper catchment, the factor was increased by 20%.

The results of the regional flood analysis are shown in Table 4-12 for various return periods.

Table 4-12: Results of the regional flood analysis

Return Period (years)	Q_{Torit} (m^3/s)
20	282
50	328
100	365
200	405
1 000	510
10 000	693

Recommended design flood peaks

A summary of the flood peaks obtained using various methods is shown in Table 4-13for the 100, 200 and 10 000 year RI floods. The Snyder and regional FFA values for the 100 and 200 year RIs are very similar and the Snyder peaks are recommended.

For the 1:10,000 year peak, the regional FFA value is significantly lower than the Creager and Snyder values, which can be ascribed to the fact that the analysis was based on only 47 years. Consequently, the Snyder 1:10,000 year RI value was excluded and the 10 000 year design flood peak was calculated as the average of the Creager and Snyder 10 000 year flood peaks, i.e. 1 638 m3/s.

Table 4-13: Summary of design flood peaks using various methods

Return Period	100	200	10 000
Creager (m^3/s)	-	-	2102
Snyder (m^3/s)	372	416	1173
Regional FFA (m^3/s)	365	405	693
Design (m^3/s)	**372**	**416**	**1638**

Spillway

Given that the reservoir will be at least 50% full at the beginning of a flood event (the minimum operating level) and probably nearer to full given that floods will normally occur during the wet season when the reservoir will be relatively well replenished. It is thus assumed that the reservoir will be full (i.e. water level at the FSL) at the onset of the extreme flood events.

Flood routing through the proposed dam was carried out for the RDF (200 year) and SEF (10 000 year) floods, in order to evaluate the performance of the spillway. The shape of hydrographs adopted in the numerical simulations was built according to the Snyder UH, with inflow flood peaks of 416 m^3/s and 1 638 m^3/s for the RDF and SEF floods respectively.

The well-known computation procedure of reservoir flood routing in terms of finite time intervals was used. The inputs to these computations are the inflow design hydrograph, the stage-volume relationship of the reservoir and the spillway characteristics (type of overflow and spillway dimensions).

The routed hydrographs are shown in Figure 4-13 and Figure 4-14 for the RDF and SEF respectively for an ogee spillway of 65 m length. A constant discharge coefficient equal to 2.1 was used for the routing.

The 200 year flood peak attenuates from 416 m^3/s to 385 m^3/s (7.5%). However, there is almost no attenuation of the 10 000 year flood. This is expected considering that the 10 000 year flood volume is approximately 115 million m^3, which is significantly more than the approximately 14 million m^3 of buffer storage available above the full supply level.

Figure 4-13: Results of the 200 year (RDF) flood routing

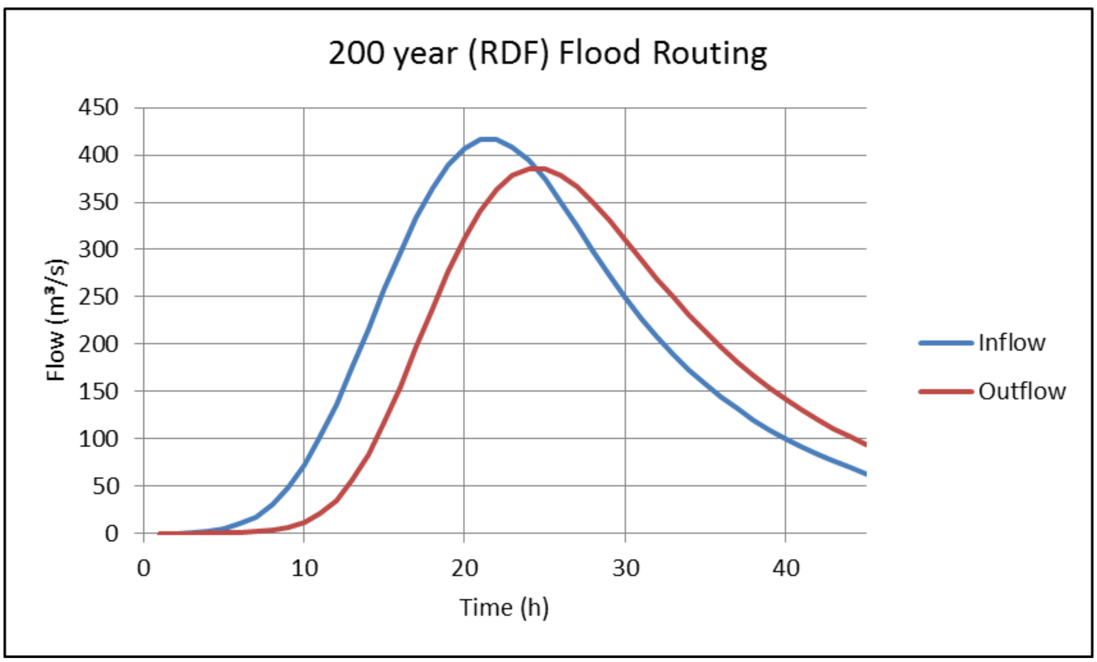
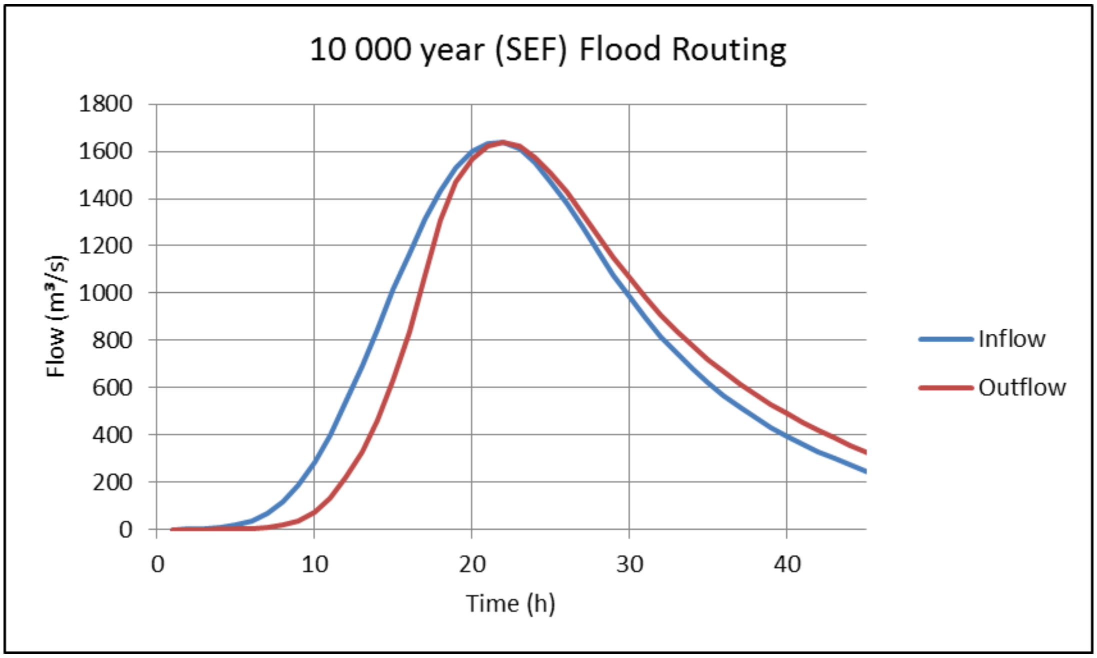


Figure 4-14: Results of the 10 000 year (SEF) flood routing



The estimated extreme flood events (inflow and routed outflow) and their return periods are summarized in Table 4-14.

Table 4-14: Summary of extreme flood events and their return periods.

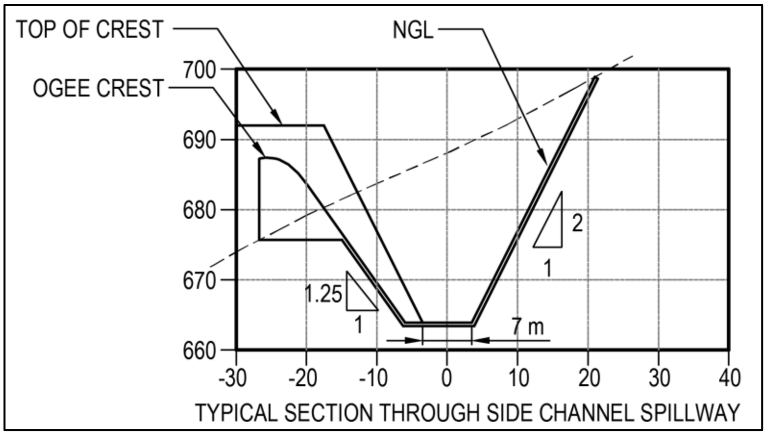
Flood return period (years)	Flood peak (m^3/s) Inflow	Flood peak (m^3/s) Outflow
1:200 (Recommended Design Flood)	416	385
1:10 000 (Safety Evaluation Flood)	1638	1638

A side channel type spillway need not be aligned with the dam wall's centreline and the crest of the spillway can be angled as needed to fit in with the local topography. The compact layout of the proposed site thus lends itself to a side channel type spillway, with an uncontrolled straight ogee overflow section with a trapezoidal discharge channel to safely convey the flood waters back into the river. It is proposed that the spillway be located on the right abutment and founded on solid rock along its entire length.

The discharge channel can be significantly narrower than the overflow sill for a side channel. However, it must be made deeper and/or steeper to maintain the required discharge capability. The deep channel on the abutment will thus likely necessitate the excavation of predominantly hard rock, which is more costly than ordinary earthfill. However, since a rockfill quarry would have to be opened to source the required quantities of rockfill for the upstream rip-rap layer (if the dam is an earthfill embankment), or the rockfill shells (if the dam is a rockfill embankment), the fixed cost of establishing the quarry would in any case be required. Additionally, the entire volume of excavated material (or at least the majority thereof) could be used in both the earthfill or rockfill type embankments.

The discharge channel has to contain relatively large floods and will have a steep slope. Lining of the channel invert and sides with reinforced concrete is thus provided for. If during the geotechnical investigations the foundation rock proves to be very hard erosion resistant sound rock, the concrete lining may be omitted.

Figure 4-15: Section through spillway crest and channel.



The spillway and freeboard combinations must be able to accommodate the extreme flood events as above without overtopping the embankment. An uncontrolled ogee overflow is chosen for its high discharge capability, thus reducing the required freeboard and spillway size.

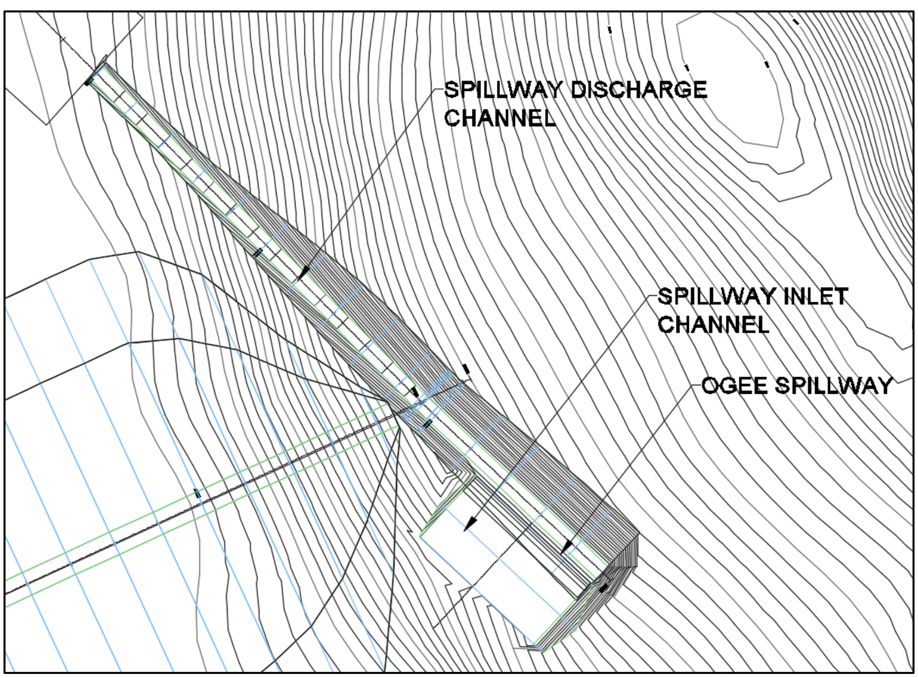
The discharge capacity is given by the following relationship:

$$Q = Cd*L*Ht^{1.5}$$

Where	Q	=	discharge in m³/s
	Cd	=	discharge coefficient (2.13 at the design head Hd of 4m)
	L	=	crest length in m (65 m)
	Ht	=	total head on crest in m

A crest length of 65 m, which in combination with a head of about 5.1 m (i.e. flow with zero freeboard remaining) delivers a discharge capacity of 1638 m³/s, equal to the 1:10 000 year flood event.

Figure 4-16: Spillway layout.



The end of the spillway discharge channel must be provided with an energy dissipating structure before releasing the flood waters back into the river channel. A ski jump is proposed at the downstream end of the discharge channel and would discharge into a plunge pool. A concrete lining should extend for approximately 10 m downstream of the ski jump to provide protection against low flows which would not spring clear from the ski jump and prevent undercutting of the structure. The plunge pool banks should be protected with riprap if not founded on hard rock.

Table 4-15: Spillway details.

Parameter	Value
Spillway type	Side channel with straight uncontrolled ogee
Spillway width	65 m
Discharge channel description	Trapezoidal concrete lined discharge channel cut into the right abutment with 1V:0.5H side slopes
Discharge channel bottom width	7 m
Maximum discharge with zero freeboard (i.e. 5 m flow depth)	1638 m^3/s

4.2.2.4 Outlet works

The outlet works of a dam would serve the following purposes:

- Hydropower
- Emergency releases to drain the reservoir and drop the water level
- River diversion during construction
- Operational releases for the irrigation scheme and potable provision (this is provided for with the flow coming from the hydro power plant)
- Environmental or compensation releases

The outlet works should be sized to meet all of these different requirements, and optimised accordingly. The exact diameter of the outlet pipeline has not yet been optimised but is likely to be in the order of 1 to 3 m diameter.

For an embankment dam the outlet conduit must be encased in reinforced concrete founded on rock under the embankment. Due to the proposed position of the spillway and discharge channel, on the right abutment, it is proposed that the outlet works be positioned on the left abutment. The abutment slope flattens off approximately 250 m downstream of the toe of the embankment where there is a potential location for any hydropower structures.

Regardless of the dam type selected, flow through the outlet works would be controlled from the downstream end, most likely utilising a sleeve valve. The current study made provision for a single conduit, with internal diameter of 2 m, in a concrete encasement with battered side slopes (for compaction of clay contact zones against the faces).

It is proposed that the upstream portion of the outlet works be housed in an outlet tower. The main advantage being the selection of the best quality water. A significant contributor to water quality issues is the potential occurrence of stratification. Stratification causes the water quality in the deeper levels of the dam to become cut off from the surface layers for long periods of time by an inversion layer. This causes this water to become stagnant, very cold and generally devoid of oxygen. Any plant debris from the river that accumulates in this zone could then be decayed by anaerobic bacteria which release gasses such as methane, in addition to other undesirable compounds. If this de-oxygenated water is released from the dam, it can potentially cause fish deaths in the river downstream. Stratification could occur at the dam in question, particularly if aquaculture is implemented, which limits the water level fluctuation of the dam. Should the problem develop in future, it can be mitigated relatively easy by altering the operating rules at the dam and introducing a multilevel draw-off outlet system (i.e. outlet tower).

The tower could either be a wet-well or dry-well tower type. A dry-well tower is preferred as it allows for more convenient inspection, maintenance and operation of the various components that make up the outlet works. The wet-well is slightly simpler, but more difficult to maintain. Either type would have the inlets controlled by sluice valves and ingress of debris prevented by suitable screens. The current dam options make use of the simpler wet well type outlet tower for costing purposes. The outlet tower could be provided with an access bridge from either one of the abutments or from the embankment crest. Alternatively, in lieu of the bridge, the top of the tower could be accessed by a ladder and a boat. This would depend on the frequency at which the tower would need to be visited but is generally inconvenient from a maintenance perspective.

Siltation should also be taken into account when choosing an outlet, as a single low level offtake is at higher risk of blockage than a multiple level draw-off system. Regardless of the presence of a multi-level draw-off system, there should be a scour inlet with isolating valve at the bottom of the dam. The downstream sleeve valve would be housed in a valve chamber downstream of the toe of the embankment.

A low flow spillway, if needed, could be incorporated into the outlet tower structurally as a separate shaft. This has not been allowed for in the current options. Figure 4-17 shows a typical outlet tower with an access bridge.

Figure 4-17 Typical wet-well outlet tower and access bridge.

The outlet works parameters used for the costing of both embankment dams are given in the table below.

Table 4-16: Outlet works details.

Parameter	Value
Conduit description	Single 2 m diameter reinforced concrete outlet conduit (also for river diversion during construction) with a downstream outlet
Outlet tower type	Circular reinforced concrete wet well tower with steel pedestrian access bridge.
Outlet tower foundation elevation	664 masl
Top level of outlet tower	692.5 masl (equal to embankment NOC)
Overall tower height	30 m
Diameter of outlet tower	3 m inside diameter
Number of offtakes	4 No (incl. bottom scour)

4.2.2.5 Access

There is an existing gravel road leading southwards from Torit. Although quite rough, this road is serviceable and could be imporved relatively easily. 9 km out of Torit a track branches off to the right down to the damsite. This track is also quite rough but is serviceable. It passes within a few hundred metres of the damsite.

4.2.2.6 Cost estimate

Costings of the two dam options were produced based on the design parameters as presented in the preceding sections and in the Table below. At the current level of study and information, the earthfill embankment looks to be the more economical option of the two. However, the availability of materials and extent and type of excavation from the spillway channel may still impact the costing of the rockfill option. The geological conditions on site would also most likely dictate the most cost effective option and could thus still have a significant impact on cost and viability of the two options. Further optimization of the spillway and embankment details and arrangement, as well as firming up the construction rates and undertaking a more detailed geotechnical investigation are thus recommended.

Table 4-17: Summary of dam parameters and cost estimate.

Dam Type	**Earthfill Embankment**	**Rockfill embankment**
Spillway	Side channel with straight uncontrolled ogee overflow	
Non-overspill Crest Level (masl)	692.5	
Full Supply Capacity (Mm^3)	44.98	
Full Supply Level (masl)	687.4	
Dam Height (m)	42.5	
Depth at full supply (m)	37.4	
Crest length (m)	340	
Dam wall volume (m^3)	1 283 000	844 000
Crest width (m)	8.5	8.5
Upstream slope	1V :3H	1V :1.75H
Downstream slope	1V :2.5H	1V :1.6H
Dam construction cost ($US mil)	53.5	58.6

Table 4-18: Earthfill dam cost estimate

EARTHFILL DAM COST MODEL					
(Note that not all items in the cost model are applicable)				Max wall height (m)=	42.5
	16-Feb-17	Crest width (m)	8.5	NOCL=	RL 692.5 m
	Proposed Kinyeti Multipurpose Dam : 45.0 Mm3 gross storage capacity			FSL=	RL 687.4 m
	Geotechnical investigations.xlsx				
No	**DESCRIPTION**	**UNIT**	**RATE 2016 USD**	**QUANTITY**	**AMOUNT (Excl VAT) USD**
1	**Clearing**				
	(a) sparse	ha	840	0.0	0
	(b) bush	ha	2 160	2.0	4 332
	(c) trees	ha	5 160	6.0	31 049
2	**River diversion**	Sum	60 000		60 000
3	**Excavation**				
	(a) Bulk				
	(i) all materials	m³	12	185 191	2 222 294
	(ii) extra over for rock	m³	30	138 893	4 166 802
	(b) Confined				
	(i) all materials	m³	16	4 379	70 069
	(ii) extra over for rock	m³	38	2 190	83 207
	(c) Preparation of solum				
	(i) all materials	m²	1.0	66 629	66 629
	(ii) extra over for rock	m²	16	13 326	213 212
4	**Drilling & Grouting**				
	(a) Curtain grouting	m drill	180	8 022	1 444 014
	(b) Consolidation grouting	m drill	138	1 720	237 360
	(c) Slurry trench - fill	m3	78	1 750	136 500
5	**Embankment**				
	(a) Earthfill	m³	10	1 189 610	11 896 103
	(b) Filters	m³	16	341 589	5 465 429
	(c) Rip rap (cut and fill from extra over in spillway exca	m³	36	0	0
	(d) Overhaul beyond 1km (one way)	m³km	2	52 330	104 659
	(e) Toe drain	m³	16	1 371	21 934
	(f) Spillway plunge pool protection	Sum	60 000		60 000
6	**Concrete Works**				
	(a) Formwork				
	(i) gang formed	m²	66	12 258	809 001
	(ii) intricate	m²	78	7 744	604 054
	(b) Concrete				
	(i) mass	m³	310	7 674	2 378 878
	(ii) structural	m³	380	2 255	857 024
	(c) Reinforcing	t	2 880	587	1 689 608
7	**Mechanical Items**				
	(a) Valves & gates	No	120 000	6	720 000
	(b) Cranes & hoists	Sum	300 000		300 000
	(c) Structural steelwork	t	8 000	20	160 000
	(d) Outlet pipe (SS304)	m	1 000	290	289 650
	SUB-TOTAL				34 091 809

	Proposed Kinyeti Multipurpose Dam : 45.0 Mm3 gross storage capacity				
No	DESCRIPTION	UNIT	RATE 2016 USD	QUANTITY	AMOUNT (Excl VAT) USD
8	**Fencing**	km	110	0.0	0
9	**Landscaping** (% of 1-9)	%	1		340 918
10	**Miscellaneous** (% of 1-9)	%	5		1 704 590
	SUB TOTAL A				36 137 317
11	**Preliminary & General** (% of sub-total A)	%	20		7 227 463
12	**Preliminary works**				
	(a) Access road (construction and maintenance, 3yr)	km	31 200	1.00	31 200
	(b) Electrical supply to site	Sum	12 000		12 000
	(c) Construction water to site	Sum	12 000		12 000
	(d) Railhead & Materials handling	Sum	60 000		60 000
13	**Accommodation**	Sum	In Item 11		
	SUB TOTAL B				43 479 981
14	**Contingencies** (% of sub total B)	%	15		6 521 997
	SUB TOTAL C				50 001 978
15	**Engineering** (% of sub total C)	%	7		3 500 138
	SUB TOTAL D				53 502 116
	TOTAL CONSTRUCTION COST				**53 502 116**

Table 4-19: Rockfill dam cost estimate

ROCKFILL DAM COST MODEL					
(Note that not all items in the cost model are applicable)				Max wall height (m)=	42.5
	16-Feb-17	Crest width (m)	8.5	NOCL=	RL 692.5 m
	Proposed Kinyeti Multipurpose Dam : 45.0 Mm3 gross storage capacity			FSL=	RL 687.4 m
	Geotechnical investigations.xlsx				
No	DESCRIPTION	UNIT	RATE 2016 USD	QUANTITY	AMOUNT (Excl VAT) USD
1	**Clearing**				
	(a) sparse	ha	840	0.0	0
	(b) bush	ha	2 160	1.4	2 993
	(c) trees	ha	5 160	4.2	21 448
2	**River diversion**	Sum	60 000		60 000
3	**Excavation**				
	(a) Bulk				
	(i) all materials	m³	12	185 191	2 222 294
	(ii) extra over for rock	m³	30	138 893	4 166 802
	(b) Confined				
	(i) all materials	m³	16	2 935	46 959
	(ii) extra over for rock	m³	38	1 467	55 764
	(c) Preparation of solum				
	(i) all materials	m²	1.0	41 821	41 821
	(ii) extra over for rock	m²	16	12 546	200 740
4	**Drilling & Grouting**				
	(a) Curtain grouting	m drill	180	8 022	1 444 014
	(b) Consolidation grouting	m drill	138	1 720	237 360
	(c) Slurry trench - fill	m3	78	1 750	136 500
5	**Embankment**				
	(a) Rockfill	m³	27	750 846	20 272 852
	(b) Filters	m³	16	69 353	1 109 650
	(c) Rip rap (cat and fill from extra over in spillway exca	m³	36	0	0
	(d) Overhaul beyond 1km (one way)	m³km	2	34 779	69 558
	(e) Toe drain	m³	16	1 371	21 934
	(f) Spillway plunge pool protection	Sum	60 000		60 000
6	**Concrete Works**				
	(a) Formwork				
	(i) gang formed	m²	66	12 258	809 001
	(ii) intricate	m²	78	6 334	494 057
	(b) Concrete				
	(i) mass	m³	310	7 674	2 378 878
	(ii) structural	m³	380	1 588	603 509
	(c) Reinforcing	t	2 880	527	1 516 684
7	**Mechanical Items**				
	(a) Valves & gates	No	120 000	6	720 000
	(b) Cranes & hoists	Sum	300 000		300 000
	(c) Structural steelwork	t	8 000	20	160 000
	(d) Outlet pipe (SS304)	m	1 000	198	198 275
	SUB-TOTAL				37 351 093

No	DESCRIPTION	UNIT	RATE 2016 USD	QUANTITY	AMOUNT (Excl VAT) USD
	Proposed Kinyeti Multipurpose Dam : 45.0 Mm3 gross storage capacity				
8	**Fencing**	km	110	0.0	0
9	**Landscaping** (% of 1-9)	%	1		373 511
10	**Miscellaneous** (% of 1-9)	%	5		1 867 555
	SUB TOTAL A				39 592 158
11	**Preliminary & General** (% of sub-total A)	%	20		7 918 432
12	**Preliminary works**				
	(a) Access road (construction and maintenance, 3yr)	km	31 200	1.00	31 200
	(b) Electrical supply to site	Sum	12 000		12 000
	(c) Construction water to site	Sum	12 000		12 000
	(d) Railhead & Materials handling	Sum	60 000		60 000
13	**Accommodation**	Sum	In Item 11		
	SUB TOTAL B				47 625 790
14	**Contingencies** (% of sub total B)	%	15		7 143 868
	SUB TOTAL C				54 769 658
15	**Engineering** (% of sub total C)	%	7		3 833 876
	SUB TOTAL D				58 603 534
	TOTAL CONSTRUCTION COST				**58 603 534**

4.3 HYDROPOWER PRODUCTION

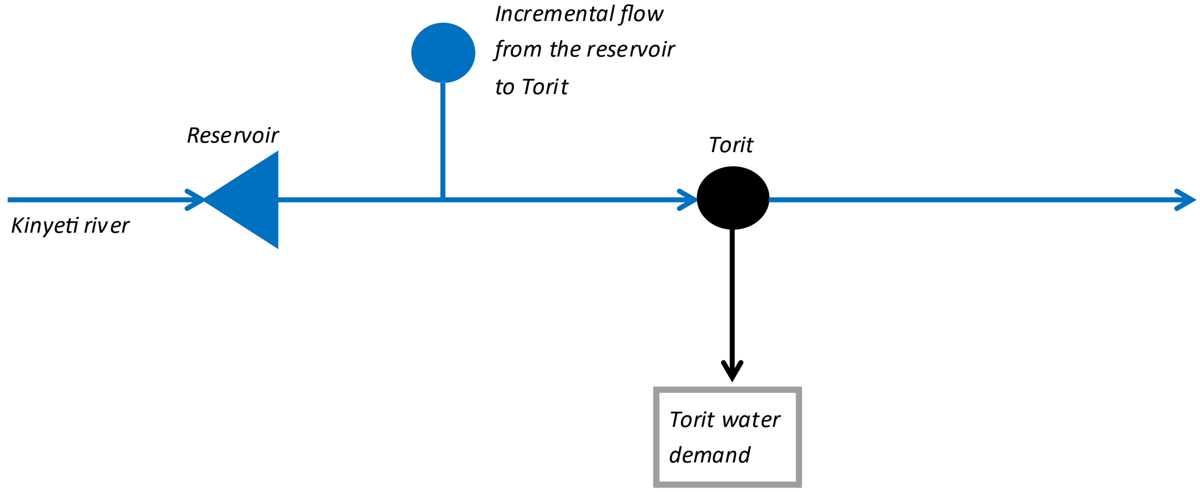
4.3.1 Energy produced and installed capacity

4.3.1.1 Set up of the model

ARCHITECTURE OF THE MODEL

The figure below shows the architecture of the model as it was elaborated under excel.

Figure 4-18: Model architecture schematic



MODEL INPUTS

Model inputs include:

- Catchment inflows to the reservoir;
- Potable water demand for Torit;
- Environmental flow downstream of the dam;
- Reservoir characteristics.

These inputs are briefly described below.

<u>Catchment inflows</u>

The hydrology of the Baro Akobo Sobat basin was modelled as part of the baseline assessment phase of the BAS multipurpose water resources development study. This included modelling of the Kinyeti River catchment and its contribution to the Badingilo swamp. For the purposes of this feasibility study for the Kinyeti River Multipurpose Development Project, the hydrological modelling of the Kinyeti River catchment previously undertaken, was refined in order to produce a more comprehensive account of the hydrology.

Catchment rainfall

For the simulation of long term flow sequences at the dam site, reliable rainfall records are required. The primary source of rainfall data for this feasibility study was the database of patched monthly rainfall values across the Nile Basin (NBI, 2014), the Nile Basin Encyclopedia and the Global Historical Climate Network. From this dataset, two rainfall stations in the vicinity of the study catchment were selected, viz. at Torit and Agoro. Each of the observed rainfall records was tested for stationarity. Conjunctively, the patched rainfall records covered the period from 1905 to 2004.

In order to extend the observed patched rainfall to 2014, the global high resolution, land precipitation gridded rainfall dataset from the Climatic Research Unit (CRU) at the University of East Anglia was used (Harris et al., 2014). The CRU dataset has a resolution of 50km by 50km and monthly CRU rainfall data are available from 1901 to 2014.

Monthly catchment rainfall (attached in Annex 4) expressed as percentage of Mean Annual Precipitation (MAP) for the Kinyeti Dam catchment was calculated using a Thiessen Polygon approach. A MAP of 965 mm for the study catchment was calculated based on the MAPs of selected rainfall stations in the region using Kriging.

A daily rainfall record at Juba, supplemented with daily modelled rainfall data from the Swedish Meteorological and Hydrological Institute (SMHI) database were used to disaggregate the monthly catchment rainfall to representative daily rainfall patterns. The SMHI dataset is at a 45km by 45km resolution, downscaled from Global Climate Models (GCMs) which have been forced by known or estimated climate parameters from CMIP5 historical data.

Evaporation

Due to a lack of observed evaporation data in the vicinity of the Kinyeti Dam, the potential evapotranspiration values as calculated by means of the Thornwaite equation for the Kinyeti River catchment in the WRAS report (SMEC, 2012), were assumed. Table 4-20 lists the monthly potential evapotranspiration estimates, which equate to a Mean Annual Evaporation of 1054 mm.

Table 4-20: Potential evapotranspiration (mm)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
103	98	110	99	89	79	72	71	75	84	86	88

NAM rainfall-runoff model

The NAM rainfall-runoff model (Nielsen and Hansen, 1973) was used as the deterministic model for generating synthetic flow sequences at the dam site. The model accounts for moisture in four inter-related storage zones. Due to a lack of any significant length of flow records in the vicinity of the study catchment, it was not possible to calibrate the NAM model based on observed flows in the study catchment. Consequently, calibration parameters for the Alwero River catchment, based on calibrations undertaken during the baseline assessment phase of the BAS multipurpose water resources development study were transferred to the Kinyeti River catchment. These parameters are listed in Table 4-21.

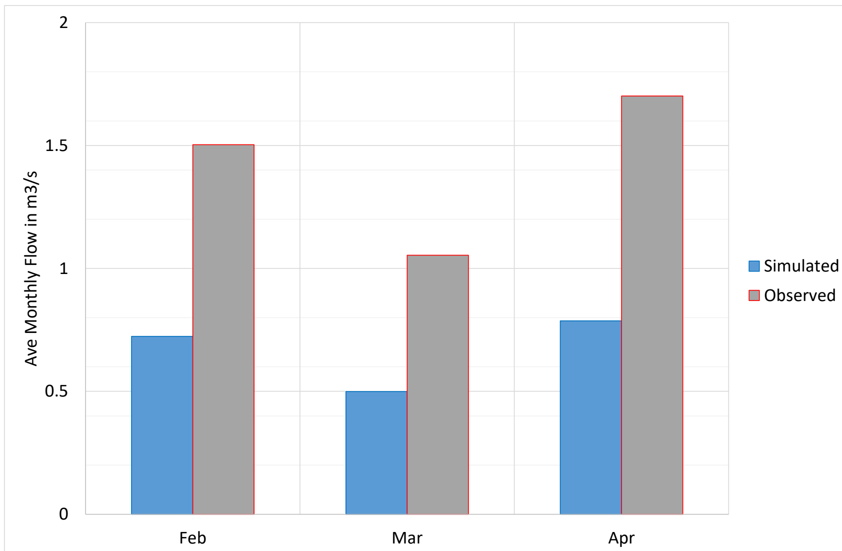
Table 4-21: NAM calibration parameters used for the Kinyeti River catchment

L_{max}	U_{max}	QOF	TIF	TOF	TG	CKOF	CKIF	CKBF	CQOF	CQIF
700	40	0.7	0.75	0	0	0.5	20	50	0.5	0.1
mm	mm	m^3/s	-	-	-	days	days	days	-	-

Simulated inflow sequence to Kinyeti Dam

Various observations in literature and during field missions, have noted that springs contribute to the flow in the Kinyeti River. As part of a Hydrology Mission to the Kinyeti River Basin (Sep, 2014), daily flow measurements were recorded in the Kinyeti River at Torit from September 2015 to October 2016. Due to the very short record period of just over one year, a re-calibration of the Kinyeti River NAM model based on the observed flows was not feasible. However, the observed flow record does provide useful information on the baseflows of the Kinyeti River, as evident from Figure 4-19, which shows the observed and simulated average monthly flow in the Kinyeti River for the dry season, i.e. February to April.

Figure 4-19: Observed and average simulated low flows in the Kinyeti River during the dry season



From Figure 4-19 it is evident that the NAM model baseflows appear to be under-simulated during the dry months, which could be due to unaccounted for spring flow contributions. In order to correct the under-simulated baseflows, a constant value of 0.75 m3/s (which is the average of the difference of observed and simulated flows for February, March and April) was added to the simulated daily flow series (throughout the year), to provide for the contribution of springs to the river flow.

The final simulated flows for the Kinyeti River catchment are attached as Annex 4. A summary of the statistical parameters of the final simulated flow series is shown in Table 4-22. The average monthly flow distribution is shown in Figure 4-20, while the exceedance probability plot for the daily flow time series is shown in Figure 4-21.

Table 4-22: Statistical parameters: Kinyeti River simulated flows (1905 to 2014)

Index	Value
Mean Annual Runoff (mil m^3)	154
Max daily avg. flow (m^3/s)	77
Min daily avg. flow (m^3/s)	0.8
90^{th} exceedance percentile - daily flows (m^3/s)	1.0
50^{th} exceedance percentile - daily flows (m^3/s)	3.3
10^{th} exceedance percentile - daily flows (m^3/s)	10.8
Runoff Coefficient	0.23

Figure 4-20: Average monthly flow distribution in the Kinyeti River at the proposed dam site

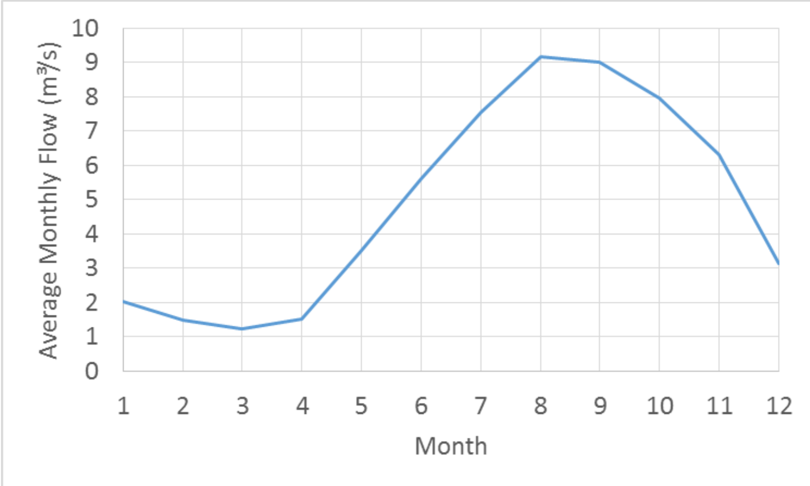
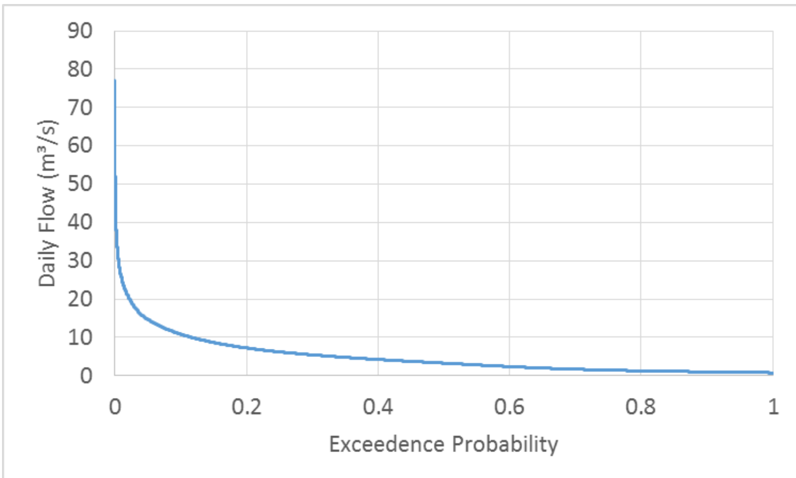


Figure 4-21: Flow duration plot for the Kinyeti River at the proposed dam site



Water demand downstream of the dam

The main purposes of the dam are the following:

- The dam must secure access to water for the city of Torit, it is thus the main demand to be satisfied: the gross maximum daily demand is 11,000 m^3 (water will be abstracted from the reservoir and distributed to Torit by gravity).
- It is essential to maintain an environmental flow to ensure the good state of the downstream river ecosystem. An environmental flow of 0.49 m^3/s has been selected.
- The third purpose of the dam is to produce hydropower.
- Water required for irrigation has not been included in the model in order to maximise hydropower production. It is considered that water availability for irrigation is not a constraint as the flow will be regulated during the dry season. It should be noted however that water demand for irrigation is fluctuating and can be punctually quite high. The estimated maximum volume required for irrigation is significant and represents around 117 000 m^3/day. According to the model, this volume will be available 94% of the time. This means that specific management rules should be implemented to face severe droughts (refer to section 3.3).

- Water requirements for aquaculture do not represent a constraint as the ponds can be filled in during the rainy season. Water demand for this sector is thus not included in the model.

Elevation-Volume-Surface relationship for the reservoir

The relationship between the volume of the reservoir, the elevation and the area was estimated with the following formula:

V= 0.5 * H * (A1 +A2)

With:

V = Volume of the reservoir

H = Head of the reservoir

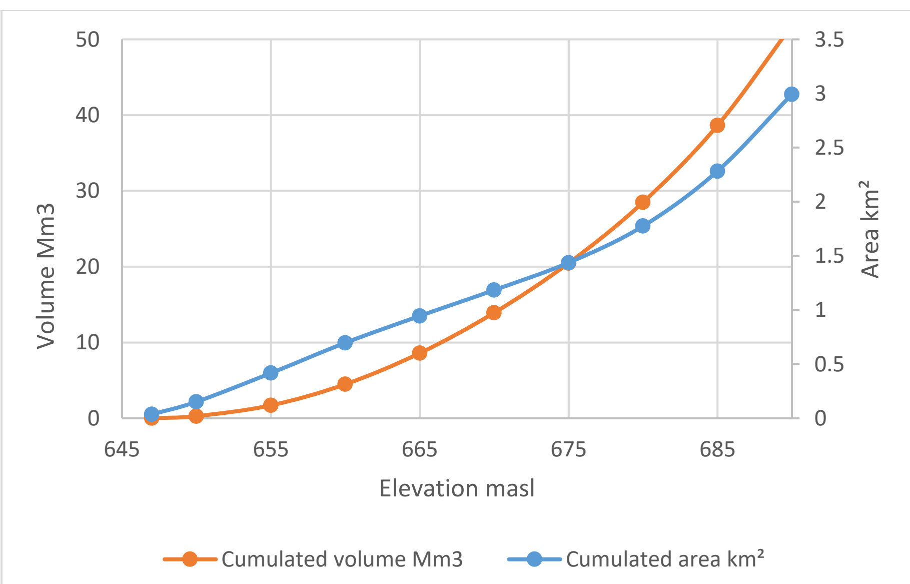
A = Area of the reservoir

The elevation-surface-volume relationship for the reservoir is given below in Table 4-23 and Figure 4-22.

Table 4-23: Elevation-surface-volume relationship for the reservoir

Elevation (masl)	Cumulated area (km²)	Cumulated volume (Mm^3)
647	0.036	0
650	0.152	0.28
655	0.417	1.7
660	0.697	4.49
665	0.945	8.59
670	1.184	13.92
675	1.437	20.47
680	1.775	28.5
685	2.283	38.64
690	2.993	51.84

Figure 4-22: Elevation-surface-volume relationship for the reservoir



MODEL OUTPUTS

The key model outputs are the following:

- Satisfaction of water needs downstream (environmental flow)
- Installed capacity
- Energy produced

4.3.1.2 Key results of the modelling

FIRST STEP: MANAGEMENT CURVE OF THE DAM

The first step of the model is to estimate, on a daily basis, the minimum volume of the reservoir required to satisfy the demand every day of the year. The following approach was taken:

<u>Estimation of the quantity of water that can be released from the dam to (i) meet the demand every day and (ii) produce hydropower</u>

This was done for the 109 years of historical data, on a daily basis. In this approach, it is considered that **inflows to the reservoir are known every day**.

For this estimation, **the input data for a day (n) are the following:**

- Inflow: Qin(n) (reservoir inflow)
- Reservoir: V(n-1); Vmax ; Vmin
- Outflow: (i) Evaporation; (ii) water running through the turbine: Environmental flow, water, available for hydropower production
- Turbine efficiency: 0.8

With :

V(n-1) : Volume of the reservoir for the day n-1

Vmax: Maximum volume of the reservoir (45 Mm3)

Vmin: Minimum volume of the reservoir (22.5 Mm3)

The output data are:

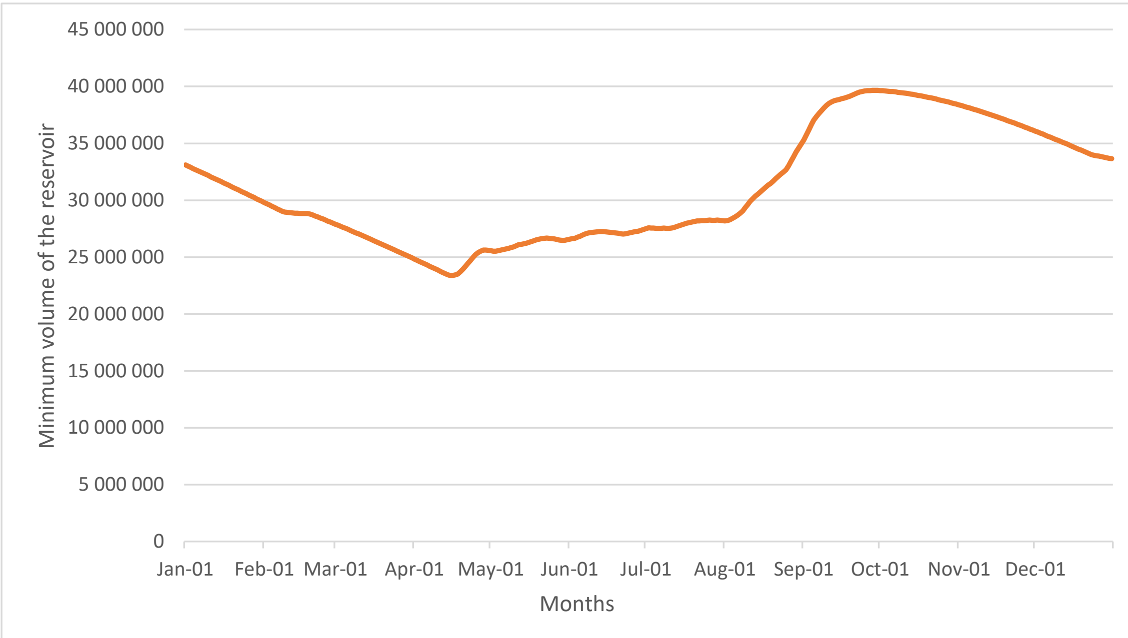
- Reservoir: V(n);
- Outflow: volume of water going through the turbine every day; volume of floodwater going through the spillway.
- Percentage of days on which the demand is not met

The only variable is the volume of water released from the dam to generate hydropower. This volume is fixed in order to guarantee that the demand is met 100% of the time.

Drawing of the curve

One output of the previous estimation is the volume of the reservoir V(n) at a daily scale, to ensure that the demand is met 100% of the time. For each day of the year, there are 109 values (as there are 109 years of data). The minimum value for each day Vmin(n) is selected in order to draw the curve presented on Figure 4-23.

Figure 4-23: Management curve of the dam



SECOND STEP: ESTIMATION OF THE PRODUCTION OF ELECTRICITY

Estimation of the capacity of dam (m^3/s) to meet the demand 95% of the year

This was done for the 109 years of data, on a daily basis, **it is now considered that daily inflows to the reservoirs are not known.** The estimated daily minimum volume of the reservoir (see above) is used to calculate how much water can be released from the dam every day.

For this estimation, **the input data for a day (n) are the following:**

- Reservoir: V(n-1); Vmax; Vmin ; Vmin(n)
- Outflow: evaporation, Environmental flow; Water for hydropower production
- Capacity of the turbines (m^3/day)
- Efficiency of the dam: 0.8

With :
V(n-1) : Volume of the reservoir for the day n-1
Vmax: Maximum volume of the reservoir (45 Mm3)
Vmin: Minimum volume of the reservoir (22.5 Mm3)
Vmin(n): Estimated minimum volume of the reservoir to meet the needs 100% of the time

The output data are:

- Reservoir: V(n);
- Outflow: volume of water going through the turbine every day for hydropower production and to satisfy the demand downstream; volume of floodwater going through the spillway.
- Energy production
- % of days with no satisfaction of the demand

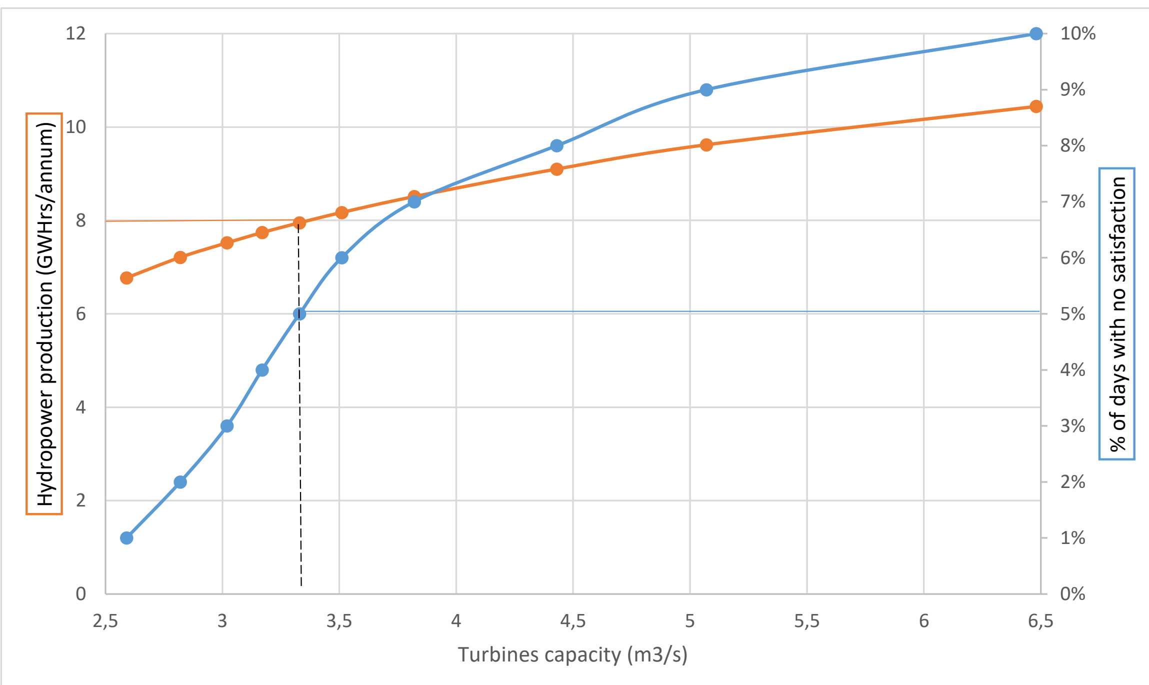
There is one variable which is the capacity of the turbines (i.e the volume of water that can go through the turbines every day (m3/day)). When the capacity increases, the production of energy increases but the percentage of days with no satisfaction of the demand also increases. The capacity of the turbines was selected by looking at the impact of the capacity on the percentage of days with no satisfaction of the needs and on the hydropower production of the dam.

Key results of the model – definition of the capacity of the turbines and hydropower production

Figure 4-24 hereafter presents the main results of the model:

- Percentage of days with no satisfaction of the demand according to the capacity of the turbines
- Hydropower production according to the capacity of the turbines

Figure 4-24: Capacity of the turbines



In order to maximize energy production and to guarantee a relatively low percentage of days with no satisfaction of the demand, a turbine flow capacity of **3.33 m³/s** is proposed (capacity of **1,070 kW**). With this capacity:

- The hydropower production is **7.95 GWHrs/annum**. Considering a demand of 100 kWHrs/person/year, the project will provide energy to around **80,000 people**.
- 5% of the time, the demand is not satisfied. This ratio is acceptable if emergency management rules are set to face scarce situations.

4.3.2 Hydropower equipment

INPUT DATA AND ASSUMPTIONS

The production of hydropower will be for the city of Torit, the network will not be connected to the national grid. It is thus important to consider that the demand for electricity will not be constant throughout the day (greater demand during the day). In order to consider this variation, a load factor was fixed. The load factor is the ratio between the proposed capacity of the turbines (1,070 kW) and the nominal capacity. With a **load factor of 0.6**, the **nominal capacity of the turbines is 1,780 kW** (see Table 4-24).

This difference of production between the day and the night will have an impact on the regulation of the flow: the flow going through the turbines during the day will be greater than during the night. This regulation is not acceptable at infra-daily step and a regulation of the turbined flow is required downstream of the dam. This re-regulation of the flow will be achieved with a re-regulation dam located downstream of the first dam. The reservoir associated with the second dam should be able to store around half the daily maximum volume going through the turbine to maintain the flow during off-peak demand periods. As the maximum daily volume going through the turbine is around 300,000 m^3, then the reservoir capacity should be around 150,000 m^3. This reservoir is shown on Figure 4-11. Based on the assumptions of the main dam, the costs associated to this re-regulation dam should be around 3 million USD.

Table 4-24: Input data and assumptions considered to propose the hydropower equipment

Input data		
Reservoir Full Supply level	687.5	masl
Reservoir Lowest level	676.3	masl
Estimated downstream level	648	masl
Estimated maximum gross head	39.5	m
Estimated minimum gross head	28.3	m
Power needs		
Required power	1,070	kW
Load factor	0.6	
Nominal power	1,780	kW
Assumptions		
Net head / Gross head ratio	0.97	/
Estimated maximum net head (Hnom)	38.3 l	m
Estimated minimum net head (Hmin)	27.45	m
Estimated net head	28.3	m
Turbine efficiency at Hmin P nom	0.89	/
Turbine efficiency at Hnom P nom	0.92	/
Generator efficiency at P Nom	0.965	/
Turbine efficiency at Hmin Pmin	0.56	/
Turbine efficiency at Hnom Pmin	0.56	/
Generator efficiency at Pmin	0.95	/
Electrical enclosures and transformers efficiency	0.97	/

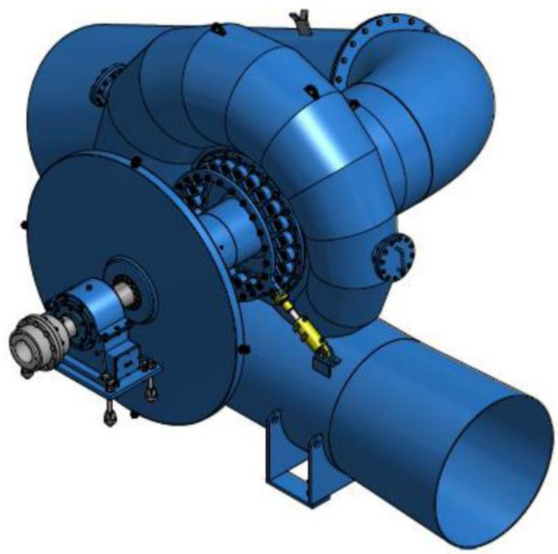
PRELIMINARY DESIGN

The turbine discharge was defined according to the power output and the head. It also considers that the turbine should deliver the requested electrical output (**1,780 kW**) for the minimum net head. With the efficiency presented above, the required flow is evaluated at **7.9 m³/s**.

Considering this discharge (7.9 m³/s) and the net head (28.3 m), the Francis turbine appears to be the most suitable with a horizontal turbine layout (see Figure 4-25). Operating with a net head of 38 m, the Kinyeti Francis turbine could go up to **9 m³/s** and **2,900 kW**.

It should be noted that there is a minimum capacity for the turbine. Below this capacity, the turbine cannot be operated. This minimum capacity is around 30 % of the maximum capacity (350kW at minimum head, 500 kW at maximum head).

Figure 4-25: Horizontal Francis Turbine



The Francis turbine would come with the following equipment:

- 2,000 mm steel penstock;
- pipe reduction 2,000 mm -> 1,500 mm;
- 1,500 mm counterweight butterfly valve;
- according to the local grid constraints, a flywheel could be required;
- 3.5 MVA / 3 kV synchronous generator;
- according to the local grid, 3.5 MVA voltage transformer;
- Medium voltage switchgear.

Furthermore, a 200 mm fixed cone valve should also be installed to deliver the compensation water when the turbine is not operated.

All these equipment would be set up in the powerhouse (dimensions: 15m * 14m *15 m (height)). The power plant would be equipped with a 20 T gantry crane and a cooling system (preferably using fans). The following drawings show a preliminary design of Kinyeti HPP.

Figure 4-26: Preliminary hydropower plant design - sectional view

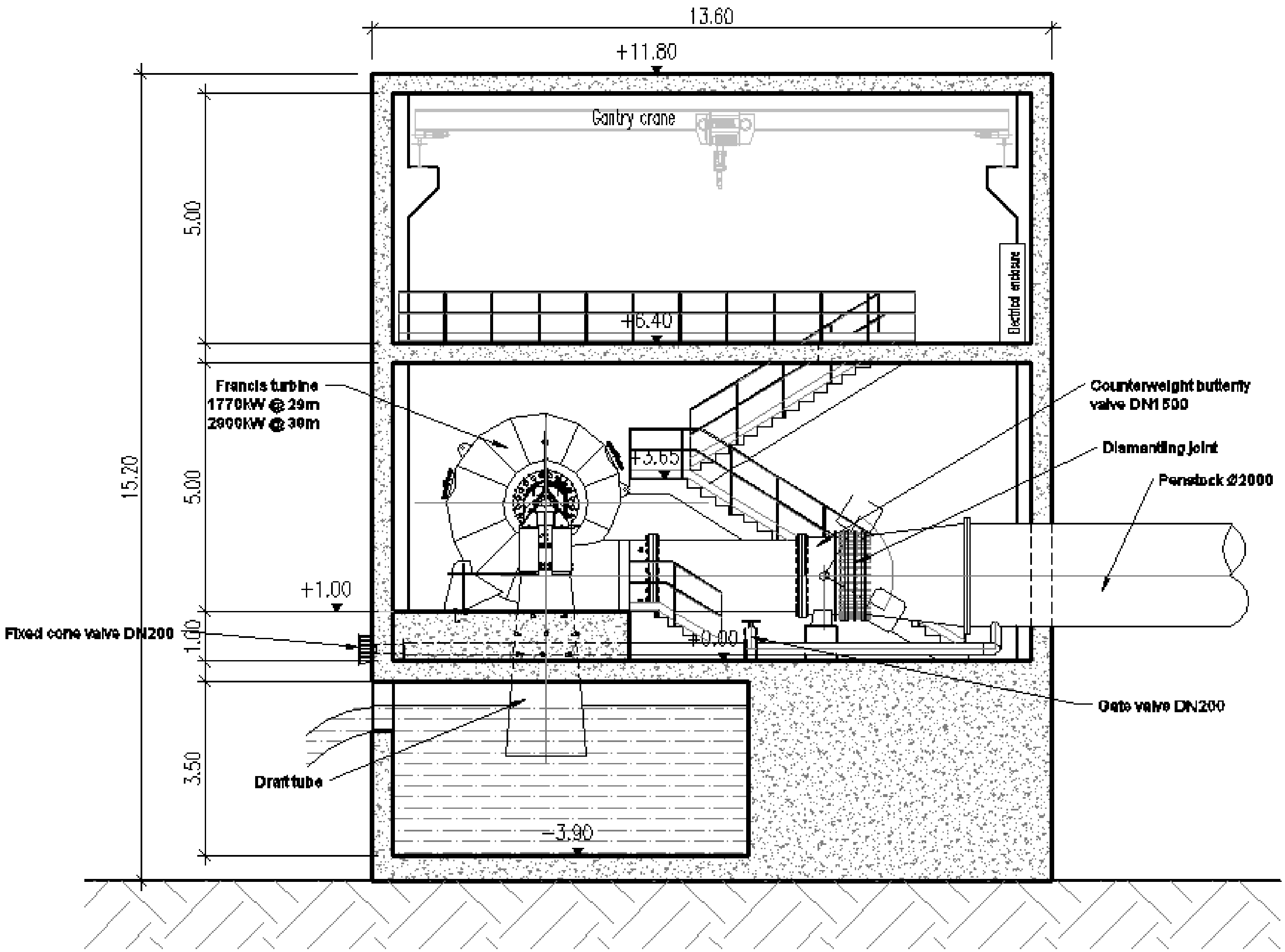


Figure 4-27: Preliminary Hydropower plant design – plan view (turbine level)

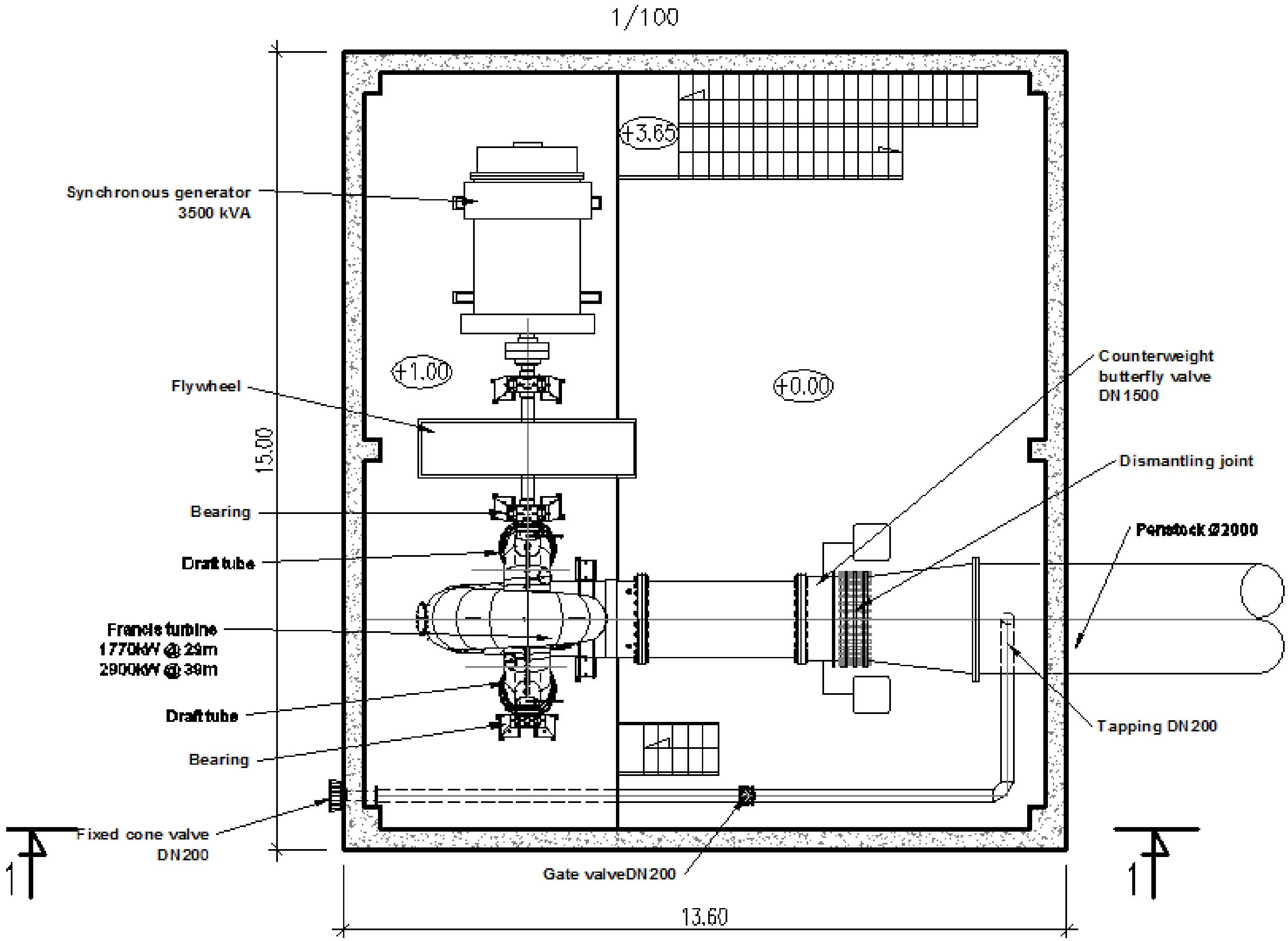


Figure 4-28: Preliminary Hydropower plant design – plan view (control level)

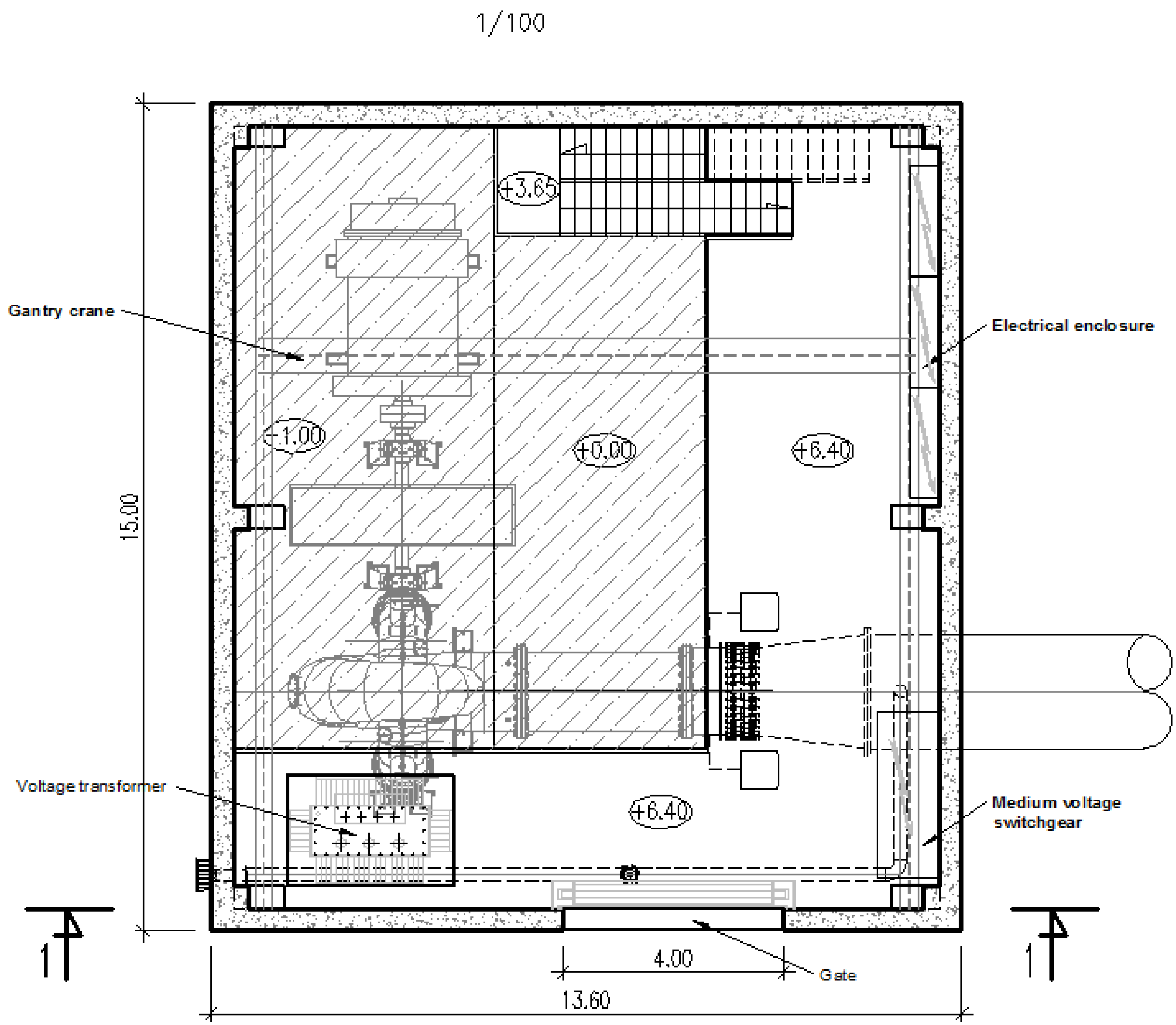


Figure 4-29: Hydropower plant, downstream view – compensation water through a fixed cone valve

4.3.3 Estimation of the costs

A first estimation of the costs is given in the table below. The total costs for this type of infrastructure would be around 3.9 million USD.

Table 4-25: Hydropower equipment: estimation of the costs

Main	Item	Units	Rate (USD 2016)	Quantity	Total (USD)
HPP construction	Excavation	M3	30	7500	225 000
	Civil work	M3	500	1500	750 000
	Embankments	M3	40	625	25 000
Hydro mechanical equipment	Turbine	Unit	/	1	1 100 000
	Synchronous generator	Unit	/	1	
	Butterfly valve	Unit	/	1	
Compensation water (ϕ200mm)	Pipe and gate valve	Unit	/	1	10 000
	Fixed cone valve	Unit	/	1	20 000
Electro-mechanical equipment	3.5 MVA transformer	Unit	/	1	50 000
	Medium voltage switchgear	Unit	/	1	250 000
	Others	Unit	/	1	300 000
Others	Cooling system	Unit	/	1	50 000
	Gantry crane	Unit	/	1	100 000
				TOTAL	**2 880 000**
+ Miscellaneous (10%)					**3 168 000**
+ Contingencies (15%)					**3 643 200**
+ Engineering (7%)					**3 900 000**

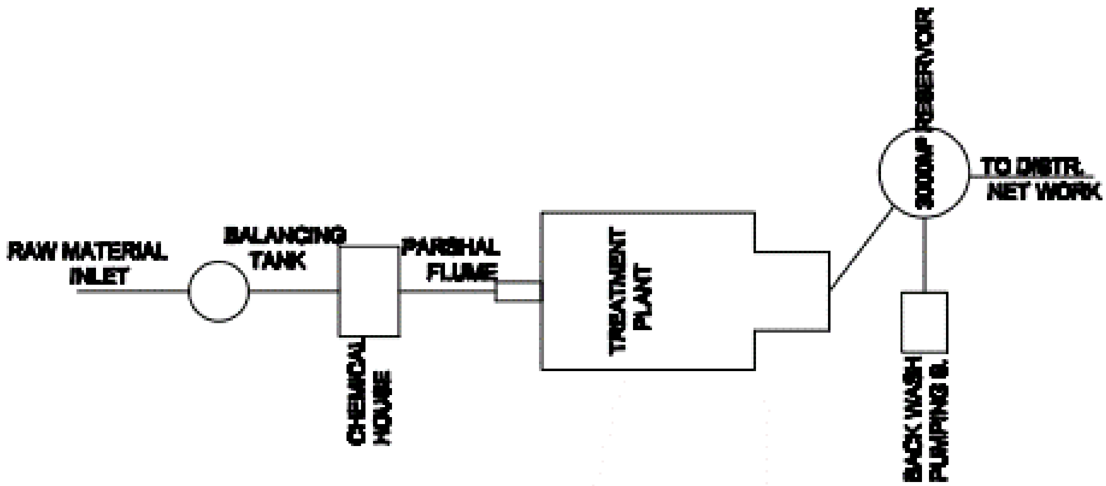
4.4 POTABLE WATER SUPPLY FOR TORIT

A feasibility study was carried out for potable water supply and sanitation for the city of Torit in 2016 by Gauff Ingenieure. In this feasibility study, water is abstracted from a reservoir and distributed to Torit by gravity. Different scenarios are envisaged, one of them (scenario C) includes a storage at the exact same location than the proposed Kinyeti multi-purpose reservoir. It is thus proposed to select scenario C of Gauff study which is coherent with the proposed multipurpose project.

4.4.1 Raw Water Rising Main

A raw water rising main of Diameter 350 mm is required to convey water from the raw water pumping station (RWPS).The works should be sited as high as possible (around RL675) based on the minimum operating level of the reservoir.

Figure 4-30: Site plan layout



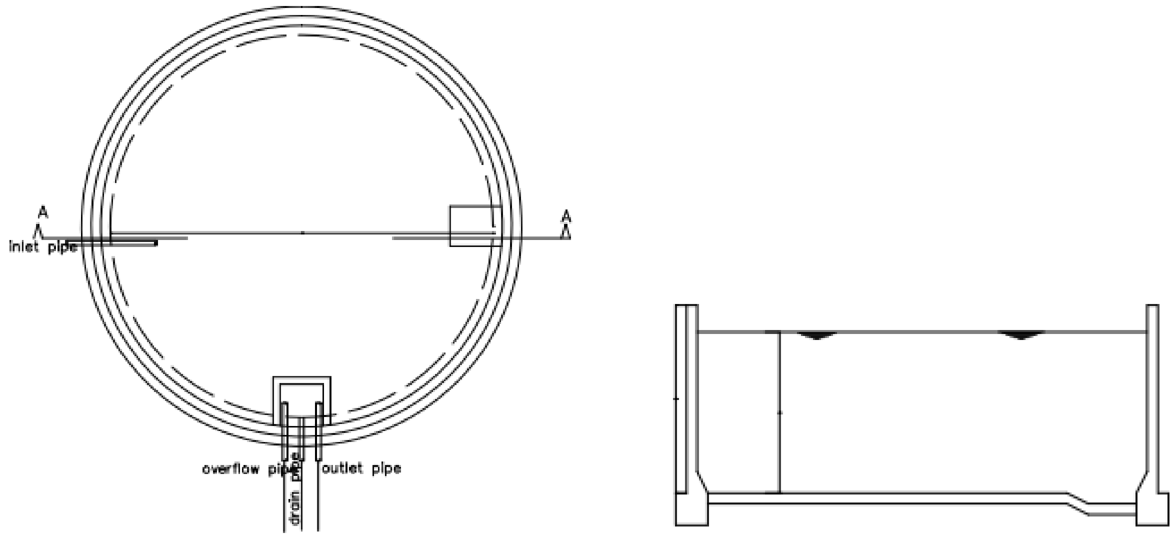
4.4.2 Recommended Treatment

BALANCING CHAMBER

The raw water from the reservoir will be pumped to a reinforced concrete tank of 200 m^3 capacity balancing chamber located in front of the treatment processes. The balancing tank is sized for a minimum detention time of 15 minutes. The balancing reservoir normalizes the flow of raw water to the treatment plant. From the balancing tank, the raw water is conveyed to the treatment plant by gravity.

The gravity main is DN 350 mm from the balancing tank to the treatment plant, sized for the future year 2041 raw water flow of 10,979 m3/day or 127.07l/s. The balancing tank is to be provided with overflow, by-pass and washout pipes. The DN 350 mm outlet pipe will be supplied with a manually operated valve to control the inflow to the treatment plant.

Figure 4-31: 200 m3 balancing chamber (floor plan on the left and section A-A on the right)



HYDRAULIC RAPID MIXING AND COAGULATION

For facilitating rapid mixing in the coagulation process, a Parshall flume is to be provided, which will be located just before the flocculator. A Parshall flume, which is a conventional flow measuring device, is used as a rapid mixer if a hydraulic jump is included immediately downstream of it.

Parshall flumes are designated by the width of the throat at the centre. Table 4-26 below lists standard flume dimensions for various throat widths and the range of discharge corresponding to each flume size.

Table 4-26: Dimensions and Capacities of Parshall Flumes for Various Throat Widths

W	A	B	C	D	E	F	G	Free Flow Capacity	
								Min	Max
mm	mm	mm	mm	mm	Mm	mm	mm	m^3/day	m^3/day
150	620	600	390	400	600	300	600	122	9550
300	1370	1340	600	850	900	600	900	274	39500
460	1450	1420	750	1030	900	600	900	367	60200
610	1530	1500	900	1210	900	600	900	1030	81100
910	1680	1650	1200	1570	900	600	900	1500	123000
1220	1830	1790	1520	1940	900	600	910	3190	166000
1520	1860	1940	1830	2150	900	600	910	3920	210000

Adapted from Okun and Ponghis, 1975

Maximum day demand flow in the treatment plant varies from 3,252 m^3/day in the year 2016 to 5,462 m^3/day in the year 2022, 7,063 m^3/day in the year 2027, and to 10,979 m^3/day in the year 2041. This requires systematic sizing of the units. One partial flume with a throat width of 300 mm or two partial flumes with a width 150 mm would accommodate the minimum and maximum flows from 2016 to 2041. For convenience during the second phase expansion, a Parshall flume with a width of 150 mm is proposed now to accommodate flow up to 2027, and an additional Parshall flume of 150 mm width will be provided during the second phase.

The equation used to compute the discharge based on the measured value of ha for a given throat width W is:

$$Q = 2.27 W h_a^{3/2}$$

where

Q	=	Discharge (m^3/sec)
h_a	=	Depth at entrance to the flume at specified measuring point (m)
W	=	Width of throat (m)

A coagulant diffuser (DN 50 mm perforated pipe) will be fixed (Figure 4-33). The diameter and spacing of the perforation shall be 10 mm and 10 cm respectively. To measure the flow, a calibrated staff gauge will be fixed on the interior wall of the flume. The depth of water at the measuring point and the corresponding flow are presented in Table 4-27. A second Parshall flume of same size will be added during the second phase, the flow in each flume is assumed to be half of the total volume.

Table 4-27: Water Depth (ha) in the Proposed Flume (W = 150 mm) for Various Discharges

Year	Flow				Width	Depth	
	Average		Max			Min	Max
	m^3/day	m^3/sec	m^3/day	m^3/sec	m	mm	mm
2016	1,670.36	0.019	3,252.86	0.038	0.15	148	231
2017	1,746.34	0.020	3,400.83	0.039	0.15	153	238
2018	1,823.98	0.021	3,552.02	0.041	0.15	157	245
2019	1,902.60	0.022	3,705.13	0.043	0.15	162	252
2020	2,441.25	0.028	4,754.10	0.055	0.15	191	297
2021	2,502.28	0.029	4,872.94	0.056	0.15	194	302
2022	2,805.30	0.032	5,463.05	0.063	0.15	209	326
2023	2,875.42	0.033	5,599.59	0.065	0.15	213	331
2024	2,947.31	0.034	5,739.59	0.066	0.15	216	337
2025	3,020.97	0.035	5,883.04	0.068	0.15	220	342
2026	3,096.50	0.036	6,030.13	0.070	0.15	223	348
2027	3,627.31	0.042	7,063.83	0.082	0.15	248	387
2028	3,718.00	**0.043**	7,240.43	0.084	0.15	252	393
2029	3,810.98	0.044	7,421.49	0.086	0.15	257	400
2030	3,906.24	0.045	7,607.01	0.088	0.15	261	406
2031	4,003.90	0.046	7,797.19	0.090	0.15	265	413
2032	4,514.40	0.052	8,791.33	0.102	0.15	287	447
2033	4,627.25	0.054	9,011.11	0.104	0.15	292	455
2034	4,742.91	0.055	9,236.34	0.107	0.15	297	462
2035	4,861.49	0.056	9,467.26	0.110	0.15	302	470
2036	4,983.04	0.058	9,703.96	0.112	0.15	307	478
2037	5,107.62	0.059	9,946.57	0.115	0.15	312	486
2038	5,235.29	0.061	10,195.20	0.118	0.15	317	494
2039	5,366.16	0.062	10,450.06	0.121	0.15	322	502
2040	5,500.29	0.064	10,711.27	0.124	0.15	327	510
2041	5,637.80	0.065	10,979.06	0.127	0.15	333	519

Figure 4-32: Coagulant diffuser – DN50PVC Plan, scale 1 :50

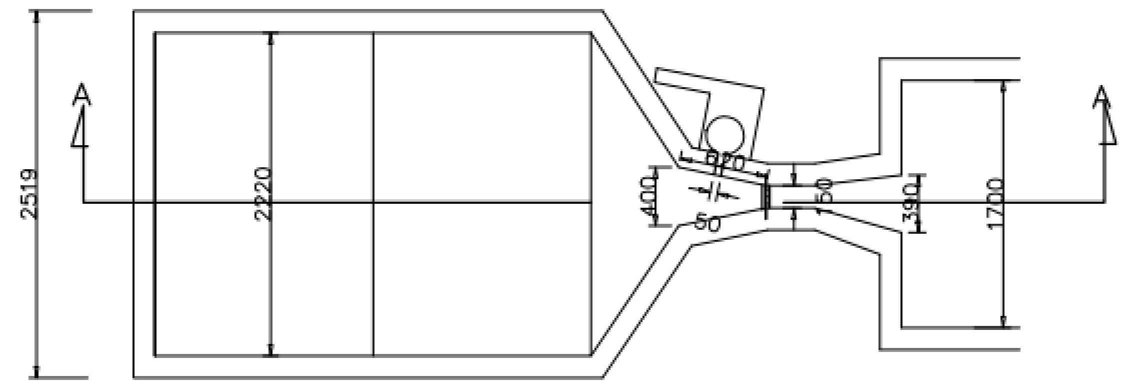
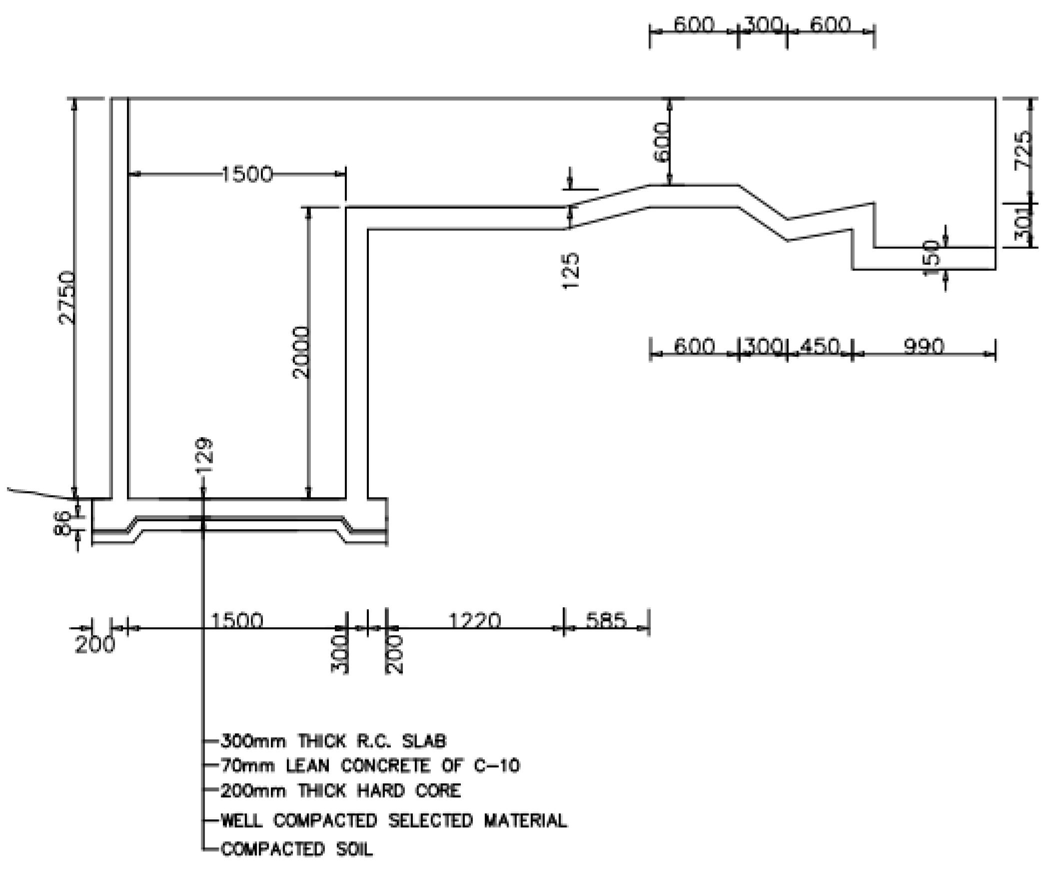


Figure 4-33: Coagulant diffuser – DN50PVC Section A-A, scale 1 :50



FLOCCULATORS

Horizontal flow baffled channel flocculators is designed. The common design guides for this type of flocculators are:

Assumed velocity gradient in s^{-1}	:	0.40-0.60	m/sec
Length of unit chamber (L)	:	0.75-1.50	m
Width of unit chamber (B)	:	0.50-1.25	m
Depth of unit chamber (h)	:	2.50-3.50	m
Detention Time (t)	:	15-25	minutes

The design flows for sizing the units are 63.2 l/s for the maximum day demand for the year 2022, and 127.01 l/s for the maximum day demand for the year 2041. Three units sized for a flow rate of 63.2l/s would be sufficient for the maximum day demand in 2041, where one will serve as a standby. It is therefore proposed to provide two of these units during Phase I construction, and that one unit to be added later in 2022 to accommodate demand for the second phase.

The coagulated water from the rapid mixer will split into two V-notched weirs. Thus each train will be sized for a flow rate of 63.2 l/s.

The horizontal flocculator is sized using the parameters shown in Table 4-28.

Table 4-28: Design parameter, horizontal baffled flocculator

Horizontal Baffled Flocculator				
Design Values	**Units**	**Ranges**	**Section 1**	**Section 2**
Velocity in m/sec			0.2	0.2
Assumed velocity gradient in s-1		0.40-0.60	45	25
Length of Flocculator	m		4	4
Width of unit chamber (B)	cm	0.50-1.25	0.76	0.92
Depth of unit chamber (h)	m	2.50-3.50	3	3
Detention Time (t)	min	15-25	14	14
Flow in m^3/day			5463	5463
Flow in m^3/sec			0.0632	0.0632
Volume of Flocculator m^3			53	53
Total calculated width of Flocculator in m	m		4.43	4.43
Adjusted width of each section			4.4	4.4
For Water at 15oC dynamic viscosity μ in kg/m.s			0.00114	0.00114
Density of water in kg/m^3 ρ			1000	1000
Velocity in m^2/s			0.00000114	0.00000114
Number of baffles in first flocculator			5.29751425	4.354931202
Spacing between baffles			0.755071117	0.918499011
Head loss			0.197669725	0.061009174

HORIZONTAL FLOW SEDIMENTATION

The basic design guides for a sedimentation basin are the surface loading and detention time. Since the treatment process prior to sedimentation (rapid mixing and flocculation) are designed properly and expecting reasonable operation the following guide values are adopted:

Detention period	:	2.5 – 3.5Hr
Surface loading rate (maximum)	:	1.2m3/h/m2
Length to width ratio	:	>3
Minimum depth	:	3 m

Using the above guide sedimentation tank with the following dimensions is proposed.

Table 4-29: design parameter – regular sedimentation tank

Rectangular Sedimentation Tank		
Year	**2022**	**2041**
Two tanks are to be provided	2	3
Overflow Rate in m/h	0.6	0.6
Flow in m3/day	5463	10979
Flow in m3/sec	0.0632	0.1271
Surface Area in m2	151.8	305.0
Length to width ratio	>3	>3
Width in m	5.5	5.5
Length in m	20	20
Assumed depth	3.5	3.5
Volume	385	385
Checking detention time	3.38	2.52

In order to facilitate drainage of the basin, the floor will have 1% slope from the side wall. Sludge collecting channel fitted with drainage pipe will be provided at the inlet side.

RAPID SAND FILTERS

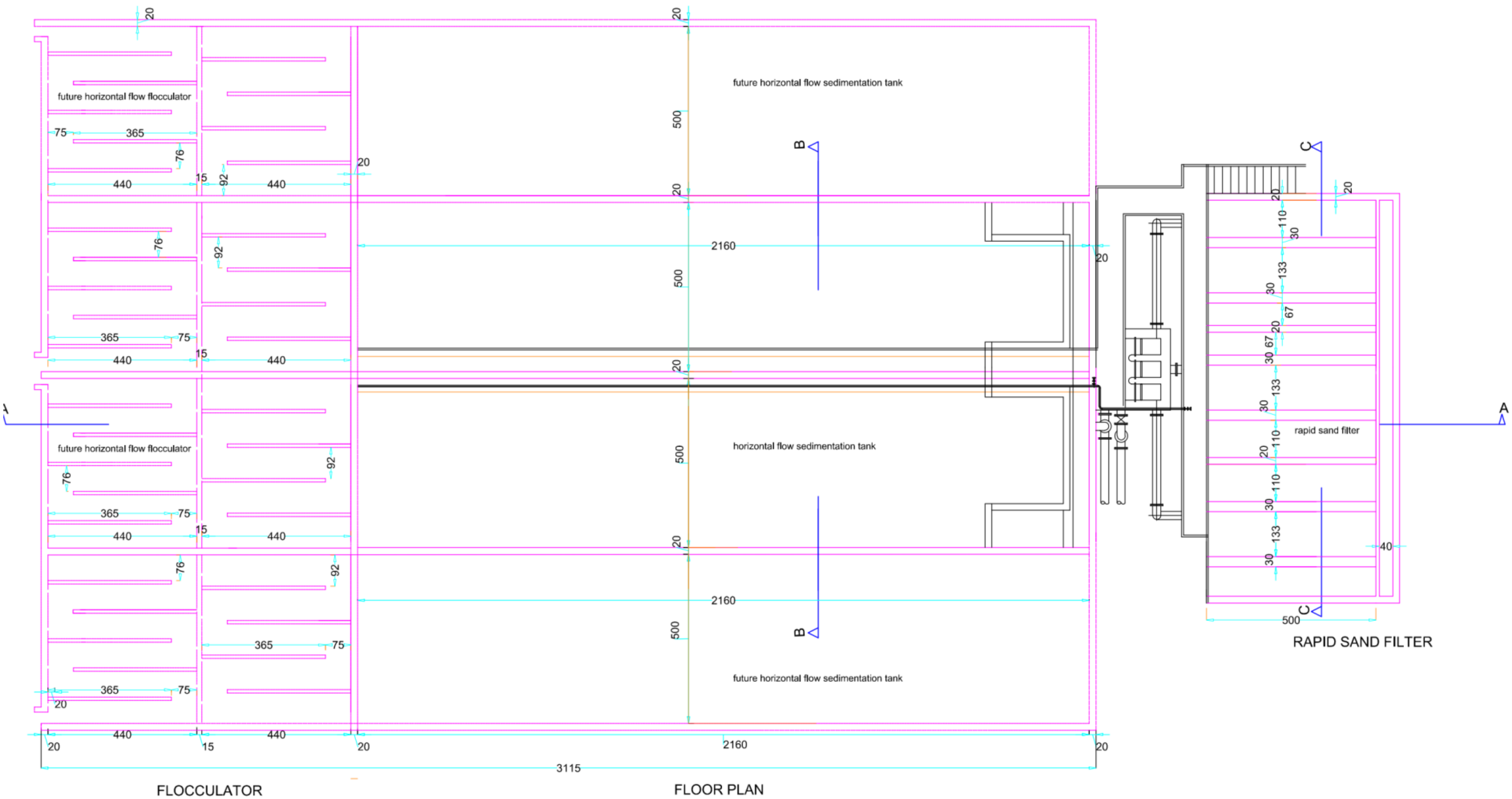
The raw water treated in the above unit operations will be subjected to further treatment by a rapid sand filtration (RSF). A filter bed area of 20 m^2 (4 m x 5 m) is fixed and analyzed for different flow conditions and number of filter units. As can be observed from the analyses in Table 4-30 one unit is sufficient up to year 2028 and after wards two units are sufficient. As a principle a treatment plant should contain a minimum of two units, one operational and one standby. Therefore, it is recommended that two filter units be constructed during Stage I construction and a third one in Year 2028.

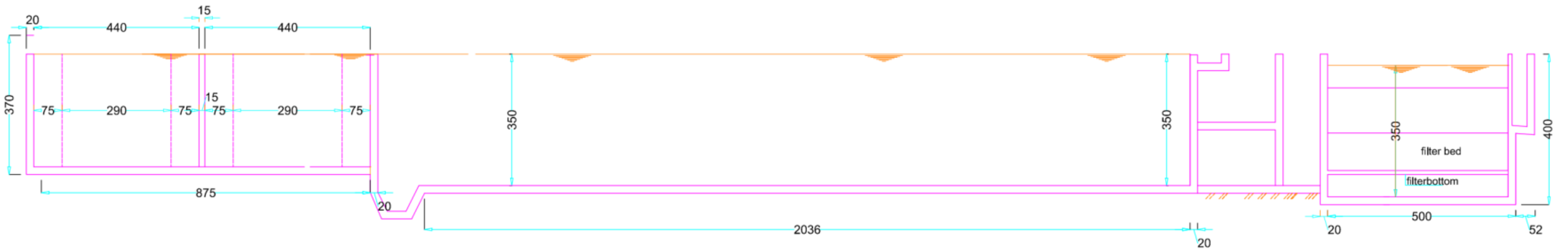
Table 4-30: filtration rate and number of filter units

Year	Q	Q	Filtration Rate, m/hr			Recommendation
	m3/day	m3/hr	3	2	1	
2016	3,252.86	135.54	2.3	3.4	6.8	Use two units, one will be standby
2017	3,400.83	141.70	2.4	3.5	7.1	Use two units, one will be standby
2018	3,552.02	148.00	2.5	3.7	7.4	Use two units, one will be standby
2019	3,705.13	154.38	2.6	3.9	7.7	Use two units, one will be standby
2020	4,754.10	198.09	3.3	5.0	9.9	Use two units, one will be standby
2021	4,872.94	203.04	3.4	5.1	10.2	Use two units, one will be standby
2022	5,463.05	227.63	3.8	5.7	11.4	Use two units, one will be standby
2023	5,599.59	233.32	3.9	5.8	11.7	Use two units, one will be standby
2024	5,739.59	239.15	4.0	6.0	12.0	Use two units, one will be standby
2025	5,883.04	245.13	4.1	6.1	12.3	Use two units, one will be standby
2026	6,030.13	251.26	4.2	6.3	12.6	Use two units, one will be standby
2027	7,063.83	294.33	4.9	7.4	14.7	Use two units, one will be standby
2028	7,240.43	301.68	5.0	7.5	**15.1**	Use three units, one will be standby
2029	7,421.49	309.23	5.2	7.7	**15.5**	Use three units, one will be standby
2030	7,607.01	316.96	5.3	7.9	**15.8**	Use three units, one will be standby
2031	7,797.19	324.88	5.4	8.1	**16.2**	Use three units, one will be standby
2032	8,791.33	366.31	6.1	9.2	**18.3**	Use three units, one will be standby
2033	9,011.11	375.46	6.3	9.4	**18.8**	Use three units, one will be standby
2034	9,236.34	384.85	6.4	9.6	**19.2**	Use three units, one will be standby
2035	9,467.26	394.47	6.6	9.9	**19.7**	Use three units, one will be standby
2036	9,703.96	404.33	6.7	10.1	**20.2**	Use three units, one will be standby
2037	9,946.57	414.44	6.9	10.4	**20.7**	Use three units, one will be standby
2038	10,195.20	424.80	7.1	10.6	**21.2**	Use three units, one will be standby
2039	10,450.06	435.42	7.3	10.9	**21.8**	Use three units, one will be standby
2040	10,711.27	446.30	7.4	11.2	**22.3**	Use three units, one will be standby
2041	10,979.06	457.46	7.6	11.4	**22.9**	Use three units, one will be standby

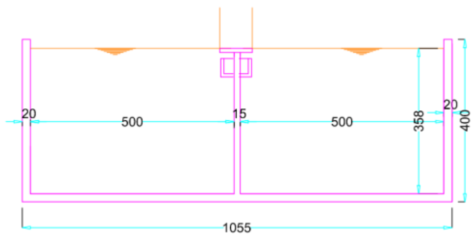
The layout of the treatment plant is show below.

Figure 4-34: Layout of the proposed water treatment plant

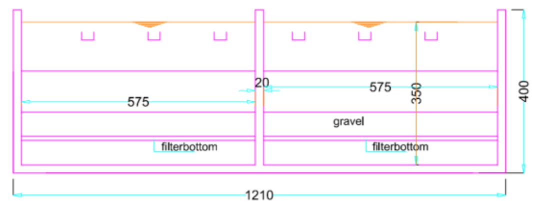




SECTION A-A



SECTION B-B



SECTION C-C

4.4.3 Estimated Cost of Proposed Water Supply Infrastructure

The summary of costs from the Gauff study is shown below in Table 4-31. The total cost for the project is 22 Million €. Out of this, 4,757,000 € are for the dam and 2,250,000 € for the sanitation component. Based on the assumptions from the Gauff study, a total envelop of 16 Million USD is required for implementation of the water supply system.

Table 4-31: Costs assessment for Torit potable water supply

Item No.	Description	Unit	Unit Rate (EUR)	Quantity	Amount (EUR)
A1	**Source Works**				
A1.1	Construction of intake structure incl. pipework	m³	500	130	65,000
A1.2	Construction of concrete weir, wing walls & facing of wall	m³	500	6,500	3,250,000
A1.3	Construction of dam wall (Earth-, rockfill)	m³	50	24,000	1,200,000
A1.4	Construction of access road	km	80,000	4	280,000
A1.5	Guard house	nr	6,000	1	6,000
A1.6	Toilet with septic tank	nr	10,000	1	10,000
A1.9	Fencing of dam site	nr	11,200	1	11,200
A2	**Water Treatment**				
A2.1	Water Treatment Units	m3/day	-	3,000	2,460,000
A2.2	Pump House	m²	1,000	70	70,000
A2.3	Backwash Tank V = 250m³	m³	-	250	206,250
A2.4	Chemical Building incl. dosing equipment	m²	1,500	160	240,000
A2.5	Chlorination Building incl. dosing equipment	m²	1,500	20	30,000
A2.6	Clear Water Reservoir V = 500m³ (RC)	m³	-	500	195,000
A2.7	Administration Building	m²	1,000	50	50,000
A2.8	Sludge Drying Beds	m²	430	75	32,250
A2.9	Backwash Lagoons	m²	430	75	32,250
A2.10	Guard House	nr	6,000	1	6,000
A2.11	Fencing of WTP site incl. gate (150m x 130m)	sum	41,300	1	41,300
A2.12	Generator house	m²	1,330	40	53,200
A2.13	Site ancillary works	sum	10,000	1	10,000
A3	**Electrical & Mechanical Works**				
A3.11	Backwash pump (1D + 1 SB), 9 kW	nr	21,000	1	21,000
A3.12	Airblower (1D + 1 SB), 15 kW	nr	59,500	1	59,500
A3.14	Generator Set incl. cables and controls for backwash (75	nr	47,250	1	47,250
A3.15	Solar System incl. controls and installation for for lighting	kWp	2,625	18	47,250
A3.16	Generator Set incl. cables and controls for lighting (12 kVA)	nr	8,750	1	8,750
A4	**Transmission Mains**				
A4.5	Supply and install OD 355 HDPE pipes incl. fittings	m	170	21,400	3,638,000
A5	**Storage Reservoir**				
A5.1	Storage Tank, Elevated steel tank, V=500 m³, height=23m	nr	378,800	1	378,800
A6	**Distribution Network**				
A6.1	Supply and install OD 63 HDPE pipes incl. fittings	m	25	9,100	227,500
A6.3	Supply and install OD 110 HDPE pipes incl. fittings	m	50	8,400	420,000
A6.4	Supply and install OD 160 HDPE pipes incl. fittings	m	70	10,200	714,000
A6.5	Supply and install OD 225 HDPE pipes incl. fittings	m	110	2,800	308,000
A6.6	Supply and install OD 315 HDPE pipes incl. fittings	m	150	1,800	270,000
A6.6	Supply and install DN 350 steel pipes incl. fittings	m	270	200	54,000
A7	**Kiosks**				
A7.1	Construct water kiosk complete with overhead plastic tank & protection cage, pipe work, fencing & gate	nr	15,000	32	480,000
A8	**Tank Filling Station**				
A8.1	Construct a water tanker filling station	nr	35,000	3	105,000

Item No.	Description	Unit	Unit Rate (EUR)	Quantity	Amount (EUR)
A9	**Office site**				
A9.1	Administration block	m²	900	206	185,400
A9.2	Workshop and store	m²	900	83	74,700
A9.3	Generator house	m²	1,330	10	13,300
A9.4	Pipe shed details	nr	74,700	1	74,700
A9.5	Guard House	nr	6,000	1	6,000
A9.6	Fence (50x33m)	sum	13,720	1	13,720
A9.7	Septic Tank	nr	3,500	2	7,000
				Sub Total	**15,402,320**
B	**SANITATION**				
B1	**Septage Works**				
B1.1	Construct sludge drying beds	nr	465,000	1	465,000
B1.2	Constructed Wetland	sum	45,000	1	45,000
B2	**Schools Sanitation**				
B2.1	Construct pour flush toilets for boys (5 No stances)	nr	25,400	21	533,400
B2.2	Construct pour flush toilets for girls (5 No stances)	nr	25,200	17	428,400
B3	**Public Facilities**				
B3.1	Construct public toilets (hospital) (7 No stances)	nr	46,500	2	93,000
B3.2	Construct ablution blocks	nr	171,400	4	685,600
					2,250,400
				Sub Total	**17,652,720**
	Allow 10% for preliminary & general items				1,765,272
	Allow 10% for physical contingencies				1,765,272
	Allow 5% for price variation				882,636
				TOTAL	**22,065,900**

4.5 FISHERIES

4.5.1 Description of the activity

Fishery activities are widespread in South Sudan. According to the IOM survey, this activity is practised in Torit County, in the following bomas:

- Owodo and Autak Bomas in Bur Payam
- Hilleu in Homodonge Payam (close to the proposed reservoir)

Fishery is an essential activity in South Sudan and accounts for a significant proportion of protein inputs in the diet of people. As such, the development of this activity will contribute to the economic development of the area but also to the improvement of food safety. According to the “Fishery and Aquaculture Country Profile” released by the FAO and available on their website, the per capita consumption of fish in South Sudan is 17.40 kg/year (about half dried and half fresh).

The main species found in South Sudan are given in the Comprehensive Agricultural Management Plan (RSS, 2015). There are listed in Table 4-32 below.

Table 4-32: Fish species found in South Sudan

Common name	**Local (Arabic) name**	***Scientific name***
Nile Tilapia	Bulti	*Oreochromis niloticus*
Nile Perch	Dabs	*Lates niloticus*
Heterotis	Nok	*Heterotis niloticus*
Gymnarchus	Wir	*Gymnarchus niloticus*
African Catfish	Garmut	*Clarias* spp.
African Catfish	Surta	*Heterobranchus bidorsalis*
Alestes	Kawara	*Alestes* spp.
Hyperopsis	Sauya	*Hyperopsis bebe*
Elephant Snout Fish	Khashm el binat	*Mormyrus caschive*
Elephant Snout Fish	Khashm el binat	*Mormyrus hesselquisti*
Bagrus Catfish	Kabarus	*Bagrus dogmac*
Synodontus	Galabaya	*Synodontis membanaceus*
Chrysichthys	Abu rial	*Chrysichthys auratus*
Mormyroops	Tazara	*Mormyrops anguilloides*
Petrocephalus	Ras al hagar	*Petrocephalus* spp.
Tigerfish	Kas	*Hydrocyon brevis*
Distichodus	Kraish	*Distichodus* spp.
Moonfish	Batkoiya	*Citharinus citharus*
Silver Catfish	Shilbaya	*Eutropius niloticus*
Nile Carp	Dabs	*Labeo niloticus*
Barbel	Binni	*Barbus bynni*
Lungfish	Samak el tin	*Propterus* spp.

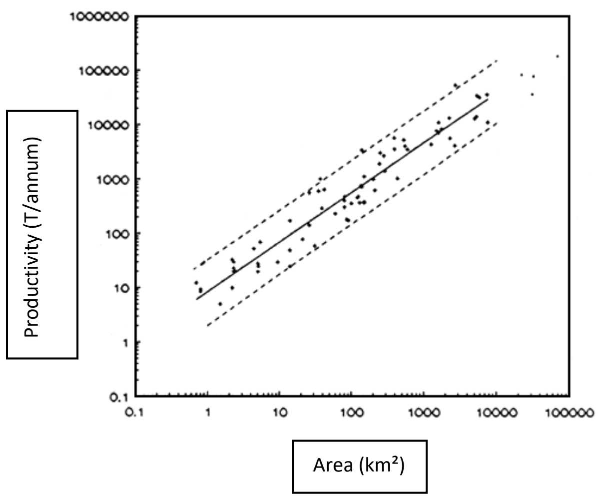
4.5.2 Development of the activity in the reservoir

BENEFITS FROM THE DEVELOPMENT OF THE ACTIVITY

The most important factor for the development of fisheries in lakes/reservoirs is the surface area of water. In order to assess the productivity of the Kinyeti reservoir the mean area of the reservoir is considered. This area is 232 ha.

There are different relationships to estimate the fish productivity according to the surface of water. One relationship was established by Crull in 1992 is given in Figure 4-35 for information.

Figure 4-35: Relationship between the area of water and the fishery productivity



Source FAO, 1992

In order to assess the productivity of the reservoir, an average productivity of 150 kg of fish per hectare is chosen. For an area of 232 ha, it gives a productivity of 34.8 T of fish per year. As mentioned above, the average per capita fish consumption in South Sudan is 17.4 kg of fish per year. It means that the reservoir will provide fish for around 2,000 people.

According to a study realized for Lake Victoria, the captures per fisherman per year are estimated to be around two Tones a year so the Kinyeti reservoir would provide employment to around 17 people full time. Finally, in the same study, the gross margin was estimated to be around 276 USD/T so the gross margin of the fishery activity in the Kinyeti reservoir would be around 9,600 USD.

ASSOCIATED COSTS

Fishing gear

100 metres long gill net may cost up to US$150. The fishermen could be trained in making gill nets, provided that they can easily get the ropes from the market.

Boats

Locally constructed boats could be used to operate in the reservoir. A locally constructed boat in South Sudan may cost up to US$300.

4.5.3 Institutional framework

The fishermen need to be organized and licensed in cooperatives to provide needed inputs and also regulate the productions.

4.6 IRRIGATION

4.6.1 Introduction

The Kinyeti Irrigation and Drainage Project (KIDP) is included in the Kinyeti river multipurpose development project. The KIDP involves the development of 1,000 ha of land in Torit County, Eastern Equatoria State. The project area will be irrigated from the Kinyeti river, the flow will be regulated by the upstream dam.

This section presents a summary of the implementation modalities, current farming practices of the proposed project area, and estimate cost summary for the proposed scheme. Details of the technical viability including outline design based on the identified resources are presented in Annex 2.

4.6.2 Selection of command area location and option for water abstraction method

REVIEW OF EXISTING STUDIES

In order to select the command area location and option for water abstraction, a comprehensive review of previous studies on already identified potential irrigation sites was carried out. These studies include:

- Report on Reconnaissance and Scoping Mission in Eastern Equatorial State (John K. etal, 2012)
- Feasibility Assessment for Sustainable Irrigated Crop Production in the Kinyeti River Catchment (Roelof T etal, 2015)

The main findings are the following:

- The report on Reconnaissance and Scoping Mission in Eastern Equatorial State (John K. etal, 2012) outlines the general framework for Integrated Water Resources Management in the Kinyeti River sub basin. There is a focus on the development of Watershed Management actions and appropriate institutional mechanisms. The report also underlines the need for promoting small scale irrigation along the Kinyeti River but, does not specifically identify suitable irrigation sites.
- The Feasibility Assessment for Sustainable Irrigated Crop Production in the Kinyeti River Catchment (Roelof T etal, 2015) provides information for the planning of infrastructure for productive water use in agriculture, livestock, and WASH. In addition, the study identifies three pilot areas for implementation of small scale irrigation along the Kinyeti River. The suitability of these sites with regard to the current study objective was assessed and the findings are summarized as follows:
  - **Katrire irrigation site**: This is a micro level gravity system intended to irrigate 3 ha of land, which was proposed on a tributary of Kinyeti River upstream of the proposed dam site. The site is out of option as it is not going to use the regulated flow from the dam.
  - **Imilai Irrigation site**: small scale irrigation along the Kinyeti River at a distance of about 1.6 km downstream of the proposed Kinyeti dam. The site has no adequate command area for the scale of scheme under consideration (1,000 ha). Both sides of the river at this location are occupied by villages, smallholder's peasant agriculture and scattered trees and bushes that require major bush clearing. Instead, the area is more suitable for small scale irrigation using small pumps.

- **Lohila Irrigation** site: The site is only 0.8 km west of Torit town and found to be not viable for the scale of irrigation under consideration due to the following factors:
  - Selected location for diversion headwork is very close to the Torit town (only 0.8 km) and the nearby command areas can be used for future expansion of the town. Moreover, rain-fed agriculture and settlements are practiced on the left side of the river bank that will be most likely affected by the development of 1,000 ha. of land
  - The site requires longer approach canal for pumping station.
  - Much of the area to the south of the selected diversion heed work site requires major land leveling for surface irrigation

Based on the above, all the three sites identified by the previous study were found to be non-viable. Therefore topographic maps with 1 m and 5 m contour intervals from DTM-DEM derived from ALOS PRSIM stereoscopic high resolution satellite images (refer to Annex 3) were used to assess the river course and the topography of the adjacent land and identify a suitable command area and water abstraction method (pump/ Gravity diversion).

SELECTION OF THE COMMAND AREA BASED ON SATELLITE IMAGES ANALYSIS

The opportunity to develop irrigation between the dam and the city of Torit was studied. However, this area was found not suitable for the scale of irrigation scheme under consideration (1,000 ha): both sides of the river are partly occupied by villages and peasant agriculture. The remaining areas, particularly the upper 11 km from the dam is covered with scattered trees and bushes that would require major clearing. Therefore, there is no adequate compact command area and the area rather seems more suitable for micro/small scale irrigation (< 100 ha).

The land slope towards the Kinyeti River varies from a maximum of 10% near the proposed dam site to a minimum of 0.4% near Torit town which indicate more suitable topography for surface irrigation and lower pumping head for water lifting for irrigation as you move down towards the Torit town. Moreover, the site has no settlements and therefore an area 10 km North West of Torit town that lies along the left sides of the Kinyeti River has been selected for the envisaged irrigation scheme due to the following factors:

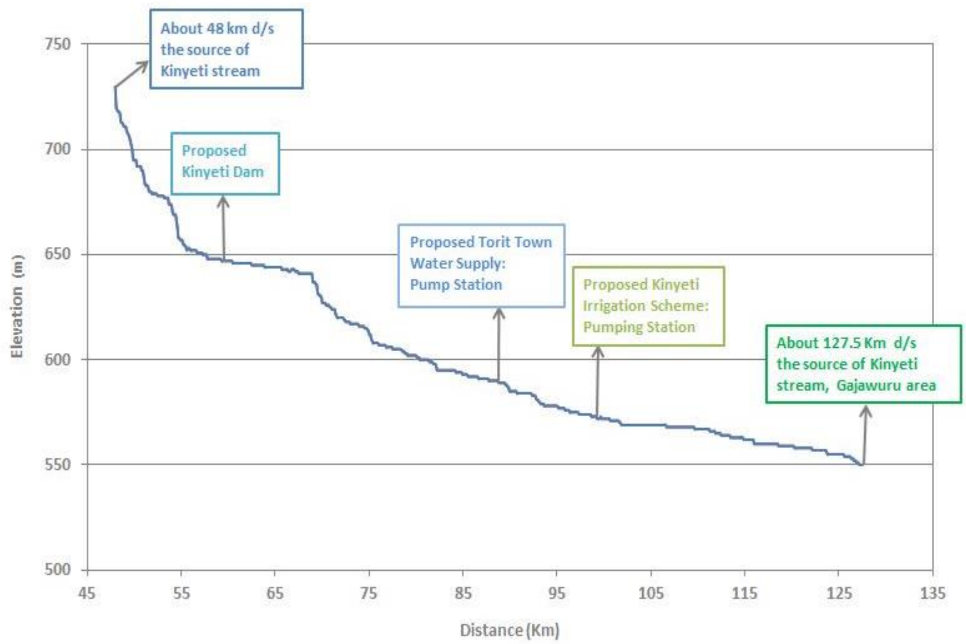
- Suitable topography which is characterized by the flat to moderate slopes in the range of 0.3-4% over large portions of the area.
- The site has no settlements and farming
- Easily accessible
- Requires minor land leveling for surface irrigation

METHOD OF WATER ABSTRACTION

The River is characterized by low banks, very wide section and very low gradient that makes it inappropriate for the siting of gravity diversion head works. The Longitudinal profile of Kinyeti River (refer to Figure 4-36) that was generated from DTM-DEM derived from ALOS PRSIM stereoscopic high resolution satellite images (see Annex 3 for detail) shows that the change in elevation between the dam site (650 masl) and proposed pumping station (572 masl) along the river course is only 78 m over a distance of about 40 km (river bed slope of only 0.2%) and therefore the idle length of the canal would be excessively large to command sufficient land areas in the case of gravity diversion. Furthermore, gravity diversion structure across the Kinyeti River needs to be very high and long to raise the water level on the upstream side to create the necessary head to divert the flow by gravity through the canal intake (head regulator) which implies high cost of construction.

Therefore, for the Kinyeti Irrigation Project, water lifting by pump is preferred over gravity diversion headworks due to low river bank and low river bed gradient to avoid large idle length of 30-35 km main canal and construction of massive costly diversion structure across the river with high embankments along upstream bank to protect the structures from high floods.

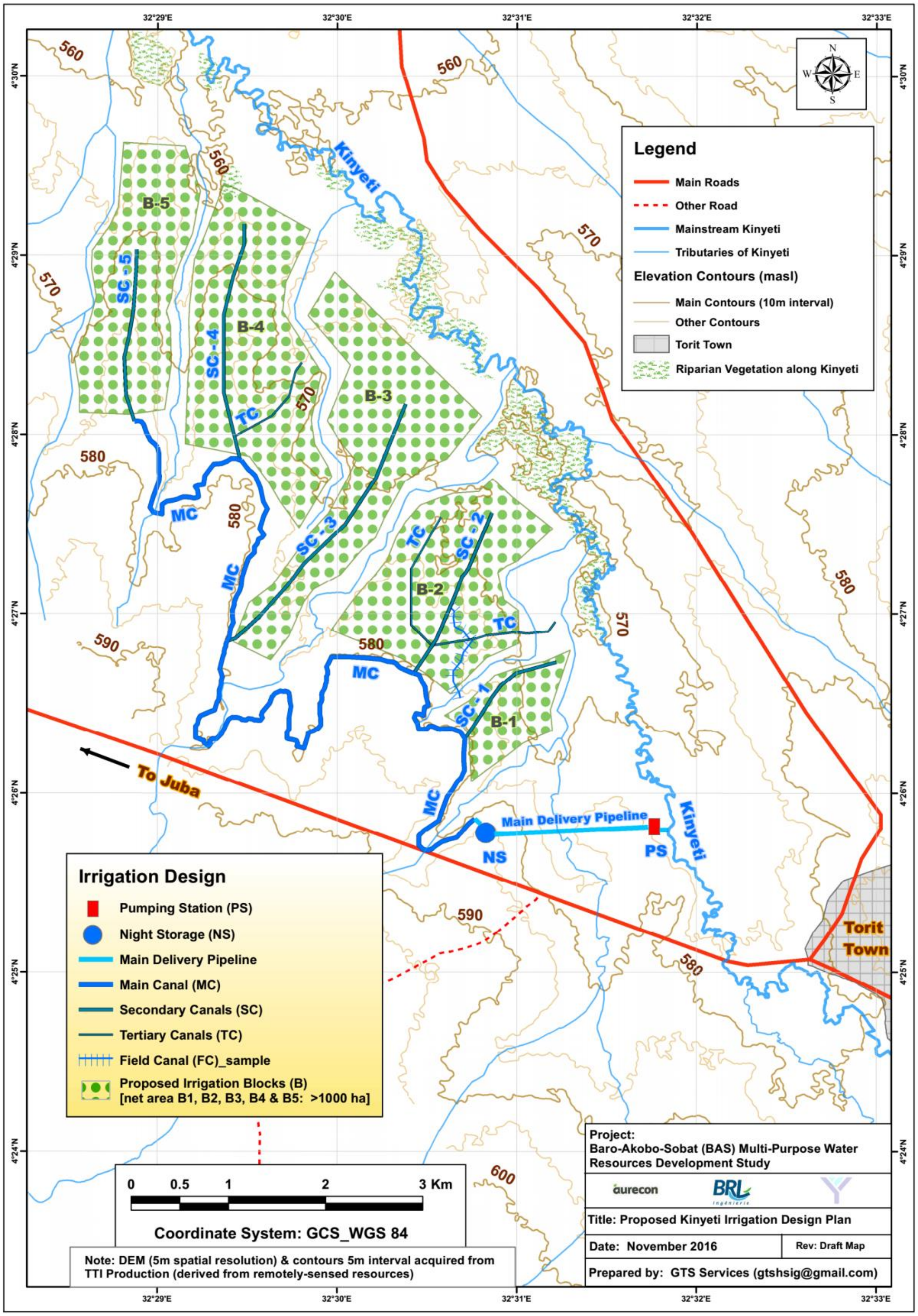
Figure 4-36: Longitudinal profile of the Kinyeti river



Source of Elevation Data: DTM - DEM derived from ALOS PRSIM stereoscopic high resolution satellite images)

The main irrigation components planned in the Kinyeti Irrigation and Drainage Project (KIDP) are shown on Figure 4-37.

Figure 4-37: Kinyeti irrigation design plan



4.6.3 Implementation modalities

The MEDIWR will take primary responsibility to develop the KIDP, including Detail Engineering design, implementation, and establishment of the Operation and maintenance crew for main structures, and monitoring and evaluation of the project.

As for the institutional aspects, the WASH Strategic Framework clearly states the joint responsibility of MEDIWR and MAFCRD in relation to irrigation development and management. But, this demarcation has not been well established on the ground; and the delineation of roles and responsibilities between the Central and State Governments is still unclear as well. Although it is the responsibility of the two institutions at national level, the scheme cannot be managed from Juba and requires establishment of Operation and Maintenance crew on site. The MEDIWR can take a leading role to establish the crew with relevant stakeholders, especially MAFCRD and Eastern Equatorial State Government.

The scheme is at feasibility study level and requires detail design for implementation. The responsibility for the detailed design work and implementation of the schemes lies with MEDWR. However, there is a capacity limitation and therefore technical assistance in the form of consultancy service required to support the efforts of MEDIWR in the detail engineering design of the irrigation schemes. A cost provision for such service is built in the unit investment cost of the schemes. Moreover, based on the existing modalities, scheme implementation shall be outsourced to private contractor**.**

At grassroots level, the user community, organized into Water Users Association (WUA), mobilizes their members to participate in the operation and maintenance of on-farm operation and minor maintenance. Upon completion of implementation, the system as whole will be handed over to the Operation and Maintenance (O&M) crew established at scheme level. On-farm facilities can be delegated to scheme users to ensure day–to–day on–farm, O&M of the scheme with direct supervision and technical assistance of the O&M crew.

4.6.4 Project Rationale

The main rainy season in the area is from mid-May to October. The area receives mean annual rainfall of about 1,025 mm. It has a single peak with a maximum value of 169 mm in July and average rainfall less than 100 mm that occurs during November to April. The average maximum temperature is about 34^{O} C and Mean minimum temperature is about 19^{O}C. Estimated Potential Evapo-transpiration (PET) is about 1,769.4 mm per year with mean maximum monthly PET of 181.6 mm in the month of January and mean monthly PET of 147.45 mm.

Nearly 75% of rainfalls occur during May to October and 25% between November and April. On average November, December, January, February, March, and April are the driest months. During these months, available soil moisture does not meet plant water requirement and irrigation is a prerequisite for crop production.

Currently, In South Sudan, irrigated agriculture is practiced on less than 5% of the cultivated land. The natural conditions of South Sudan are characterised by a diverse range of geographical regions, with annual rainfall ranging from less than 500 mm in the far North and far South-east to up to 1,500 mm in the South-west. Fluctuation in annual production is significant due to the unstable climate that causes large inter-annual and annual fluctuations of precipitation, leading to either dry spells or droughts. Flood and drought occur occasionally, threatening national food security. For instance, cereal production in 2012 was only 67% of the national requirement (IDMP, 2015).

According to situation analysis report CAMP, (2015), the gross cereal yield has stagnated at a low level since 2009, approximately from 1 T/ha to less than 0.8 T/ha due to rain fed farming and low level of cereal area harvested per capital. The report also identified these two aspects as key issues and challenge for low agricultural production.

Under such condition, irrigation development is vital, in order to stabilize the availability of water for crop production and improve rural income through increased agricultural production and productivity to enhance food security and resilience; and contribute to meeting the other national needs and goals.

4.6.5 Current farming practices and proposed cropping pattern

CURRENT FARMING PRACTICES

Major livelihood practices are crop farming and livestock rearing. The most prevalent form of land use in the area is small scale subsistence agriculture. Food crops grown in the area include maize, sorghum, sesame, groundnut, vegetables, millet and cassava. According to the IOM (2013) drought, and crop disease are major livelihood shocks in the project area.

Fluctuation in annual production is significant due to the unstable climate that causes large inter-annual and annual fluctuations of precipitation, leading to either dry spells or droughts and there is a limited scope to expand rain-fed cultivation. But there is an obvious opportunity to improve the productivity of the existing rain-fed systems through irrigation (John K etal, 2012). As the data for this particular project area was not available, average yield per unit area from the project surrounding areas, Jebel and Rajaf East in Table 4-33 below is used which shows low agricultural production.

Table 4-33: Average crop yield and net income for project surrounding areas (Jebel & Rajaf East)

No	Crop	t/ha	SSP/ha
1	Maize	0.70	2,523.00
2	Sorghum	1.05	3,761.00
3	Cassava	1.60	8,439.50
4	Common beans	0.60	2,930.50
5	ground nut	1.75	4,242.50
6	Sesame	0.40	1,896.00
7	Okra	1.95	11,942.50
8	Tomato	3.00	13,334.00
9	Egg Plant	1.80	
10	Jew's Mallow	3.60	15,964.00
11	Onion	2.90	5,800.00
12	Amaranthus	3.20	7,732.50
13	Cowper	0.65	2,341.00
14	Green pepper	0.80	10,029.00

Source - (IDMP, 2015)

PROPOSED CROPPING PATTERN RELATED TO CURRENT PRACTICES

Based on the above information, a possible cropping patterns is proposed with 185% annual cropping intensity in two growing seasons. The proposed crops are based on the capacity and experience of people to cultivate these crops. It includes the following: maize, sorghum, beans, groundnut, vegetables, bananas and millet. More information on the cropping pattern is included in Annex 2.

4.6.6 Operation and Maintenance

The irrigation method planned for the project area is pump irrigation that requires experienced senior pump expert to maintain its operational function properly. Under the senior pump expert, several support specialists and service technician are also needed/necessary for annual planning and monitoring of pump operation as well as safeguarding of supplies and the facilities. Therefore, establishing a crew consists of the professionals who can properly operate and manage the facilities. The crew shall be established prior to the commencement of scheme construction and it is also important to clearly layout the roles and responsibilities of the crew and demarcation with that of the WUA.

Irrigation and Drainage Directorate of MEDIWR will take an initiative in collaboration with relevant stakeholders, especially MAFCRD and Eastern Equatoria state government, in organizing self-sufficient operation and maintenance crew, which will be stationed on site.

4.6.6.1 Operation

Scheme operation is one of the most important tasks of the crew to be established for scheme operation and maintenance along with WUA to deliver irrigation water to the users. This includes timing, flow rate and duration of irrigation application based on the planned method for irrigation water distribution and irrigation planning and scheduling. The aim is to deliver the right amount of water to the farmers at the right time to realize the benefit from the irrigation scheme.

WATER DISTRIBUTION METHODS

Water used for the scheme will be abstracted from the regulated flow released from the dam. Water is then lifted by pump and carried to the night storage at high ground in the command area from where it will flow by gravity through open canals to irrigation plots. A proper water distribution network, best suited to topography, is prepared to achieve optimum land and water use. This network preparation took into account the operation system, which will involve equitable distribution of water to all fields within a fixed time to meet the crop water requirement with least human intervention. Map drawn to a convenient scale showing detailed network system will be provided to the irrigation technicians and WUA; who are accountable for operation and maintenance. On this layout map, all the specific features will be indicated. Operation and maintenance manual, which describes concise instruction for operation of the scheme, shall be prepared and provided to the Irrigation Technicians and WUA during detail engineering design phase of the scheme for the day - to- day operation as well as for long-term activities.

SEASONAL IRRIGATION PLANNING

Irrigation planning involves making decisions on the cropping pattern and calendar for the coming irrigation season and making decisions on what types of crop to grow. The aim of irrigation planning is to describe the allocation and distribution of the available water supply to various interested groups. In the project area, there is no shortage of water, the flow is regulated and assumed to be sufficient for the planned 1,000 ha of land on continues daily supply based on 24hr water pumping to the night storage and 12 hours irrigation periods.

IRRIGATION SCHEDULING

Irrigation scheduling is a prerequisite for timely supply of irrigation water and mandatory to obtain optimum yield. Both over and under irrigation will result in reduction of crop yield. Excess water on the other hand causes water logging. Therefore, it is necessary to assess the actual weekly crop water requirement in advance, considering the moisture depletion and sustained crop-growth and prepare a schedule of irrigation, for frequency of watering and quantum of water needed. This will depend upon rainfall, crop development stage, soils, fertilizer, and climatic condition and crop factors. The schedule shall be communicated to all farmers so that they are ready to utilize the water efficiently. The schedule should match the water potential available. Generally, this is done at an interval of one week or multiple of weeks, to maintain the rotation water system.

4.6.6.2 Maintenance

Maintenance of these facilities can be done either by maintenance crew established for the purpose or by the user's community, depending on the type and scale of the maintenance work to be carried out. Maintenance on the electromechanical facilities, night storage, main canal and secondary canals will be fully done by the skilled technicians from the maintenance crew. Minor maintenance for on-farm irrigation facilities can be done by the user's community themselves or otherwise by skilled artisans, such as a mason or a carpenter. The user community could be organized in groups, which will be given training in undertaking such maintenance works.

Senior social worker from maintenance crew together with WUA committee members will then lay down rules and regulations for the utilization of the on-farm irrigation facilities to ensure order and proper utilization of the facilities. Under these committees, groups of users will be organized who will be oriented in the basic on -farm maintenance activities. These farmer groups will be responsible for the implementation of the regulations and maintenance of order during utilization of the facilities. Details of on-farm and conveyance system maintenance modality will be worked out during scheme design phase.

4.6.6.3 Monitoring and evaluation

Planning and Programmes Directorate of MEDIWR takes primary responsibility to develop monitoring and evaluation plan. The plan will be prepared with active participation of all stakeholders from all levels of the government to provide a continuous tracking and feedback mechanism to all stakeholders in the process. The monitoring and evaluation plan to be developed by the directorate includes both monitoring and evaluation of the progress on the implementation of the plans and outcomes and impact of the plan.

4.6.7 Cost Estimate

At current prices, the scheme would cost an estimated USD 15,260,000. This includes a provision of 15 percent of total baseline costs for physical and price contingencies, 10 percent of the baseline costs for detail engineering design of the scheme including construction supervision and other administrative costs. The cost estimate also includes costs for construction of access road to the pumping station as well as farm road along the main and secondary canals, which accounts for 11% of the direct construction cost and 6% overall total cost estimate.

Unit rate estimates for the items were derived from "RSS, MEDIWR, Irrigation Development Master Plan (IDMP.2015)" document prepared for a similar project with price adjustment at current USD inflation rate and suppliers' quotations. Summary of the costs is presented in Table 2 below, whereas The bill of quantities and rate for each item for the investment in the irrigation project are given in Table 11 Annex 2.

Table 4-34: Kinyeti Irrigation & Drainage Project Cost Summary

No	Item	Total Amount	
		(USD)	%
1	General Provision	20,000.00	0.13%
2	Pump station and pipeline work	4,735,706.36	31%
3	Night storage	821,910.40	5%
4	Irrigation & Drainage Canals	1,528,326.02	10%
5	Farm road	840,000.00	6%
6	Total Direct Cost	7,945,942.77	52%
7	Taxi (15%)	1,191,891.42	8%
8	Overhead cost (40%)	3,178,377.11	21%
9	Detail Design and construction supervision (10%)	1,112,431.99	7%
10	Physical and price contingency (15%)	1,835,512.78	12%
11	**G. Total**	**15,264,156.07**	100%
	Net Command area = 1000 ha	15,264 USD/ha	

4.7 AQUACULTURE

The development of irrigation could be combined with the development of aquaculture and small ponds along the coast (settlement area) could be constructed and managed by individuals or cooperatives depending on the available lots of land and their ownership.

4.7.1 Implementation modalities

DESIGN OF THE PONDS

The size of each pond could be about 200 m² (a rectangular pond with length of 20 m and width of 10 m and a depth of 1.5 m). Such types of small ponds could easily be managed by the farmers and any possible epidemic on the fishes could easily be contained within that pond. The dikes on all sides of the ponds could be strengthened by plants/fruit trees on the embankments.

FERTILIZATION OF THE PONDS

The ponds could be integrated with vegetable/fruit growing plots in which the waste from the fish could be used as fertilizers for the farm plots. The ponds will be earthen ponds being fertilized with agricultural by products (such as wheat or barley or rice or cereal bran or any other by products). Fruit and vegetable residues could also be used as supplementary feed. Cattle dung (100 g/m²) or chicken manure (50 g/m²) need to be applied once every 2 weeks as fertilizers.

4.7.2 Production potential and sizing

Aquaculture yields vary according to the technology used. Thus, intensive tilapia farming attains yields that exceed 10 tonnes/ha; semi-intensive 3 to 5 tonnes/ha; and extensive farming in reservoirs produce less than 1.5 tonnes/ha. Since the ponds are earthen ponds, and the fishermen can use some supplementary feed, we can consider a semi intensive production of about 3 to 5 tonnes/ha/year. This is about 60-100 kg per 200 m² pond/year.

There could be separate ponds for hatchery purposes, where parent stock could be kept and the fingerlings would be introduced into the nursery ponds.

Smaller ponds, usually with a size of about 100 m² and with a depth of 70-80 cm are most common for keeping the brood stock and serving as nursery pond to keep the hatched ones for sometimes. Two to three thousand 2-cm fry can be stocked in a 100 m² pond, for culture up to fingerling size (5 cm). The grow-out ponds can be stocked with a density of 2 fingerlings/m².

Water is regulated by the dam and will not be a constraint to develop aquaculture downstream of Torit. As explained above, fish farming will be associated to the development of irrigation. It is proposed to develop 100 ponds in a 5 years period (20 ponds every year).

4.7.3 Costs and benefits

CONSTRUCTION COSTS OF A 200 M² POND WITH A DEPTH OF 1.5 M

The major cost is labour cost for excavation works, which could be on the average (in that locality) about US$50 for about 10 m² area with a depth of 1.5 m. So, construction of a 200 m² pond may cost up to US$1000. Some pipes and piping works may be required for inlets and outlets of the water from the ponds.

The anticipated cost to build 100 ponds is 100,000 USD.

TRAINING

A one-week training is required on how to manage the ponds and the fishes regularly; use of fishing gears; preparing supplementary feeds; etc. The training expenses could be estimated from the number of potential trainees and can be integrated in the enhancement measures proposed in the ESIA.

FISHING GEAR

They need beach seine nets to collect the fishes from the ponds and some other facilities such as collecting plastic jars; cold storage facility, etc. A 30- meters long beach-seine net may cost up to US$100.

BENEFITS

It may be difficult to find appropriate market in and around the project area. A kg of fish (Nile tilapia) may be sold in the towns nearby the project area (e.g. Torit) for US$2. Thus the yield that could be obtained from a 200 m² pond (80 kg on average) could be sold for US$160, it represents US$16,000 per year for 100 ponds.

4.8 LIVESTOCK WATERING

Water regulation by the dam will ensure a minimum flow in the river even during the dry season. This will secure access to water for the livestock. As such, there are no costs associated to this component of the multipurpose project and no particular infrastructure to build.

The expected benefits are related to the health of the livestock. This will be have positive impacts on the weight of the animals and on the production of milk.

ASSESSMENT OF THE NUMBER OF LIVESTOCK THAT WILL BENEFICIATE FROM THE PROJECT

A buffer zone was drawn around the river (buffer zone of 15 km on each side of the river, for a total area of 1,000 km²). The number of livestock that will benefit from the project is given in the table hereafter.

Table 4-35: Assessment of the number of livestock positively impacted by the project

	Density in Eastern Equatoria (CAMP, 2015)	Number of heads in 2015 in the buffer zone	Number of heads in 2041 (increased by 50%)
Cattle	33.7/km²	33,700	50,550
Sheep	32.3/km²	32,300	48,450
Goats	70/km²	70,000	105,000

Source: CAMP, 2015

ASSESSMENT OF THE BENEFITS RELATED TO LIVESTOCK WATERING

The assessment of the benefits related to livestock watering is given in Table 4-36. The following assumptions were made:

- Average weight gained with the project:
  - Cattle: 150 kg/head
  - Sheep: 10 kg/head
  - Goats: 10 kg/head
- Selling cost of meat: 1 USD/kg for the cattle and 2 USD/kg for sheep and goats
- Percentage of the livestock sold every year: 5%

Table 4-36: Benefits of the multipurpose project on the livestock sector

	Cattle	**Sheep**	**Goats**
Additional benefit associated with the sale of meat in 2016	101,100	12,920	28,000
Additional benefit associated with the sale of meat in 2041	151,650	19,380	42,000
Average increase in the production of milk (L/head)	1	-	-
Price of milk (USD/L)	0,25	-	-
Additional benefit associated with the sale of milk in 2016	2,106	-	-
Additional benefit associated with the sale of milk in 2041	3,159	-	-
Total benefit 2016	**144,126**		
Total benefit 2041	**216,189**		

DEVELOPMENT OF RANGELAND

Livestock watering is not the only issue related to livestock in that area and rangeland development should be investigated.

4.9 WATERSHED MANAGEMENT

There is an ongoing livelihood based watershed management programme located in the Imatong mountains (the upper part of the Kinyeti catchment). This project "Improving South Sudan's livelihood and ecosystems management through watershed management" is being implemented by the AWF. The programme is a five years programme which aims at ensuring that the catchment area of the Upper Imatong mountains is well managed to ensure the sustainable access to water to the communities and ecosystems downstream. Activities being implemented are twofold:

- Training and equipping of forest guards and game rangers
- Interventions to enhance and provide communities livelihood alternatives

Livelihood based watershed management activities should be proposed in compliance with AWF activities once the implementation of the Kinyeti project starts.

4.9.1 Major causes of forest and soil degradation

The Wildlife Conservation Society (WCS) (2012) report that "Lack of livelihood options for internally displaced people (IDP) and returning refugees has resulted in an overdependence on natural resources as a source of income, causing a rapid spread of unsustainable trade in bushmeat across the region" and that "the illegal logging of indigenous species, especially mahogany (*Khaya senegalensesis* and *K. grandifolia*), is increasing » but the regional impact of this illegal activity is not well documented.

Figure 4-38: deforestation in the Upper Kinyeti for construction (on the left) and traditional charcoal (on the right)

Source: AWF

4.9.2 Proposed Livelihood Based Watershed Management Interventions

In the upper-watershed, it has been observed that large areas (even sloping areas with an apparent watershed protection function) are cleared for agriculture through slash and burn. This practice perturbs the hydrological and soil retention capacity and therewith the water cycle and soil fertility in the medium to long term.

There is an obvious opportunity to regulate the land use and, most importantly, raising the awareness of the local population on the application of environmentally sustainable land and water management practices. It is considered to introduce:

- Agro-forestry practices with slope protection (e.g. by planting elephants grass on bunds);
- Establish private nurseries for the plantation of multiple tree species for fruit, fodder (e.g. leguminous for nitrogen fixation) and firewood.
- Intercropped tree species with staple crops like maize, cassava, sorghum and beans, while optimizing the root competition for nutrients and water.

4.9.3 Project Costs

The project costs are divided into running cost including inputs/materials as well as survey equipment. These costs are featured in the table below.

Table 4-37: Costs associated with livelihood based watershed management activities

No	Cost Item	Unit	Quantity	Required labour (person-day)	Unit Price (USD/Person-day)	Total (USD)
1	**Forestry and grass development activities**					
	- Tree Seedlings production	No	300,000	4,500	2	9,000
	- Agroforestry seedlings production	No	50,000	750	2	1,500
	- Pitting	No	350,000	23,000	2	46,000
	- Planting seedlings	No	350,000	7,000	2	14,000
	- Grass seed collection	Kg	1000	100	2	200
Sub-total						**70,700**
2	**Fruit seedlings production**					
	- Mango	No	8000		2	16,000
	- Avocado	No	7000		2	14,000
	- Citrus	No	3900		2.5	9,750
	- Guava	No	1000		1.5	1,500
	- Banana	No	100		2	200
Sub-total						**41,450**
3	**Hand tools and surveying materials**					
	- Pick axe	No	1000		25	25,000
	- Spade hoe	No	500		25	12,500
	- Spade /shovel	No	500		30	15,000
	- Fork hoe	No	300		30	9,000
	- Rake	No	100		35	3,500
	- Wheel barrow	No	50		100	5,000
	- Watering can	No	150		35	5,250
	- Polythene bags for fruit seedlings	Roll	100		60	6,000
	- Polythene bags for tree seedlings	Roll	400		50	20,000
Sub-total						**101,250**
Total						**213,400**
1	**Surveying Materials**					
	- Line level	No	100		100	10,000
	- Nylon string	Roll	10		40	400
	- Poles	No	200		10	2,000
	- Compass	No	10		50	500
	- Clinometer	No	10		80	800
Sub-total						**13,700**
Grand Total						**227,100**

5. POTENTIAL ENVIRONMENTAL AND SOCIAL IMPACTS

5.1 INTRODUCTION

The objectives of identifying potential environmental and social issues are to:

- Describe the baseline (current state) of the environment and socioeconomics,
- Describe what will change with the Project from the current state (positive and negative impacts),
- Propose enhancement and mitigation measures.

The baseline situation is presented in section 2 of the report. The description of anticipated changes, enhancement and mitigation measures is included in Table 5-1.

5.2 SOURCE OF INFORMATION

The approach and methodology used for acquisition of relevant data and information, prediction and evaluation of potential environmental and social impacts and development of mitigation and management plan for the Kinyeti multipurpose project include the following:

- Review of relevant environmental policies, strategies, legislations and guidelines;
- Review of relevant previous studies in the region and relevant literature;
- Review of ESIA studies of similar projects in the region or similar environment;
- Secondary data collection from National, Payam and county levels
- Field investigation at the proposed reservoir and dam site and collection of site specific baseline data and identification of potential issues;
- Conducting consultations with key stakeholders at Juba and Torit;
- Conducting impact analysis (identification, prediction and evaluation) using methods used in good ESIA practices;
- Developing feasible and cost-effective mitigation plan as well as environmental management and monitoring plan.

5.3 IMPACTS OF THE PROPOSED KINYETI MULTIPURPOSE PROJECT

The expected positive and negative impacts of the project are summarized by sector in Table 5-1.

Table 5-1: Summary of Environmental and Social impacts and proposed mitigation and enhancement measures

Impact Description	Proposed Mitigation & Enhancement Measures	Responsible Agency/ Organization	Cost in USD
HYDROPOWER COMPONENT			
Positive Impacts and Enhancement Measures			
Improved access to electricity, as a substitute to unsustainable use of oil fuel, fire wood and charcoal	- Subsidize or reduce service charge of electricity below the cost of fire wood will enhance the positive impacts anticipated on the forest and biodiversity; - Introducing energy saving lamps and electric stoves for cooking would also enhance the benefit to be obtained from the power generation.	Directorate of Electric and Dam	*N/A*
Decreased CO_2 emissions	- Raise awareness of the beneficiaries about CO_2 emissions and its adverse impacts on global warming and promote the use of clean energy (hydro-electric power) instead of gas, fire wood or charcoal.	East Equatoria State Environmental Directorate	5,000 USD (for awareness raising workshop / meetings)
Increased job diversity and Job opportunities	- Provide short term training courses for unemployed youth on metal works, barberries, bakery or other work types which depend on the use of electricity; and avail micro finance institutions and facilitate credit for those interested; - Give priority to local people for the job opportunities.	County administration office in collaboration with environmental directorate	50,000 USD (for on job training)
Beekeeping fostered	- Demonstrate modern beehives; - Create access to market for honey and its byproducts.	County administration office in collaboration with environmental directorate and NGOs	4,000 USD (for demonstration of modern beehives)
Access to improved social services (health care, education, etc.)	- Raise awareness to local people about the health-related benefits of using electricity instead of fire wood or charcoal; - Provide training on health impacts of charcoal and its toxicity; - Create awareness on how vegetation (plants and trees) are crucial to the forest ecosystem and local biodiversity.	Local Health office in collaboration with Eastern Equatoria State Environmental Directorate	*N/A*
Improved supply of energy and socio-economic development	- Creation of opportunities to support socio-economic development and modernize local economy through the provision of affordable and reliable energy; - Employment and skills development associated with the construction of dam and associated infrastructure; - Act as catalyst for infrastructure development; - Improve local key services, such as health care, schools, government services, through the provision of affordable and reliable energy; - Potential to improve policing and management of environmental resources in the vicinity of the dam due to increased presence of people associated with the project. - Creation of an amenity linked to the dam. Also, potential benefits for tourism.	Local energy office and local administration	*N/A*

Impact Description	Proposed Mitigation & Enhancement Measures	Responsible Agency/ Organization	Cost in USD
	- The benefits to beekeeping are questioned. - Employment and skills development associated with the construction of scheme and associated infrastructure;		
Negative Impacts of the Proposed Hydropower Component			
Resettlement of local communities	- Proper design of the dam and minimization of the size of the dam; - Relocate the people from the reservoir site, - Provide compensations to local people whose livelihood and houses are located on the dam and reservoir site; - Provide livelihood support for the project affected people.	Directorate of Electric and Dam/Owner of the project in cooperation with local Administration	*To be determined in RAP*
Degraded air quality and increased ambient noise level during construction Phase	- Limit the speed of construction vehicles moving along the villages and settlement areas; - Limit dust by spraying water on dusty roads; - Locate construction plants away from settlement areas; - Do not operate noisy plants during the night; - Regularly maintain the construction vehicles and machineries to suppress exhaust smock; - Cover trucks transporting granular materials with canvas covers over their load; - Promote the wearing of dust mask to protect workers on the work site during the execution of work operations generating strong release of dust or contaminants; - Prohibit burning of materials susceptible to produce toxic gases (tires, used oils, etc.); - Insure that noise reduction devices supplied with some equipment are functional and in good working condition; - Take into account the impact of dust and noise on surrounding population when designing and locating the transportation route for excavation works; - Concentrate noisy operations (blasting, use of compressors, hammering of piles, etc.) during normal/daytime working hours; - Warn surrounding population before blasting.	Construction contractor through follow up of the design consultant	Part of project construction and supervision cost
Forest degradation and loss of habitats and biodiversity due to forest clearance for construction works.	- Plant indigenous tree species to compensate any loss of trees from the reservoir area, diversion canal construction line and powerhouse construction sites; - Plant twice as many tree seedlings to compensate the removed trees. - Set-up subsidies to decrease electricity cost so that even poor family can opt to use electricity for cooking and lighting purposes rather than cutting trees for fire wood and charcoal; - Initiate awareness campaign about biodiversity protection in the community and schools;	Directorate of Electric and Dam/Owner of the project in cooperation with local Administration and Environmental Directorate	25,000 USD (for compensation tree plantation)

Impact Description	Proposed Mitigation & Enhancement Measures	Responsible Agency/ Organization	Cost in USD
	- Promote traditional measures for forest protection; - Provide training on biodiversity protection for volunteers; - Promote income generating activities related to forest products and support the establishment of cooperatives on spice production and marketing, bee-keeping and marketing and animal fattening. Include jobless youth in these organizations.		
Other risks	- Improved access to the area will also increase risk of poaching and illegal logging etc. - Impact on scared sites and heritage resources; - Economic displacement and impact on access to grazing areas that may be cut off by the dam and natural resources that may be flooded. As above N/A	As above	N/A
Modification of the natural hydrologic regime of the Kinyeti river.	- Respect the maximum admissible speed criterion in the diversion channel; - Design a sufficient channel opening to safely divert the design flood; - Provide the energy dissipation basin to dampen vortices caused by the hydraulic jump and avoid undermining phenomena; - Provide riprap protection against erosion at the outlet of the diversion channel and on the slopes of canals excavated in unconsolidated material.	Construction contractor	Part of construction cost
Potential water pollution	- Liquid and solid wastes generated during construction will have to be adequately managed. To achieve this, storage and collection systems of these pollutants on the work site must be provided; - Treat waste water generated in the construction camp before discharging into environment; - Prepare an emergency plan in case of an accidental spill of contaminants; - In case of a spill, the Contractor must immediately inform the person responsible for the environmental supervision of work operations and take measures to stop the leak, to confine the product and proceed to its recovery; - Conduct regular monitoring to prevent losses of hydrocarbons in loading stations. - Perform the maintenance of vehicles/work site equipment on a confined area with waterproof paving to avoid all losses of oil products in the ground.	Construction Contractor	Part of construction cost
Potential degradation of soils and adaptation to local geomorphology	- Strip top soil for a minimum thickness of 30 cm, put aside (in heaps) and spread over once work operations are finished. Afterward, these soils must be levelled and stabilized by renewed vegetation and the planting of trees shall reduce soil erosion; - Divert runoff water and drainage so as to bypass sections where soil is sensitive to erosion. If diversion is not possible then install protection devices (berms or diversion channels);	Construction contractor, Supervision consultant and Eastern Equatoria Environmental Directorate	Part of Construction and supervision cost

Impact Description	Proposed Mitigation & Enhancement Measures	Responsible Agency/ Organization	Cost in USD
	- Limit to the strict minimum necessary the areas to be deforested, stripped, cleared, filled and all levelling of work areas so as to limit losses of habitat, conserve the natural topography and prevent erosion. After completion of work operations, disturbed ground areas must be reinstated and levelled; - Avoid the implementation of access roads in the axis of steep slopes; - Perform construction works preferably during the dry season; - Cover barren surfaces sensitive to erosion, with the help of degradable mulch so as to avoid loss of soil and seed by runoff waters; - Put back in place materials extracted from excavations and which are not reusable as fill material.		
Displaced or disturbed terrestrial fauna	- Conduct inventory of potential host sites to ensure that they will not destroy fragile habitats of the fauna; - Install appropriate signage at strategic places to make people aware of wildlife presence and movement for drivers (to reduce risk of collision). - To compensate the overall faunal habitat loss, designated protected areas within downstream or upstream of the reservoir site; - The hunting prohibition by the workers will be applied during construction and operation of the project; - A team of ecosystem monitoring will have to be put in place to follow the animal species evolution following the filling of the dam.	Ministry of wildlife conservation & tourism in collaboration with local environmental protection office and NGOs working on wildlife conservation	10,000 USD (for installing warning signs at wildlife crossing corridors)
IRRIGATION COMPONENT			
Positive Impacts of Irrigation Component and Enhancement Measures			
- *Increased food production of the beneficiaries;* - *Reduced food insecurity;*	- Adopt well established farm management system - Providing access to market and information. - Selecting suitable crops including high value crops that have food as well as commercial value. - Promote consultation and participation of the targeted communities during the selection of crop type and seeds; - Ensure targeting food insecure households/vulnerable groups. - Provide training as how to schedule the farm products for subsistence and market purposes; - Provide training on balance diet; - Reduce product waste during the harvest; - Training of beneficiaries (producers/famers)) on agronomy;	- East Equatoria Agriculture, Forestry and Rural Development Directorate - NGOs operating in communities.	Part of the project management cost

Impact Description	Proposed Mitigation & Enhancement Measures	Responsible Agency/ Organization	Cost in USD
- *Improve livelihood of the local community* - *Direct and indirect employment* opportunities.	- Promote an economic use of the products; - Provide on-farm training about the selection of crop types and farm management for the targeted beneficiaries; - Involving women groups in the planning and implementation of project activities; - Training of beneficiaries (producers/famers) on agronomy; - Assist communities in establishing water users' associations (WUAs) for irrigation.	- East Equatoria Agriculture, Forestry and Rural Development Directorate - NGOs operating in communities.	15,000 (for training of beneficiaries)
- *Infrastructure development in the area such as improved access roads.*	- Construction of access roads and ancillary facilities needs to be considered as part of the project component to enhance the benefit of the proposed multipurpose project. Timely maintenance of access roads by the responsible offices at zonal and woreda levels would enhance the benefit of the project.	- Construction contractor in cooperation with East Equatoria Infrastructure Directorate	Part of their annual budget
- *Reduced women's workload.*	- Involve women groups in the planning and implementation of project activities;	- East Equatoria Agriculture, Forestry and Rural Development Directorate - NGOs operating in communities.	20,000 USD (for training of beneficiaries on farm management)
Negative Impacts of the Irrigation Component and Proposed Mitigation Measures			
1. Negative impacts during the Construction Phase			
Forest degradation and loss of habitats and biodiversity due to forest clearance for construction works.	- Avoid expansion of irrigation farms into dense woodland & forested areas; - During clearance and preparation works, maintain some indigenous trees; - Plant indigenous trees along the road sides and canal sides; - Protect river buffer zone between the irrigation field and the river channel; - Plant compensation tree plantation in consultation with local environmental protection offices, - Conduct watershed management activities such as construction of terraces, soil bunds, tree plantation, etc. - Support the establishment of a forest biosphere reserve in the upper catchment; - Initiate awareness campaign about biodiversity protection in the community and schools; - Promote traditional measures for forest protection; - Provide training on biodiversity protection for volunteers;	- Construction contractor, Local Agriculture & Forestry Development Office, - Environmental protection office at local level, Wildlife Conservation & Tourism Directorate at Eastern Equatoria State	25,000 USD (for initiating biodiversity campaign and training volunteers on biodiversity conservation)

Impact Description	Proposed Mitigation & Enhancement Measures	Responsible Agency/ Organization	Cost in USD
	- Promote income generating activities related to forest products and support the establishment of cooperatives on spice production and marketing, bee-keeping and marketing and animal fattening. Include jobless youth in these organizations. - Economic displacement and impact on access to grazing areas that may be cut off by irrigation scheme and of natural resources that may be lost.		
Water pollution	- Avoid discharging construction spoil in the river system or any water source; - Construct sediment settling dam to filter out sediment; - Properly collect and dispose solid and liquid waste from the construction camp; - Establish water quality monitoring stations, take regular water samples and conduct water quality tests to check the status and evolution of water pollution.	- Construction contractor through follow up of the consultant	Part of construction cost
Displacement of people	- Relocate people if any from the proposed irrigation command area, - Provide compensations to people whose livelihood and houses have been impacted by the project infrastructure; - Support the development of livelihood and income generating activities for the affected people.	Project proponent in cooperation with Local Administration office	To be estimated in RAP
Decreased air quality and increased ambient noise level	- Limit the speed of construction vehicles moving along the villages and settlement areas; - Limit dust by spraying water on dusty roads; - Ensure regular maintenance of the construction vehicles and machineries to suppress exhaust smock; - Cover trucks transporting granular materials with canvas covers over their load; - Promote the wearing of dust mask to protect workers on the work site during the execution of work operations generating strong release of dust or contaminants; - Prohibit burning of materials susceptible to produce toxic gases (tires, used oils, etc.).	Construction contractor through follow up of the consultant	Part of construction cost
Deteriorated sacred sites due to project activities.	- Ensure that sacred and cultural heritage sites are not affected by the irrigation scheme and its activities if any.	Relevant organization in East Equatoria State / Culture and tourism offices at local level.	Part of the routine budget of each relevant office

Impact Description	Proposed Mitigation & Enhancement Measures	Responsible Agency/ Organization	Cost in USD
2. Negative impacts during the Operation Phase			
Increased soil salinity	- Conduct soil and water quality tests and design the water and soil management measures on the investigation results; - Apply only required amount of water based on the crop water requirement. Avoid over use; - Drain out excess water from the irrigation field - Treat soil acidity with limestone;	Irrigation management body	Part of the operation cost
Bee Keeping	- Introduce modern beehives and provide forage for the bees at the spot; - Avoid or minimize the use of pesticides; - Avoid the use of herbicides instead of pick weeds by hand.	Irrigation management body	Part of the operation cost
Rise of the water table	- Increase field application efficiency which could significantly reduce the rise in the groundwater; - Provide drainage system and do not allow water logging.	Irrigation management body	Part of the operation cost
Reduction of downstream Kinyeti river flows	- Establish hydrological measurement station at the appropriate locations of the river and establish the amount of flow at different seasons and months; - Abstract/divert only amount of water that required for the proposed irrigation purpose; - Reduce loss of water during the application of irrigation and along the diversion channels; - Maintain environmental flow along the main river channel, which is not less than the minimum flow occurred at the driest month; - Ensure the downstream users receive adequate flow of water.	Ministry of Electricity, Dam, Irrigation & Water Resources in collaboration with ENTRO, Environmental protection office at local level, Project Proponent	10,000 USD (for purchasing of hydrology measurement instruments)
Increase in malaria and other water related diseases	- Avoid excess water in the irrigation field; - Drain out water holding spots; - Clear the channels and its shores to avoid weeds - Increase flow speed of water in the channel - Put boots while working in the irrigation field to prevent penetration of foot by the larvae of Schistosomiasis. - Provide mosquito net for the people residing near the irrigation farm and for those working in the irrigation farm.	Irrigation management body in collaboration with local health office	*N/A*
Water pollution	- Avoid the use of herbicides and promote the use mechanical or hand picking of weeds; - Minimize the use of fertilizers and pesticides; - Collect drain water from the irrigation farm and treat before discharging into environment or downstream river system; - Establish water quality monitoring stations and take regular water samples and conduct water quality tests to check the status and evolution of water pollution;	Irrigation Management body/Project proponent	Part of irrigation operation cost

Impact Description	Proposed Mitigation & Enhancement Measures	Responsible Agency/ Organization	Cost in USD
WATER SUPPLY			
Positive Impacts and enhancement Measures			
Provide safe access to water	- Ensure that households/communities with unsafe sources, are prime beneficiaries of the scheme - Ensure active participation of women groups in scheme site selection and realization.	Water supply office of Torit town	Part of the project cost
Improve health and livelihood of the people	- Minimize the tariff of the water per meter cub to promote use of safe water by poor households; - Treat water to fulfill the standard quality of drinking water. - Employment and skills development associated with the construction of water supply scheme and associated infrastructure	- Water supply office of Torit town	Part of the project operation cost
Negative impacts and mitigation Measures			
Water pollution generated by the water treatment by-products	- Collect and dispose water treatment waste properly; - Dispose waste at authorized places; - Use water treatment methods that minimize wastes.	Water supply office of Torit town	Part of the project operation cost
Increase volume of sewerage	- Collect and treat the sewerage from the town; - Reuse the treated water for irrigating fodder fields and tree plantations.	Water supply office of Torit town	Part of the project operation cost
AQUACULTURE COMPONENT			
Positive Impacts and Enhancement Measures			
- *Contribute to Food Security;* - *Supply Good Protein and Maintain Balanced Diet;* - *Promote Proper Utilization of Natural Resources;* - *Diversify Livelihood of the People;* - *Use as Pilot Program;*	- Provide training for the beneficiaries on pond construction, application of fertilizers, aeration of ponds, harvesting and storing of aquaculture products; - Create and/or facilitate access to credit and facilitate linkages with local and central markets	- Fisheries and aquaculture development office, NGOs working in the area of aquaculture	10,000 USD for the introduction and demonstration of modern aquaculture and 25,000 USD for maintenance and management of aquaculture ponds

Impact Description	Proposed Mitigation & Enhancement Measures	Responsible Agency/ Organization	Cost in USD
Negative Impacts			
Pollution of water bodies	- Properly manage the drainage water contaminated with fertilizers and other chemicals used in the process of aquaculture farming; - Collect and treat the drainage and maintain the water quality standard before discharging into the environment; - Recycle the water used in the fish ponds, - Avoid use of long-lasting toxic chemicals.	Project owners/beneficiaries; environmental protection office at woreda level; fishery and aquaculture development office	Part of the project operation cost
LIVELIHOOD BASED WATERSHED MANAGEMENT			
Positive Impacts			
- *Increased food availability through improved soil fertility and crop productivity.* - *Arresting soil and water degradation.* - *Job opportunities*	- Ensure active participation of communities in selecting watershed management activities. - Ensure that watershed management activities are developed within the context of the local key livelihood activities. - Employment and skills development associated with the implementation of watershed management projects.	- Local level environmental protection office - Local level fishery and aquaculture development office	To be estimated separately as a self-content project
		Total Environmental Mitigation and Enhancement Cost	**199,000 USD**

5.4 CONCLUSION

The implementation of the proposed multipurpose project will provide electricity for the community which in most cases have no access to electricity. Current supply is provided by diesel generator sets for a limited number of consumers. Most residents depend of forest resources to satisfy the demand for fire wood. The development of irrigation, aquaculture and fisheries shall also sustain food production for the community, strengthening food and nutrition security. These different project components will support the local economic development and its diversification. It will reduce the dependence of the community on forest-related products (fire wood, charcoal, timber products, bush meat, etc.), preventing further degradation of the forest ecosystems and enabling the development of ecotourism. It should be noted that the development of watershed management activities together with the reduction of deforestation in the area will have positive impacts on erosion and sedimentation of the rivers in the sub-basin. This should result in improved water quality downstream in the basin.

The identified adverse impacts (water and soil pollution, modification of the hydrological regime of surface and ground-water resources, increased sedimentation, people resettlement, etc.) shall be genuinely mitigated by an adequate resettlement action plan, watershed management measures, and adapted construction and operation practices by the Contractor, as recommended in the table above.

6. COST-BENEFIT ANALYSIS

The cost-benefit analysis (CBA) determines **the financial and economic relevance of a project** (or programme) by evaluating the differential of costs and benefits between the situation with project and the situation without project (baseline scenario). In the current study, the CBA aims at assessing:

- The financial feasibility of the different activities (Hydropower, Irrigation & Aquaculture and Fishery) (*i.e. Are the benefits higher than the costs? What is the payback period?)*
- The socio-economic relevance of the project (i.e. Are the socio-economic indirect impacts positive? Do they justify the project?)

Two analyses are conducted:

- **A financial analysis** which allows the assessment of the profitability of each activity in the investors' point of view. The analysis takes into account the financial costs and benefits, i.e. the investments and O&M costs and the revenues of the activity implemented (hydropower, irrigation & aquaculture, fishery).
- **An economic analysis** which evaluates the viability of the projects from the society's point of view. This analysis takes into account the financial costs and benefits plus the externalities of the projects.

An externality is a cost or benefit generated by an activity and that affects a party that did not choose to incur this cost or benefits (e.g. improvement of health for beneficiaries, indirect employment, etc.). It makes it possible to appreciate the relevance of the project for the society as a whole.

The following table presents the financial costs and benefits and the externalities of the project. All these costs and benefits have been evaluated in the CBA. It should be noted that one of the main benefits of the project will be the creation of employment in the project area and this will constitute a catalyst for economic development. Benefits related to employment are mostly included in the financial benefits "revenue". The employment created during the construction of the different project components (dam and irrigation scheme for instance) is not included.

Table 6-1: Financial costs and benefits and externalities of the project

Benefits of the project	Costs of the project
Financial costs and benefits	
Revenue from electricity sales Revenue from irrigation Revenue from aquaculture Revenue from fishery Revenue from water sales Revenue from livelihood based watershed management activities	Investment costs O&M costs Mitigation costs
Externalities	
The avoided extra cost for electricity using the next best alternative energy source to hydroelectricity Value of avoided carbon emissions thanks to hydroelectricity Avoided deforestation thanks to hydroelectricity Improvement of health thanks to water supply Improvement of livestock productivity Tourism development	Environmental externalities are internalized thanks to the implementation of mitigation measures

6.1 BENEFITS GENERATED FROM THE KINYETI MULTIPURPOSE PROJECT

Financial benefits and positive externalities are distinguished in order to carry out a financial analysis, distinct from the economic analysis.

- Financial benefits are monetary gains resulting directly from the project. These benefits are used to carry out the financial analysis.
- Positive externalities are indirect monetary and non-monetary benefits resulting from the project. Non-monetary positive externalities have been monetarized in order to carry out the economic analysis.

6.1.1 Financial benefits

ELECTRICITY SALES

The estimation of electricity sales depends on the production of hydropower and the selling price of electricity. For a price of 0.1 USD/kWHrs and a production of 7.95 GWHrs/annum, electricity sales are estimated to be around 795,000 USD/annum.

The benefits generated from electricity sales have been included in the sensitivity analysis (selling price of hydropower varies from -20% to +20%).

IRRIGATION BENEFITS

Current yields in South Sudan are quite low. It is anticipated that irrigation development will be complemented by an improved access to quality seeds which should result in a significant increase of the yields.

Yields and selling price of the crops have been determined in accordance with the values used in the economic model of the Baro-Akobo-Sobat IWRDMP. Irrigation benefits are presented in Table 6-2 below.

Table 6-2: Yields and benefits associated to the development of irrigation

Crop	Wet season	Dry Season	Yield (T/Ha)	Production (T/Year)	Selling price (USD/T)	Selling price of the production USD
	Area (%)	Area (%)				
Maize	30	35	4	2600	215	**559,000**
Sorghum	28	20	2	960	230	**221,000**
Beans	5	10	3	463	197	**91,000**
Groundnut	10	10	1,6	320	830	**266,000**
Vegetables	15	10	10	2,500	197	**493,000**
Banana	5	5	30	3,000	229	**687,000**
Millet	2	0	1.1	23	215	**5,000**
Cropping Intensity	95	90				**2,322,000**
Overall cropping intensity		185				

The benefits generated from the development of irrigation have been included in the sensitivity analysis (benefits vary from -20% to +20%).

AQUACULTURE BENEFITS

The net value of production associated with the development of aquaculture depends on the productivity of the ponds and the wholesale price of fish. A productivity of 80 kg fish/pond/year and a selling price of fish of 2 USD per kg gives a net value of production of 12,800 USD for 100 ponds.

The benefits generated from the development of aquaculture have been included in the sensitivity analysis (benefits vary from -20% to +20%).

FISHERIES BENEFITS

The gross margin associated with the development of fisheries in the reservoir depends on the productivity of the reservoir and the gross margin associated with the sale of fish. A productivity of 150 kg fish/ha/year and a gross margin of 276 USD/T of fish gives a gross margin of 7,680 USD/year.

The benefits generated from the development of fisheries have been included in the sensitivity analysis (benefits vary from -20% to +20%).

WATERSHED MANAGEMENT

There will be direct financial benefits with the implementation of livelihood based watershed management activities. These benefits will be for the following activities:

- Fruit production could generate up to 210,000 USD/annum for 70 Tons of fruits produced (selling price estimated to be around 3 USD per kilo)
- Agro-forestry products could generate up to 320,000 USD/annum for an area of 40 ha (benefits could be up to 8,000 USD per hectare).

These activities could generate significant benefits from the 10th year of implementation of the project (time for the trees to achieve maturity).

REVENUES GENERATED BY THE SALE OF POTABLE WATER

Potable water supply to the city of Torit is a service and does not generate direct financial benefits. However, the revenues generated by the sale of water must cover operation and maintenance expenditures to ensure that the water network is maintained in a good condition.

6.1.2 Positive externalities

The positive externalities of the project are the following:

- The avoided extra cost for electricity using the next best alternative energy source to hydroelectricity
- The value of avoided carbon emissions thanks to hydroelectricity
- The value of avoided deforestation thanks to hydroelectricity
- The improvement of health of the drinking water supply beneficiaries
- The improvement of gender equality
- The improvement of livestock productivity
- Tourism development

The first three externalities have been estimated with the **avoided costs method**. This method assumes that the costs of avoiding damages, health issues, pollution, ecosystem losses, etc. is a useful estimate of the positive externalities provided by the different project components.

The other three externalities have been assessed with the **market-price method**. It consists of evaluating an impact using the current price on the market. For instance, the tourism development is evaluated from the average expenditure per tourist, the improvement of livestock is evaluated from the price of meat and milk, etc.

EXTERNALITIES RELATED TO HYDROPOWER PRODUCTION

The working assumption is that hydropower will provide energy which would otherwise be provided by fuel (50%) and charcoal (50%). Hydropower related externalities included in the CBA are the following:

- Avoided cost of next best alternative energy source (fuel) Total USD/kWHrs/year
- Value of carbon emissions avoided
- Reduced deforestation

Employment related benefits are included in "electricity sales" as this revenue will be used to pay the various workers.

EXTERNALITIES RELATED TO POTABLE WATER SUPPLY

Positive externalities from potable water supply will mostly be on health. Girls' education will be enhanced through the promotion of hygiene in learning premises and access to a safe source of water. It will also promote gender equality as it will reduce the burden on women who have to collect water every day and can spend up to one hour every day in this task. Potable water related externalities included in the CBA are the following:

- Avoided cost of lives lost: Annual deaths due to diarrhoea diseases (unsafe water).
- Cost of medical treatment avoided: costs of treatment avoided due to water related diseases.
- Value of time saved: time spent to collect water.
- Value of increased life expectancy: this is actually one of the most important positive externalities. The major benefits of the project will be on health as there will be enhancement of the access to safe water, access to a non-toxic source of energy (toxic gas due to charcoal burning), improved access to food, improved infrastructure network, etc.
- Enhancement of educational services, and increase of school attendance for girls through promoted hygiene at learning premises and access to safe water (this positive externality cannot be monetarized).

EXTERNALITIES RELATED TO LIVESTOCK WATERING

Water regulation by the dam will ensure a minimum flow in the river during the dry season. This will secure access to water for the livestock. As already emphasized, livestock positive externalities will be on the weight of the animals and on the production of milk. Livestock related externality will be on:

- Net value of production (additional sale of meat and additional sale of milk)

EXTERNALITIES RELATED TO TOURISM DEVELOPMENT

A significant positive externality of the project relates to the development of ecotourism. Potable water supply in Torit and electricity provision is highly favourable for the development of tourism in the surroundings of Torit (Imatong mountains, Kidepo game reserve, Badingilo national park)

A rough estimation of the benefits that could be generated from tourism development was made with the following assumptions:

- In the baseline situation, there are 1,000 tourists/annum in the area and in 25 years' time there will be 10,000 tourists/annum.
- The average expenditure per tourist is 100 USD/day
- A coefficient of 0.8 was applied to the net value of production in order to take into account the production costs

Benefits related to employment are included in the above externalities as the revenues from tourism will be used to pay the various workers.

6.2 COSTS OF THE KINYETI MULTIPURPOSE PROJECT AND FUNDING

Investment, operating and maintenance costs were estimated for the following:

- Dam and re-regulation dam (includes a provision made for resettlement of the population living in the reservoir area)
- Hydropower
- Irrigation
- Water supply
- Fisheries
- Aquaculture

Finally, the costs for mitigation and enhancement identified in the EIA are included.

These costs are described in the above sections and summarized in Table 6-3.

Table 6-3: Costs summary of the Kinyeti River multipurpose development project

Component	Investment costs (USD)	Resettlement costs (USD)	Operating and maintenance costs (USD/annum)
Dam	56,500,000	250,000	565,000
Hydropower	3,900,000	-	39,000
Irrigation	15,300,000	-	153,000
Water supply	16,000,000	-	350,000
Watershed management	227,000	-	-
Fisheries	7,650	-	45
Aquaculture	100,000	-	200
ESIA – mitigation and enhancement costs	199,000	-	-
TOTAL	92,233,650	250,000	1,107,245

6.3 MAIN RESULTS OF THE COST-BENEFIT ANALYSIS

The following assumptions are made for the analysis:

- The discount rate is 6 %.
- Investment costs are covered by a loan and the **interest rate of the loan is 4%.**
- The **repayment period of the loan is 20 years** and the repayment only starts the 7th year of the project.
- There are no benefits or positive externalities the two first years of the project (time for implementation of the components).[3]
- Operation and maintenance costs are of the dam are supported by the irrigation and hydropower sectors
- Three main loans are contracted:
  - 1 loan for the dam and water supply components contracted by the state, as a public investment
  - 1 loan for the hydropower component contracted by the company who will operate the hydropower production
  - 1 loan for irrigation, aquaculture and watershed management contracted by the company who will operate the schemes and the ponds.

ECONOMIC PROFITABILITY OF THE PROJECT

The main results with the above assumptions for the economic analysis of the project are presented in Table 6-4 below.

Table 6-4: Indicators of the economic profitability of the project

Economic profitability of the project	
IRR	10%
NPV	11,000,000 USD
Benefits/Costs	1.11
Payback period	18 years

The economic analysis takes into account the financial benefits but also the externalities of the project. As it can be seen in the table, the project has an Internal Rate of Return (IRR) of 10% and a Net Present Value (NPV) of 11 Million USD. This fully justifies the project.

[3] **Except for the employment created during the construction which has not been included in this CBA.**

FINANCIAL PROFITABILITY OF THE PROJECT

The main results with the above assumptions for the financial analysis of the project are presented in Table 6-5 below.

Table 6-5: Indicators of the financial profitability of the project

Hydropower – financial analysis	
IRR	10%
NPV	1,885,000 USD
Benefits/Costs	1.53
Payback period (years)	11
Irrigation and aquaculture – financial analysis	
IRR	32%
NPV	3,955,000 USD
Benefits/Costs	1.21
Payback period (years)	6
Fishery – financial analysis	
IRR	62%
NPV	78,000 USD
Benefits/Costs	10.87
Payback period (years)	3
Fruits production and agroforestry – financial analysis	
IRR	25%
NPV	305,000 USD
Benefits/Costs	7.04
Payback period (years)	14

The financial analysis assumes that the cost of the dam is not borne by the hydropower and irrigation developments, although hydropower and irrigation operations will cover operation and maintenance costs of the dam. The dam is multipurpose and will support several components. This includes irrigation and hydropower but also aquaculture, fisheries, potable water supply and recreational activities. As such, the dam will boost the local economy and it is proposed that the dam is a public investment playing a major role in supporting water supply and employment. It is important to stress that the costs and benefits of water supply are not included in the financial profitability calculations although the major positive externalities are taken into account in the economic analysis (together with the cost of the dam).

6.4 SENSITIVITY ANALYSIS

A sensitivity analysis was carried out to estimate the variation of the NPV and IRR in response to the uncertainty of different factors such as:

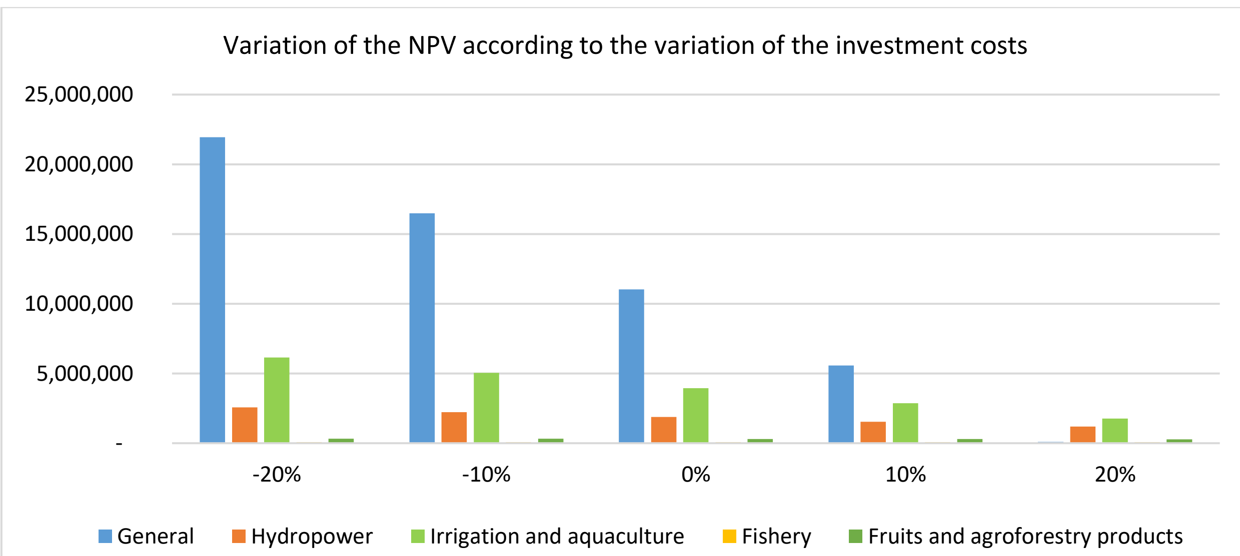
- Uncertainty regarding the investments costs, operation and maintenance costs, electricity selling price and crops selling price,
- Uncertainty regarding the loan, the interest rate and the possibility of a grant.

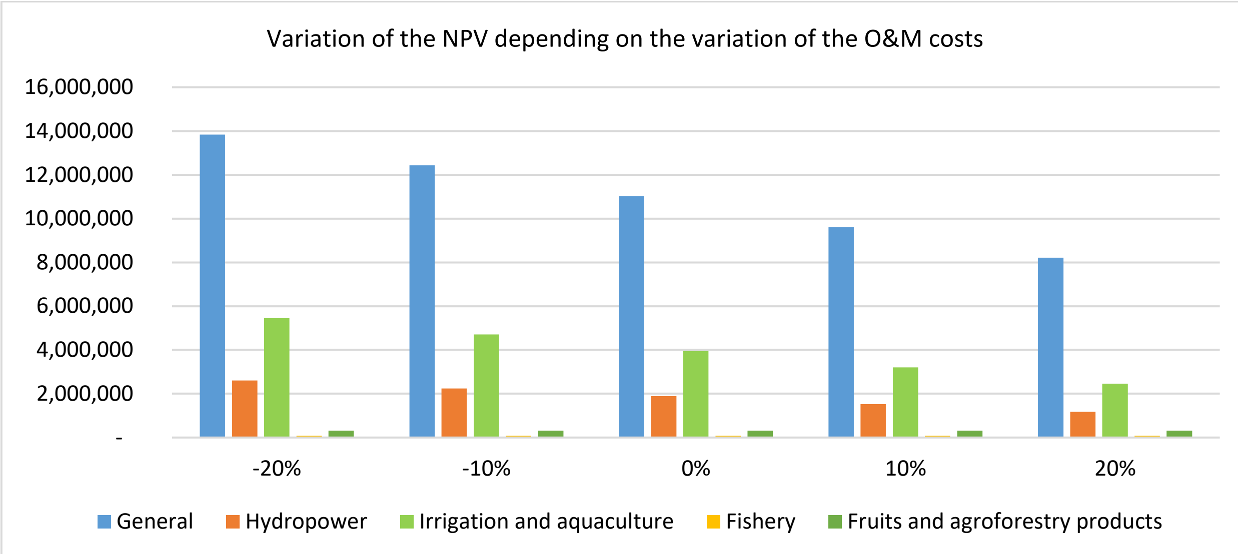
The main results are featured in Figure 6-1 below and highlight that the project is robust. Considering that the project is feasible and profitable when the NPV is positive, there are only two situations where the NPV is negative:

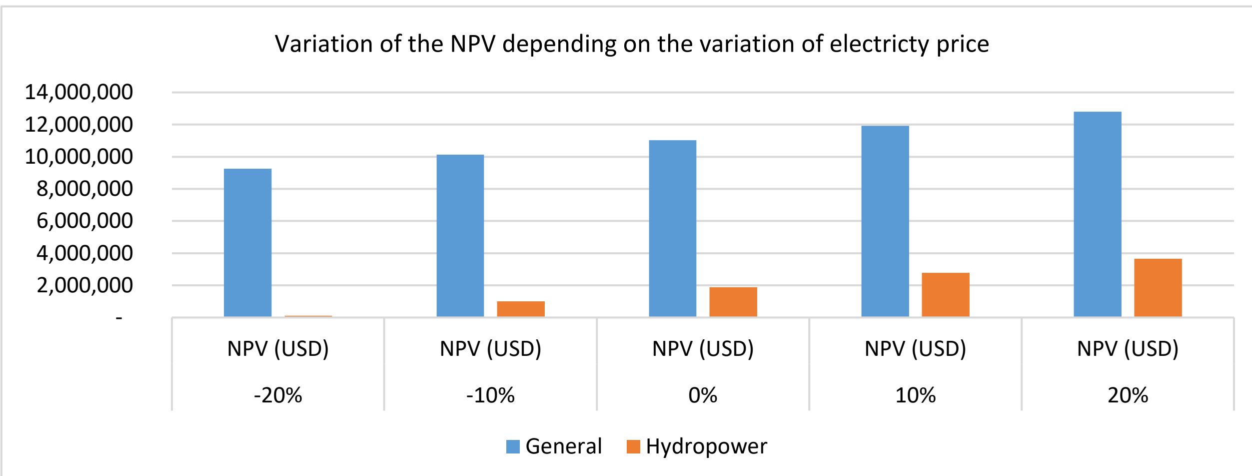
- When investment costs are increased by 20%: this is highly unlikely as high costs have been preferred in the costs estimates
- When the interest rate of the loan is 12.5% and there is no grant

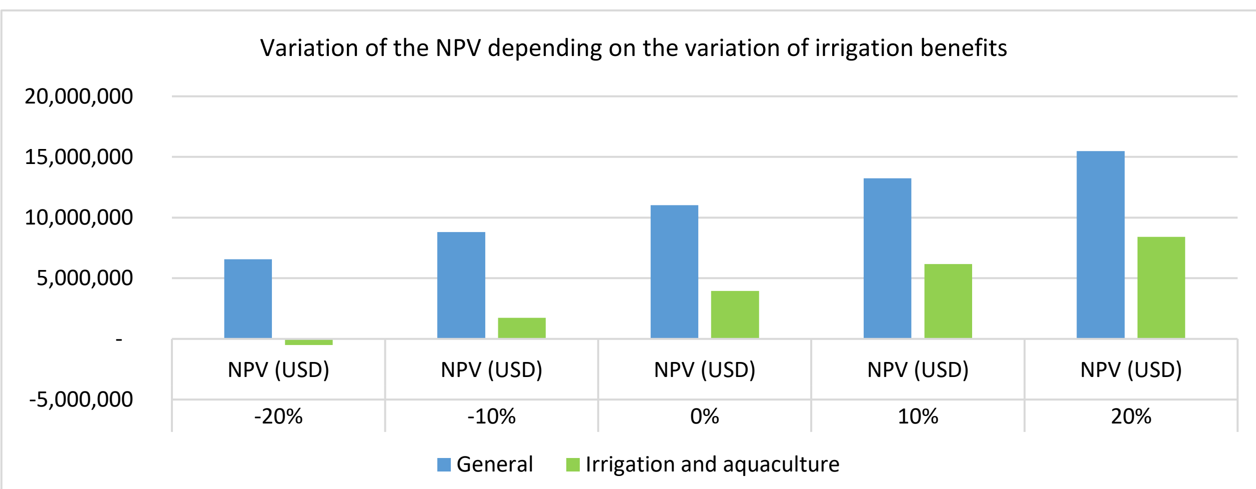
Furthermore, as emphasized above, a very conservative approach was used to estimate the costs of the different components of the project. Taking a more positive approach and reducing the total cost of the project by 10% in the sensitive analysis shows that the NPV of the project goes from 11 million USD to 16.5 million USD (increased by 65%). This highlights the potential for the multipurpose dam to generate major benefits and confirms the robustness of the project.

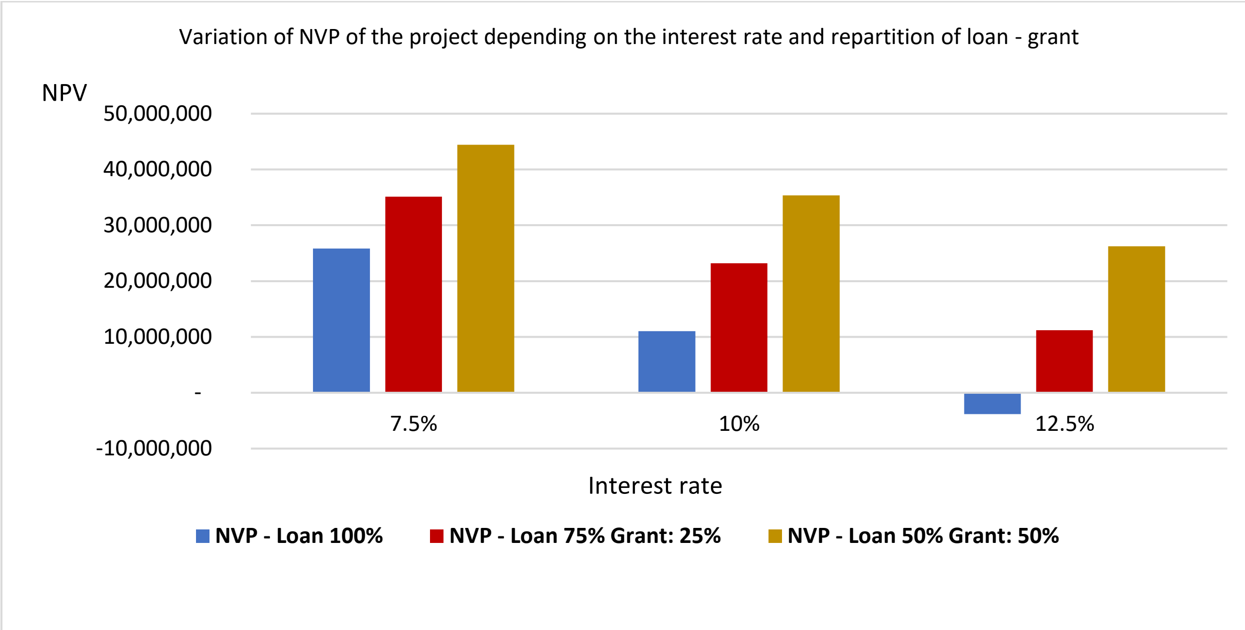
Figure 6-1: Main results of the sensitivity analysis




Variation of the NPV depending on the variation of the O&M costs
16,000,000
14,000,000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
-
-20%
-10%
0%
10%
20%
General
Hydropower
Irrigation and aquaculture
Fishery
Fruits and agroforestry products


Variation of the NPV depending on the variation of electricty price
14,000,000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
-
NPV (USD)
-20%
-10%
0%
10%
20%
General
Hydropower


Variation of the NPV depending on the variation of irrigation benefits
20,000,000
15,000,000
10,000,000
5,000,000
-
-5,000,000
NPV (USD)
-20%
-10%
0%
10%
20%
General
Irrigation and aquaculture



7. CONCLUSIONS AND RECOMMENDATIONS

The proposed project has been shown to be robust and would meet some major needs in the Torit area. Most significantly, access for the whole population to an improved water supply, something which is almost completely lacking at present, will result in numerous direct and indirect social and economic benefits. The project as a whole could play a very major role in underpinning sustainable development in the greater Torit area.

Torit is currently not connected to a sustainable supply of electricity. Only a few institutions and individuals benefit from expensive electricity provided by generators. The proposed project will bring affordable electricity to the population at large and this will provide a springboard for both improved living conditions and economic growth. A reliable electricity (and water) supply will support the proposed tourism and recreation, as well as value-added activities for agriculture.

It is important to stress that the economic viability of the project depends on it being possible to implement in its full multipurpose nature. For this to be possible it is self-evident that a return to security and stability is necessary. This situation has been assumed in the estimation of costs.

As indicated earlier in the report, it was not possible to make a second site visit to the dam site area nor the more upstream part of the river because of security issues. It was also not possible to hold more discussions with stakeholders. This has resulted in some assumptions and three main areas of uncertainty which should be investigated before final site selection and proceeding to design:

- There is virtually no information on peak floods in the basin. The gaugings stations recently installed in the catchment are collecting valuable data but as yet there have not been any significant floods recorded. Previous studies have estimated flood peaks at much lower levels than the values taken in this study. If, once the knowledge base has been improved, it is found that the values taken in this feasibility study are shown to be too high, there will be significant cost reductions implications. The continued collection of new data, together with a detailed reconnaissance on the ground will inform this aspect.

- One of the purposes of the proposed visit had been to look at possible alternative dam sites. While it has been shown to be feasible, the current project is relatively costly. As part of the proposed pre-design reconnaissance visit, it proposed to investigate the possible existence of a more cost-effective dam site and associated hydropower. The focus would be on reducing dam costs and maintaining or increasing hydropower production. None of the other components of the projects would be affected.
- As part of the design process it will be important to discuss the detailed plans with stakeholders in order to ensure their buy-in.

ANNEXES

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Annex 2: Kinyeti Irrigation and drainage project

1. INTRODUCTION

This report presents the feasibility level technical viability study conducted for the Kinyeti Irrigation and Drainage Project (KIDP). The project is initiated as one of the short-term investment ready project and an integral part of an Integrated Water Resources Development and Management Plan (IWRDMP) under the BAS Multipurpose Water Resources Development Study Project. The KIDP will involve the development of 1000 ha of land in Torit County, Eastern Equatorial State of South Sudan. The project area will be irrigated from a dam to be built across the Kinyeti River 15km South East of Torit town. The command area is located 8 km North West of Torit town on the Right side of Juba-Torit Road and left side of Kinyeti River at geographic coordinate of 4°26' - 4°30′ N latitude and 32°26′- 32°30′ E The terrain is almost flat to moderate and the land gradient towards the North-west to the left bank of Kinyeti River in most case shows from 0.3% to 4%slope.

The scope of work of the present feasibility study includes the following:

- Provision of the detailed and overall crop water requirement for infrastructure planning and for irrigation scheduling
- Feasibility-level design and cost estimation of the project engineering infrastructure, for irrigation and drainage.

2. IRRIGATION SYSTEM PLANNING

2.1. WATER SOURCE

Water for irrigation will be withdrawn from Kinyeti dam, located at a distance of 23 and 15km from the command area and Torit town respectively and 135 km from Juba. Kinyeti dam is a multipurpose project, generating hydropower and delivering water for domestic and irrigation purpose, together with its capability to reduce flooding downstream and regulate flows for other purposes. The irrigable land extends along left sides of the Juba - Torit road on the left bank of the Kinyeti River high above the river bed level that requires lifting irrigation water by pump. The pump abstract water from the river and discharge it, via a 1582 meter long pressure pipeline system, to the night storage from where irrigation water flows by gravity to irrigated plots.

2.2. Selected Method of Irrigation

The planned irrigation system uses surface irrigation method, which is gravity flow system distributing water at field level by free surface overland regime. Selected field irrigation methods are furrow and border strip to spread water as uniformly as possible in the soil to irrigate the crops. The choice between the two irrigation methods is governed by the prevailing topographic conditions of the farmland. Furrow irrigation is selected for land slope less than 3% while border strip method is selected for land slope between 3%-4%. Furrows on ground slope less than 2% are aligned down the main slope, whereas, for ground slope greater than 2% and less than 3%, cross furrows alignments are set. For ground slope between 3% - 4%, only border strips method is recommended. Both methods of irrigation are supplied with irrigation water from a head field canal. A field drains channels at the end of the run collects water to dispose it. Plastic siphon pipes are the best way of taking out water from the head field/tertiary canal.

2.3. Operation Period

The most common practice, which is followed in public run medium and large scale irrigation schemes, is to operate the system either for 12 hours or for 24 hours a day. Thus, based on the similar inference drawn from various other areas, irrigation arrangement combination of both 12hr and 24 -hour continuous operation has been adopted in this project. Night storage is also incorporated to reduce investment cost of pumps and associated structures. The design of pump to run for 24 hours would decrease their capacities, and no additional cost would be required owing to lower capacity and related structures for the pumping system.

2.4. Cropping Patterns & Calendar

The Project is being planned for cultivation of cereals, vegetables, and perennials crops in the entire command area by considering the agro-climatic zone of the area, farmers' preference, and market opportunity. Possible cropping patterns are also proposed with 185% annual cropping intensity in two growing seasons. Thus, the proposed intensity of crops is 95% in the wet and 90% in the dry season, and the crop water requirement is calculated for the entire crops. Accordingly, two growing seasons have been assumed, for crop water requirement calculation based on the calculated values of ET_O and Kc and overall irrigation efficiency of 50%. Adapted cropping pattern and calendar are presented in Table1 below.

Table A- 1: Copping Pattern Data

No	Crop	Wet season	Dry Season
		Area (%)	Area (%)
1	Maize	30	35
2	Sorghum	28	20
3	Beans	5	10
4	Groundnut	10	10
5	Vegetables	15	10
6	Banana	5	5
7	Millet	2	90
	Cropping Intensity	95	90
	Overall cropping intensity		185

3. IRRIGATION WATER REQUIREMENTS

The crop water requirement for proposed cropping pattern was calculated by using the climatic data for Torit from FAO Data base. Torit station is only 8 km away from the project site with similar agro ecological zone. This is calculated in accordance with CropWat for Windows program that uses the FAO (1992) Penman-Monteith methods for calculating reference crop evapo-transpiration. The crop characteristics like crop co-efficient (KC) are adopted in accordance with the recommendations available in FAO Irrigation and Drainage paper No 24: Crop Water Requirement and No. 33:

For crops grown in wet season, possible effective rainfall contribution in each month has been worked out by using 75% dependable rainfall with CropWat software programme mentioned above. Effective rainfall contribution is then deducted from gross crop water requirement to get net crop water requirement for each month at the field level

Average values of monthly requirements have been calculated assuming two options (24, and 12 hours) for daily operation period and the same are presented in Table 2 below.

Table A- 2: Monthly average Scheme Water Requirements for the Proposed Cropping Calendar and Pattern

	Area Under Cultivation		Water Requirements				
				24 hr irrigation		12 hr Irrigation	
Month	%	Ha	Volume / month (Mm^3)	l/s/ha	Total (m^3/s)	l/s/ha	Total (m^3/s)
January	95	950	2.2391	0.88	0.84	1.76	1.67
February	70	700	0.1355	0.08	0.06	0.16	0.11
March	5	50	0.0027	0.02	0.00	0.04	0.00
April	80	800	0.1244	0.06	0.05	0.12	0.10
May	95	950	0.9669	0.38	0.36	0.76	0.72
June	95	950	1.5776	0.62	0.59	1.24	1.18
July	88	880	0.2357	0.1	0.09	0.2	0.18
August	5	50	0.0027	0.02	0.00	0.04	0.00
September	5	50	0.0052	0.04	0.00	0.08	0.00
October	95	950	0.3053	0.12	0.11	0.24	0.23
November	95	950	1.9699	0.8	0.76	1.6	1.52
December	90	900	2.9891	1.24	1.12	2.48	2.23
Total	95	950	**10.5541**				

3.1. SCHEME WATER REQUIREMENT AND CANAL CAPACITY

The water requirement values in Table 2 above is further increased by 10 percent to account for any change or increase in the future and to provide flexibility in operation and water management. Table .3 presents scheme water requirements on monthly basis with 10% flexibility factor for the proposed cropping pattern.

The peak discharge (design discharge) is calculated on the basis of peak crop water requirement Etc., which is based on the values of potential evapo-transpiration (ET_O) & crop co-efficient (Kc). The summery is presented in Table 3 below. The peak flow rate is 1.22m^3/s and 2.45m^3/s for 12hr and 24 hour daily operation period respectively with 50% overall irrigation efficiency and flexibility factor of 10%.

Thus, the main canal is designed with 2.73l/s/ha water duty and design discharge of 2.46m3/s for 12 hours daily operation whereas the pumps were designed with 1.36l/s/ha water duty and design discharge of 1.23m3/s for 24 hours daily operation. This amounts 11.60 Mm^3 of irrigation water per year for the entire command area with the specified cropping pattern and calendar. (Table 3).

Table A- 3: Scheme Water Requirements with 50% overall Efficiency and 10% flexibility factor

Month	Area Under Cultivation		Water requirements					
	%	Ha	Volume / month (MM$^{3)}$	Duty l/s/ha (+10%)	24 hr irrigation		12 hr Irrigation	
					l/s/ha @ 50% Efficiency	Total (m^3/s)	l/s/ha	Total (m^3/s)
January	95	950	2.4631	0.48	0.97	0.92	1.936	1.84
February	70	700	0.1490	0.04	0.09	0.06	0.176	0.12
March	5	50	0.0029	0.01	0.02	0.00	0.044	0.00
April	80	800	0.1369	0.03	0.07	0.05	0.132	0.11
May	95	950	1.0636	0.21	0.42	0.40	0.836	0.79
Jun	95	950	1.7353	0.34	0.68	0.65	1.364	1.30
July	88	880	0.2593	0.06	0.11	0.10	0.22	0.19
August	5	50	0.0029	0.01	0.02	0.00	0.044	0.00
September	5	50	0.0057	0.02	0.04	0.00	0.088	0.00
October	95	950	0.3250	0.07	0.13	0.13	0.264	0.25
November	95	950	2.1669	0.44	0.88	0.84	1.76	1.67
December	90	900	3.2880	0.68	1.36	1.23	2.73	2.46
Total			11.5987					

3.2. IRRIGATION EFFICIENCY AND WATER DUTY

The following irrigation efficiency is considered for the scheme to account for losses of water during conveyance and application to the field.

Table A- 4: Adapted Irrigation Efficiency

System	Efficiency %	Overall Efficiency	Water duty at inlet (l/s/ha)				
			Net Max	50% efficiency		10% Flexibility	
			24hr	24hr	12hr	24hr	12hr
Application	65	65%	0.62	0.95	1.91		
Field Canal	92	60%	0.62	1.04	2.07	2.28	1.14
Secondary	93	56%	0.62	1.11	2.23	2.45	1.23
Main canal	90	50%	0.62	1.24	2.48	2.73	1.36

4. DELIVERY SYSTEM DESCRIPTION

4.1. IRRIGATION SYSTEM COMPONENTS

Based on analysis of the topography and characteristics of water sources (Kinyeti dam), a system consisting of Pump, Pressurized pipe line and open canals were proposed. Regulated flow released from the dam to the natural stream of Kinyeti River will be pumped to the night storage at the high ground in the command area from where it will flow by gravity through open canals to irrigation plots. Main irrigation components planned in the Kinyeti Irrigation and Drainage Project (KIDP).are as follows:

- Command area: 1000 ha of net irrigable area
- Pump station and 1.6 km transmission steel pipe line
- Night storage
- Main canal
- Irrigation and drainage facilities in the command area: Secondary, Tertiary, Field and drainage canals, farm roads, and drainage structures, etc.

4.2. PROJECT TOTAL COMMAND AREA AND LAYOUT

The gross command area is 1,317.75ha with net irrigable area of 1000ha.The command area is characterized by the flat to moderate slopes in the range of 0.3-1% over large portions of the area that lies along the left sides of the Kinyeti River. The gross command area is 1,317.75 ha with net irrigable area of 1000 ha. The adapted layout system for the demarcated command area was mainly governed by land topography. Generally, the topographic feature of the area has resulted in an uneven farm unit sizes. The secondary canals are aligned across contour along ridges where possible, while Field canals are aligned along contours and consequently furrows run crosswise to the contours. The main collector drains collect all the water from the field drains to the river and field drainage canals collect excess water from the field.

Accordingly, the whole command area was divided into five primary blocks depending on the gullies and streams bisecting the area. The Net Irrigable Areas (NIA) were estimated on the basis of Gross Command Area (GCA), and 15% was deducted and assumed to be non-irrigable due to being occupied by streams, rocky areas, land areas with slope greater than 5% and further reducing the resulting areas by 10% to account for irrigation and other infrastructures, such as road and villages.

Table A- 5: Detail of Gross command area and Net Irrigable Area

Canal	Block	Length	GCA	NIA	Qd
		(km)	(Ha)	(Ha)	(m^3/s)
MC		13.20	1,317.80	1,000.00	2.46
SC-1	B-1	1.30	98.34	75.00	0.2
SC-2	B-2	1.85	302.76	232.00	0.5
SC-3	B-3	3.00	345.45	264.00	0.5
SC-4	B-4	2.50	329.80	252.00	0.5
SC-5	B-5	1.80	241.45	185.00	0.4

4.3. PUMP SYSTEM DESIGN

4.3.1. Capacity and number of pump used

The calculation of pump capacities was based on peak water demand for the scheme based on 24 hours daily operation period, in order to utilize a minimum number of pumps. Calculated and adapted peak demand flow for the pump is 1.23 m^3/s with 50% overall irrigation efficiency. The flow is slightly higher than the respective peak demand by 10%. Pumps are to be selected to transfer the required peak flow water from Kinyeti River bed level (572 masl) in the wet well at the discharge chamber level 586 masl in the command area, 1.6 km away from the source.

Three parallel Pumps of similar characteristics are planned to deliver the required discharge of 1.23 m^3/s to the irrigation field. The arrangements would be two operational and one standby. The pump diameter was determined by taking the velocity of 1.6 m/s for both suction line and the transmission main. The pipe diameter calculated for the suction line and the transmission main is indicated in Table 6 here under.

LOCATION

The location of pump station should be selected at the safe place considering the area of the floodplain. There is no stage-discharge data for Kinyeti River at the selected pumping station. River bed elevation at selected pump station is 572 m and for the sake of costing the project, it has been assumed that the pump station shall be built 90m far from the river at the ground elevation of 574 m. These assumptions will be reviewed as more hydrological data are collected, and more importantly it becomes possible to obtain some accurate cross-sections of the river channel and adjacent flood plains.. The connection channel was also considered to lift the river water to the pump station. The Pump house is also considered for the pumping station to protect the facilities.

PIPELINE

The irrigation water lifted by the pump is carried to the night storage at high ground in the command area through 1,000 mm diameter steel pipeline. The diameter of the pipe was determined by pre determining of flow velocity inside pipe as 1.6 m/s. Summary of the pump and pipe line data is presented in Table 6 below, whereas detail calculation is given in Table 7.

Table A- 6: Summary of Pump and pipeline data

1	**Pipe Data**					
	Pipe	No	Ø , mm	Q, (m^3/s)	V, m/s	L, m
	suction	3	700	0.615	1.6	12
	Delivery -1	3	700	0.615	1.6	15
	Delivery-2	1	1000	1.23	1.6	1582
2	**Calculated Design head, Pump shaft power and Planned diesel engine output**					
	Configurations, 2+1	Two operational plus one standby				
	Design Total Head (H)	19m				
	Power at pump shaft	175 KW				
	Planned diesel engine output	201.KW				

TOTAL REQUIRED PUMP HEAD

The required flow head at the pumping station is computed by considering the minimum water level in the river and the required head at the discharge of the pumping in the canal. In general, the required total pump head is determined based on suction and discharge water level as well as head loss due to friction in flow. The suction water level for the pump is determined based on the water levels of Kinyeti whereas pump discharge level is to be fixed with the high water level in the irrigation canal which is obtained from the available 1meter contour interval topographic map. Total head losses were calculated by using the following standard formulas and the results are summarized in Table 7 below.

$$H = H_a + h = H_a + h_f + f + \frac{V^2}{2g}$$

$$H_a = Z_1 - Z_2$$

Where

V	=	velocity in m/s taken as 2.6 for delivery and 1.5 for suction
H	=	Total head required for the pump (m)
Ha	=	Actual head (m)
H	=	Total head loss=h_f+f+V^2/2g
Z_1	=	Discharge water level (m)
Z_O	=	Suction water level(m)
h_f	=	Major Friction head loss in pipe (m)
F	=	Minor friction loss
G	=	Acceleration due to gravity (9.81m/s^2)

I. Head Loss Calculation in Pumping System

Major friction head losses in pipes were computed using Hazen-Williams Friction Loss Equation and the computation was made by the use of Pipe Flow Expert Software to estimate the head loss in the pipes. The calculations results and hydraulic parameters of the pipes lines are presented in Table 7 and the Hazen-Williams Friction Loss Equation is as follows:

$$h_f = \frac{10.67 \times Q^{1.85}}{C^{1.85} \times D^{4.8655}} \times L$$

Where

hf = Major head loss (m)
C = Hazen-Williams roughness coefficient, 100
L = Pipe length (m)
D = Pipe diameter
Q = Discharge in the pipe (m3/s)

From the above and taking for minor losses 10% of the major loss, total head loss (H) is, therefore: $h = h_f + h_m$

Based on the above, the total head loss, h is as indicated in table 7 below.

Table A- 7: Calculated Pump data

1	**Basic Data**	Required discharge per 24 hours	m^3/s	1.23
		Number of Pumps	No	3
	Pump arrangement:	Two operational plus one stand by		2+1
		Required discharge for one pump	m^3/s	0.615
		Transmission line Length	m	1582.00
2	Actual head	Design intake water level (Z_O)	m	574
		Design outlet level (Z_1)	m	586
		Static Head (Ha)	**m**	12
3	Friction head loss			
3.1	Suction Pipe	Q	m^3/s	0.615
		Diameter	mm	700
		Length	m	10
		Cross Sectional Area	m2	0.384845
		Water Flow velocity	m/s	1.6
		Hazen-Williams roughness coefficient, C		100
		hf		0.0491
3.2	Delivery Pipe 1	Q	M^3/s	0.615
		Pipe		steel
		Diameter	mm	700
		Length	m	15.00

		Cross Sectional Area	m^2	0.3848
		Water Flow velocity	m/s	1.6
		Hazen-Williams roughness coefficient, C		100
		hf		0.0737
3.3	Delivery Pipe 2	Q	M^3/s	1.23
		Diameter	mm	10008
		Length	m	1582
		Cross Sectional Area	m^2	0.785398
		Water Flow velocity	m/s	1.6
		Hazen-Williams roughness coefficient, C		100
		hf		4.94
		Friction head loss (m)	m	5.06
		Static head (m)	m	12
		Total Head (m)	m	18.77
		Design total head (H)	m	19
		Power at pump shaft	KW	175
		Planned diesel engine output	KW	201

Power at pump shaft and diesel engine output were estimated by using the following formulas.

POWER AT PUMP SHAFT

$$P_s = \frac{QH}{366\eta}$$

where

PS = Pump shaft Power in kW

Q = Discharge in m3/hr

η = n Efficiency in %, 65

DIESEL ENGINE OUTPUT

$$P = P_s \frac{1+A}{\eta t}$$

where

p = Diesel engine output in KW

PS = Pump shaft Power in kW

A = Allowance (0.15 for the case of diesel engine) r

ηt = Transfer efficiency (Fixed at 1.0 as direct jointing is applied)

4.4. NIGHT STORAGE

The plan is that water will be pumped from the Kinyeti River continuously for 24 hours every day while Main, Secondary, Tertiary and on farm irrigation system operate for 12 hours a day. The maximum irrigation requirement is 1.36 l/s/ha for a 24-hour period, which is equivalent to 2.73 l/s/ha for 12-hour irrigation period. Night Storage located at the head of Main canal store during the night-time flows for release during day time irrigation. The storage capacity of the night storage was designed to accommodate the night time pumped water to allow for 24 hours operation period of the pump operation. The total volume of the storage is around 50% of the daily requirement for 1,000 ha and estimate of the storage is included in the bill of quantities.

The night storage is located near the head regulator of the main canal, which is equipped with proper inlet and outlet structures. The structures include the following components:

- Inlet chamber that opens towards the night storage body
- Outlet chamber with a gated outlet on the wall facing the night storage body.
- An RC pipe starting at the canal side of the chamber leading D/S of the drop.

In order to minimize the area occupied by the reservoirs, their effective depth is maximised to 1.5–2.0 m. Additional dead-storage depth of 0.50 m is provided to account for silting

4.5. MAIN CANAL (MC)

The main canal, which feeds four Secondary canals (SCs) is about 9.4 km stretching between the irrigation outlet at the night storage and the off taking of the fourth Secondary canal. It is planned to conduct the irrigation water from the storage to the secondary canals. The alignment of the canal follows a contour line, which runs along the left flank of the command area with a longitudinal slope of 0.33 m/km, and commands the irrigation Blocks. All the blocks lie at an elevation lower than the MCs and will be irrigated by gravity from the canals. The canal is unlined and aligned between the contour lines of 582 masl and 577 masl to minimize loose of head. Consequently, it is totally dugout type nearly all along except for few meters of localized depressions, which requires minor filling.

4.6. SECONDARY CANAL (SC)

The SC takes off from the MC. It runs on the ridge across the contour down the prevailing slope of 0.3-4%, which is steep for earthen canal and requires several drop structures. In general, the secondary canals are aligned on the ridges across the contour to serve areas between two valley lines. The sizes of the SCs vary depending on the area serviced by each secondary canal. There are four secondary Canals (SCs). All the SCs are designed as earthen canal with several drop structures that incorporate turnout on left and right sides. The size and area commanded by each SC is given in Table 5 and 8.

4.7. TERTIARY CANALS (TC)

TCs take-off from secondary canals and are designed to supply water for irrigation of a net command area of 8 to 32 ha. The design principles are the same as adopted for the MCs and SCs,.

Water is distributed down through take-off structures into field ditches, proportional to the area irrigated. The tertiary canals generally run down the prevailing slope in earth channels at the full supply level (FSL), at or a little below ground level.

4.8. FIELD CANALS (FC)

FCs are planned to take-off either from the SCs or tertiary canal and supply irrigation water to the farm unit. They run along the contour lines and serve the irrigated fields. The FCs serves plots of 4 ha – 7ha. The design discharge of field canal has been taken as less than 30 l/s based on the handiness of water rotation within the tertiary. An effort has been made to keep the farm flow within tolerable range, between 15lit/sec-30 L/sec, as optimum, which can be managed by individual farmers. The canals are connected to the secondary canals by turnouts.

5. DESIGN OF CANAL SECTION

The design discharge is taken as 2.45 m^3/s .at the head of the main canal with irrigation duty of 2.73 l/se/ha. This was calculated with 50% overall irrigation efficiency and 12 hours daily operation period including a flexibility factor of 10% to cater any future changes in irrigation planning. The different components of the subsidiary canal like, secondary, tertiary and the Farm canals have been also designed with a range of duties to account for the transit losses. Hydraulic parameters of the canals are presented in Table 8 below. The canals are designed as earthen trapezoidal cross-section, using standard Manning's formula

$$Q = AV; V = \frac{1}{n} R^{2/3} \sqrt{S}$$

Where

Q = Design Discharge (m3/sec)
A = Cross-sectional area in (m2)
V = Mean velocity (m/sec)
R = Hydraulic mean depth (m)
S = Slope of canal (m/m)
n = Manning's Roughness Co-efficient, (adapted value 0.025)

Table A- 8: Main and Secondary Canal Parameters

canal	Q	S	B	y	z	A	P	R	V	Fb
	m^3/sec	m/km	m	m		m2	m		m/s	m
MC										
1st Reach (00-3022m)	2.46	0.33	1.24	1.5	1	4.1	5.48	0.75	0.6	0.5
2nd Reach (3022-9322m)	1.000	0.6	0.8	0.95	1	1.67	3.49	0.48	0.6	0.4
SC-1	0.2	1.76	0.35	0.43	1	0.33	1.56	0.21	0.6	0.20
SC-2	0.5	0.96	0.56	0.67	1	0.83	2.47	0.34	0.6	0.31
SC-3	0.5	0.96	0.56	0.67	1	0.83	2.47	0.34	0.6	0.31
SC-4	0.5	0.96	0.56	0.67	1	0.83	2.47	0.34	0.6	0.31
SC-5	0.4	0.96	0.55	0.66	1	0.80	2.21	0.3	0.6	0.30
FC-1	0.01274	5.13	0.2	0.12	1	0.03	0.46	0.06	0.4	0.15
FC-2	0.02107	2.68	0.2	0.17	1	0.05	0.62	0.08	0.4	0.15

5.1. INTAKE STRUCTURES

Proposed intake structures on the main canal and at the head of Secondary canals include Diversion Boxes and Turnouts along with drop/falls. The purpose of these devices is to admit and regulate water from the parent canal. The design and other aspects of these structures are discussed below. The planned intake structures on the main and secondary canal-1 are summarized in Table 9 below.

5.1.1. Division boxes

Division boxes are required to facilitate the passage of appropriate portion of the flow from main canal to secondary canal and from secondary to tertiary canal in some cases. Broad crested formula is used to determine the dimensions of the structure.

5.1.2. Design of division box at 1+900 of MC (SC-1)

Portion of flow in MC is to be diverted to SC-1. The control sections of the off takes are designed as broad crested weir and controlled by lift gate.

Discharge of parent canal = 2.46 m^3/s

Off taking canal (SC-1) = 0.3 m^3/s.

The width of the opening to the

$$Q = CLH^{3/2}$$

Where

Q = Design Discharge (m^3/sec)

C = Discharge coefficient (1.7)

H = Water depth (m)

For :

Q = 300 l/sec and

H = .52 cm

L = 0.42

The following dimensions in Table 9 are determined and are found to be adequate for the intended magnitude of flow to pass to the next conveying structure.

Table A- 9: Dimensions of the Davison Box on MC

Location		Chainage	Q	Off taking Structure		
Parent Canal	Off taking Canal	(Km)	(m3/s)	Division Box		
				B-1	B-2	H
MC	SC-1	1.90	0.2	0.42	1.24	0.43
	SC-2	2.90	0.5	.54	1.24	0.67
	SC-3	7.80	0.5	0.54	0.8	0.67
	SC-4	9.70	0.5	0.64	0.8	0.67
	SC-5	12.34	0.6	0.66	0.8	0.66

5.1.3. Drop Structures

Drop structures are designed for open secondary canals as straight vertical falls. Most of the drop structures are so arranged that they can be used along with the off taking points for field canals on both sides of the secondary canals. Groves are provided in the sidewalls for fitting sheet metals gate to regulate flow into the off taking. The dimensions of the drop structures are determined using the following formulas.

Design of drop structure at CH 325.40m on SC-1 Hydraulic characteristics of the canal

Q (m^3/s)	Bed width, B (m)	Water Depth, y (m)	Side slop	Velocity (m/s)	Height of drop (m)
0.3	0.43	0.52	1:1	0.6	1

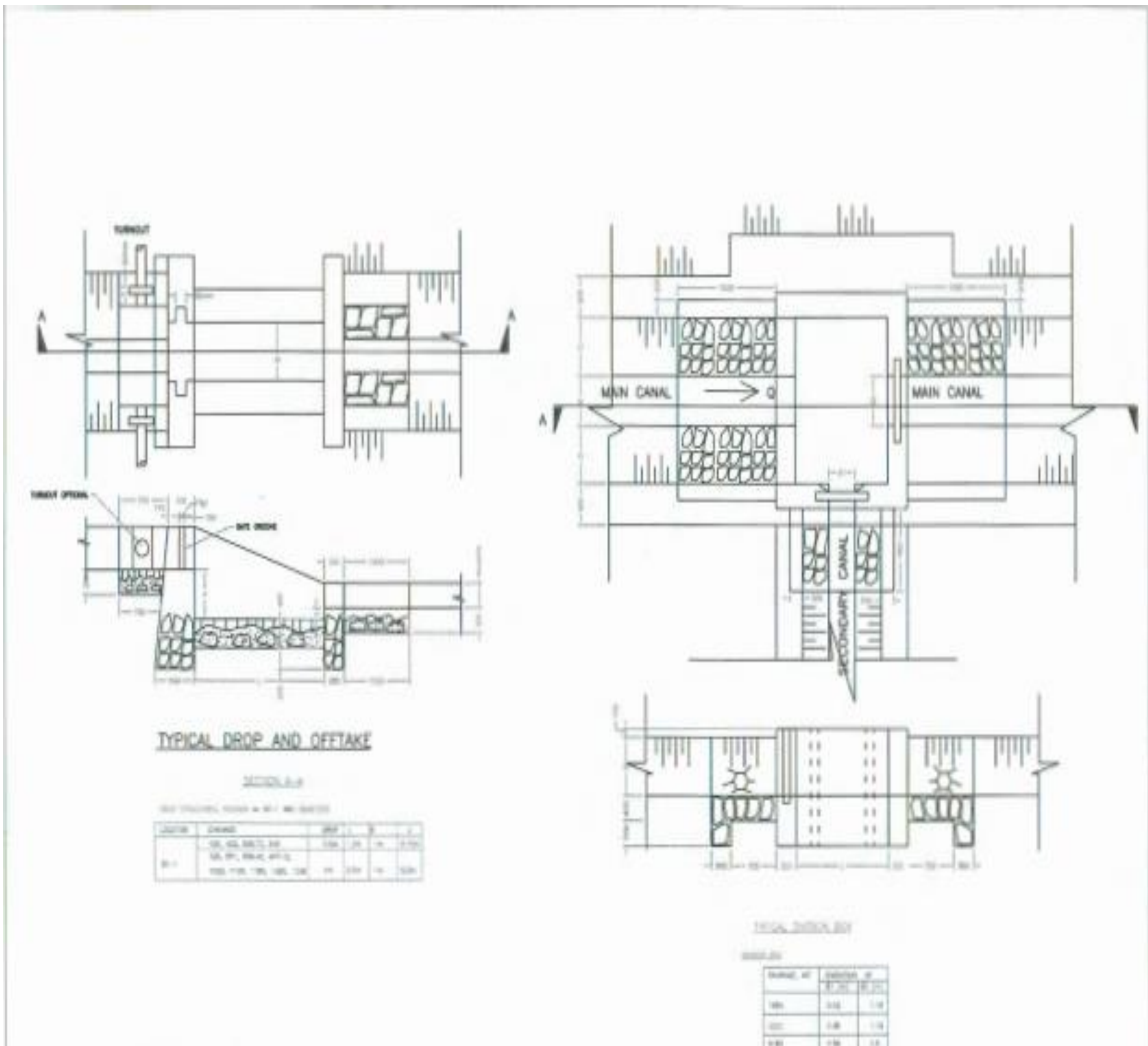


Figure 2:- Typical Drop with Offtake & Drop Box

i.Critical flow hydraulics

	Design Discharge, Q	=	0.2m3/s
b	Height of the drop	=	TELu/s-TELd/s=1
c	Width of drop bc	=	$\frac{0.734Q}{d_1^{3/2}}$
	Critical depth, dc	=	$\left[\frac{q_c^2}{g}\right]^{\frac{1}{3}}$
	Q	=	$\frac{Q}{b_c}$

ii **Stilling basin**

Length, L

$$\left(2.5+1.1\left(\frac{d_c}{h}\right)+0.7\left(\frac{d_c}{h}\right)^3\right)(hd_c)^{1/2}$$

Lip height, a

$$\frac{d_c}{2}$$

Basin width, B =

$$\frac{18.46\sqrt{Q}}{Q+9.91}$$

Abutments and wing walls will be designed against horizontal earth pressure and top level will be kept between 0.3 to 0.60 m higher than FSL as freeboard. Drop position and location of the drop structures for secondary canal 1 are summarized in the Table 10 below.

Table A- 10: Drop Structures positions on SC-1

No	location	Chainage (m)	Qnt	h	L	B	a
	SC-1		2	0.5	1.2	1	0.15
	SC-1		7	1	2.5	1	0.3

6. PROVISION OF ROADS

Currently, the project area is accessed through Juba-Torit all weather road. In addition, 18 km road to be used for farming and maintenance of facilities is planned along the main canal, secondary canal and tertiary canal

7. COST ESTIMATE

Project cost was calculated through detail estimate for pump station and main transmission pipeline, main and secondary canals in combination with cost estimate of the selected sample model areas in the case of on farm works.

Quantities of entire quantities including earth work volume for the main canals and secondary canals were worked out from respective dimensions on the drawing of the structure to provide complete list of quantities in order to prepare respective cost estimate for the work.

Regarding on farm work, the work volume was worked out on the basis of the selected sample model areas to develop cost per hectares for on farm works which includes farm structures such as farm canals and turnout. Block served by the secondary canal one was selected for detail cost analysis to develop the cost per hectare for on -farm irrigation facilities. Accordingly, longitudinal section of these selected farm canals including drop structures and turn outs details were considered for preparing cost estimate for the work volumes. Finally, combinations of the two type of cost estimate constitute total project cost. Summary of the bill of quantities is presented in Table 11 below.

Table A- 11: Kinyeti Irrigation & Drainage Project Bill of Quantity

S/ N	Description of items	Unit	Quantity	Unit Rate	Total Amount
				USD	USD
A	**General provisos**				
	Mobilization and demobilization				14,000.00
	Camping	LS			6000.00
	Sub total				20,000.00
B	**Pump station and pipeline work**				
1	**Pump house**				
1.1	Earthwork in excavation in foundation	m3	601.34	11.00	6,614.74
1.2	RCC Support Pillar and Cement concrete work in levelling	m3	15.67	448.19	7,023.14
1.3	Backfill	m3	37.33	11.00	410.63
1.4	20cm thick wall including roofing	m2	280	2,852.11	798,590.80
1.5	**Sub Total**				**812,639.31**
2	**Pump and accessories**				
2.1	Pump and engine with all the accessories	no	3	275,024.83	825,074.49
2.2	Control Panel	no	1	88,109.81	88,109.81
2.3	Overhead crane (5 ton)	no	1	79,349.76	79,349.76
2.4	Butter fly Valve (Ø700mm)	no	3	33,614.15	100,842.45
2..5	Check Valve (Ø 700mm)		3	65,191.10	195,573.30
2.6	Faxable tube (Ø 700mm)		6	8,250.74	49,504.44
2.7	**Sub Total**				**1,338,454.25**
3	**Approach Canal**				
3.1	Excavation in ordinary soil	m3	200	11.00	2,200.00
3.2	Gabion work	m3	256	140.00	35,840.00
3.3	Temporary river diversion	LS			4,564.80
3.4	**Sub Total**				**42,604.80**

4	**Pipe line work**				
4.1	Excavation in ordinary soil		1437.6	10.00	14,376.00
4.2	Sand around the pipe	m3	1624	24.00	38,976.00
4.3	Supply and install the following steel pipes complete with packing, bolt and nuts				-
4.31	700mm steel pipe with plain end to weld	m	75.00	600.00	45,000.00
4.3.2	1000mm steel pipe with plain end to weld	m	2036.38	1,200.00	2,443,656.00
4.4	**Sub Total**				**2,542,008.00**
	Total for Pump station and pipeline				**4,735,706.36**

Table 11:- Kinyeti Irrigation & Drainage Project Bill of Quantity

S/ N	Description of items	Unit	Quantity	Unit Rate	Total Amount
				USD	USD
6	**Night storage**				
6.1	Earth Work in excavation including all lead and lifts in all type of soils complete in all respect.	m3	55,500.00	11.00	**610,500.00**
6.2	Provision of Inlet and outlet chamber (35% of the earth work)	LS			**202,910.40**
6.3	Fencing with barbed wire around the reservoir	LS			**8,500.00**
6.4	Total for Night storage				**821,910.40**
S.No	Item	Unit	Quantity	Unit Rate	Total Amount
C	**Main Canal**			USD	USD
1	Site clearing to remove top soil to an average depth of 0.20 m	M^2	37401.97	2.00	74,803.93
2	Canal Excavation in ordinary soil to an average depth of 1.40mt from the reduced level in an ordinary soil and shaping to the required shape as per the drawing and direction of the site engineer	M^3	30354.34	11.00	333,897.75
3	Cart away surplus excavated material as directed by the site engineer	M^3	39704.8321	9.00	357,343.49
4	Cross drainage work	no	4	18,700.00	74,800.00
	Sub Total for Main Canal excavation				**840,845.17**
C	**Secondary canals**				
1	**Secondary canal 1 (SC-1)**				
1.1	Site clearing to remove top soil to an average depth of 0.20 m	M^2	2609.63	2.00	5,219.26
1.2	Canal Excavation in an ordinary soil to an average depth of 0.5mt from the reduced level and shaping to the required shape as per the drawing and direction of the site engineer	M^3	262.29	11.00	2,885.16
1.3	Cart away surplus excavated material as directed by the site engineer	M^3	914.69	9.00	8,232.25
1.4	**Sub Total for SC-1 excavation**				**16,336.67**

Table 11:- Kinyeti Irrigation & Drainage Project Bill of Quantity

S/ N	Description of items	Unit	Quantity	Unit Rate	Total Amount
				USD	USD
2	**Secondary canal 2 (SC-2)**				
2.1	Site clearing to remove top soil to an average depth of 0.20 m	M^2	4763.69	2.00	9,527.38
2.2	Canal Excavation in to an average depth of 0.5mt from the reduced level in an ordinary soil and shaping to the required shape as per the drawing and direction of the site engineer	M^3	1701.63	11.00	18,717.97
2.3	Cart away surplus excavated material as directed by the site engineer	M^3	2892.56	9.00	26,033.01
2.4	**Sub Total for SC-2 excavation**				**54,278.36**
3	**Secondary canal 3 (SC-3)**				
3.1	Site clearing to remove top soil to an average depth of 0.20 m	M^2	8025.83	2.00	16,051.67
3.2	Canal Excavation in ordinary soil to an average depth of 0.5mt from the reduced level in an ordinary soil and shaping to the required shape as per the drawing and direction of the site engineer	M^3	2866.90	11.00	31,535.93
3.3	Cart away surplus excavated material as directed by the site engineer	M^3	4873.36	9.00	43,860.25
3.4	**Sub Total for SC-3 excavation**				**91,447.85**
4	**Secondary Canal 4**				
4.1	Site clearing to remove top soil to an average depth of 0.20 m	M^2	6338.49	2.00	12,676.99
4.2	Canal Excavation in ordinary soil to an average depth of 0.5mt from the reduced level in an ordinary soil and shaping to the required shape as per the drawing and direction of the site engineer	M^3	2264.16919	11.00	24,905.86
4.3	Cart away surplus excavated material as directed by the site engineer	M^3	3,848.79	9.00	34,639.14
4.4.	**Sub Total for SC-4 excavation**				**72,221.99**
5	**Secondary canal 5 (SC-5)**				
5.1	Site clearing to remove top soil to an average depth of 0.20 m	M^2	4396.69	2.00	8,793.39

Table 11:- Kinyeti Irrigation & Drainage Project Bill of Quantity ...Con't

S/ N	Description of items	Unit	Quantity	Unit Rate	Total Amount
				USD	USD
5.2	Canal Excavation to an average depth of 0.5mt from the reduced level in an ordinary soil and shaping to the required shape as per the drawing and direction of the site engineer	M^3	1368.35534	11.00	15,051.91
5.3	Cart away surplus excavated material as directed by the site engineer		2467.53	9.00	22,207.76
5.4	**Sub Total for SC-5 excavation**				**46,053.06**
6	**Field canal**				
6.1	**Field Canal (FC-1)**				
6.1.1	Canal Excavation to an average depth of 0.3mt from the reduced level in an ordinary soil and shaping to the required shape as per the drawing and direction of the site engineer	M^3	22.27	11.00	244.97
6.1.2	Cart away surplus excavated material as directed by the site engineer		18.50	9.00	166.50
6.2	**Field Canal (FC-2)**				
6.2.1	Canal Excavation to an average depth of 0.3mt from the reduced level in an ordinary soil and shaping to the required shape as per the drawing and direction of the site engineer		72.80	11.00	800.80
6.2.2	Cart away surplus excavated material as directed by the site engineer		65.00	9.00	585.00
6.2.3	Total for field canal 1&2 (18.82 ha)	ha	10.82	166.11	1,797.27
6.2.4	Total for Field canal	ha	1000	166.11	**166,106.28**
7	**Interceptor Drain Right (ID)**				
7.1	Site clearing to remove top soil to an average depth of 0.10 m	M^2	4103.20	2.00	8,206.40
7.2	Excavation of drain to an average depth of 30cmin an ordinary soil and shaping to the required shape as per the drawing and direction of the site Engineer	M^3	2764.30	11.00	30,407.31
7.3	Sub Total For ICD				38,613.71

Table 11:- Kinyeti Irrigation & Drainage Project Bill of Quantity ...Con't

S/ N	Description of items	Unit	Quantity	Unit Rate	Total Amount
				USD	USD
8	**Canal Intake structures**				
8.1	**Drop & Turn out**				
A	**1 m drop**				
8.1.1	Excavation	m3	2.97	11.00	32.67
8.1.2	30 cm thick hard basaltic or equivalent stone masonry wall including floor, bedded and jointed in cement mortar 1:3	m3	2.67	141.00	376.47
8.1.3	Back fill the sides of the wall with selected materials and well compacted	m3	0.8	9.00	7.20
8.1.4	20 cm thick mass concrete to the bottom surface of the basin over 20cm hard core	m3	0.992	380.00	376.96
8.1.5	Apply three coats of cement mortar plaster 1:3 to all internal walls including external above the ground as well as bottom surface of the structure	m2	11.6	38.00	440.80
8.1.6	supply and fixe Ø 20cm Con. pipe including 8 mm x400mm x 400mm sheet metal slides in grooves for regulating discharge into the off take	pcs	2	70.00	140.00
8.1.7	Stone pitching out side the stone masonry wall	m2	7.5	76.00	570.00
8.1.8	Sub Total Cost for one Drop with Turn out on both sides	no	1	1,944.10	1,944.10
8.1.9	total cost for Turn out on SCL-1 (132ha)	no	9	1,944.10	17,496.90
8.1.10	**Total 1m Drop & Turnout for the project (1000ha)**		80.00	1,944.10	**155,528.00**
B	**0.5 m drop**				
8.1.1	Excavation	m3	2.4	11.00	26.40
8.1.2	30 cm thick hard basaltic or equivalent stone masonry wall including floor, bedded and jointed in cement mortar 1:3	m3	2.13	141.00	300.33
8.1.3	Back fill the sides of the wall with selected materials and well compacted	m3	0.6	9.00	5.40
8.1.4	20 cm thick massc concrete to the bottom surface of the basin over 20cm hard core	m3	0.57	380.00	216.60
8.1.5	Apply three coats of cement mortar plaster 1:3 to all internal walls including external above the ground as well as bottom surface of the structure	m2	7.8	38.00	296.40
8.1.6	supply and fixe Ø 20cm Con. pipe including 8 mm x400mm x 400mm sheet metal slides in grooves for regulating discharge into the off take	pcs	2	70.00	140.00

Table 11:- Kinyeti Irrigation & Drainage Project Bill of Quantity ...Con't

S/ N	Description of items	Unit	Quantity	Unit Rate	Total Amount
				USD	USD
8.1.7	Stone pitching outside the stone missionary wall	m2	5.5	76.00	418.00
8.1.8	Sub Total Cost for one Drop with Turn out on both sides	no	1	1,403.13	1,403.13
8.1.9	total cost for Turn out on SCL-1 (132ha)	no	4	1,403.13	5,612.52
8.1.10	**Total 0.5m Drop & Turn Out for the project (1000ha)**		**22.00**	**1,403.13**	**30,868.86**
2	**Division Box**				
8.2.1	Excavation	m3	47.42	11.00	521.62
8.2.2	30 cm thick hard basaltic or equivalent stone masonry wall including floor, bedded and jointed in cement mortar 1:3		16.8	141.00	2,368.80
8.2.3	Back fill the sides of the wall with selected materials and well compacted		3	9.00	27.00
8.2.4	20 cm thick mass concrete to the bottom surface of the box over 20cm hard core 1:2:4		0.8	380.00	304.00
8.2.5	Apply three coats of cement mortar plaster 1:3 to all internal walls including bottom surface of the box structures		13.45	38.00	511.10
8.2.6	supply and fixe Ø 50 cm Conc. pipe including 8 mm sheet metal slides gate in grooves for regulating discharge into the off take	no	1	160.00	160.00
8.2.7	Stone pitching for protection work	m3	1.5	76.00	114.00
8.2.8	Sub Total Cost for one Division Box			4,006.52	4,006.52
8.2.9	**Sub Total Cost for Division Box**	**no**	**4.00**	**4,006.52**	**16,026.08**
8.2.10	**Sub total for intake structure**				**202,422.94**
	Total for Irrigation canal				**1,528,326.02**
6	Farm road along the MC, Secondary and tertiary Canals & Access to Pumping station	km	20	42,000.00	**840,000.00**
7	**Total Direct cost**				**7,945,942.77**
			Taxi (15%)		1,191,891.42
			Overhead cost (40%)		3,178,377.11
Detail Design and construction supervision (10%)					1,112,431.99
Physical and price contingency (15%)					1,835,512.78
G. Total					**15,264,156.07**
Command are = 1000 ha					**15,264 USD/ha**

Annex 3: Digital Elevation Model

I/ SELECTED IMAGES

- **ALOS PRISM image characteristics**

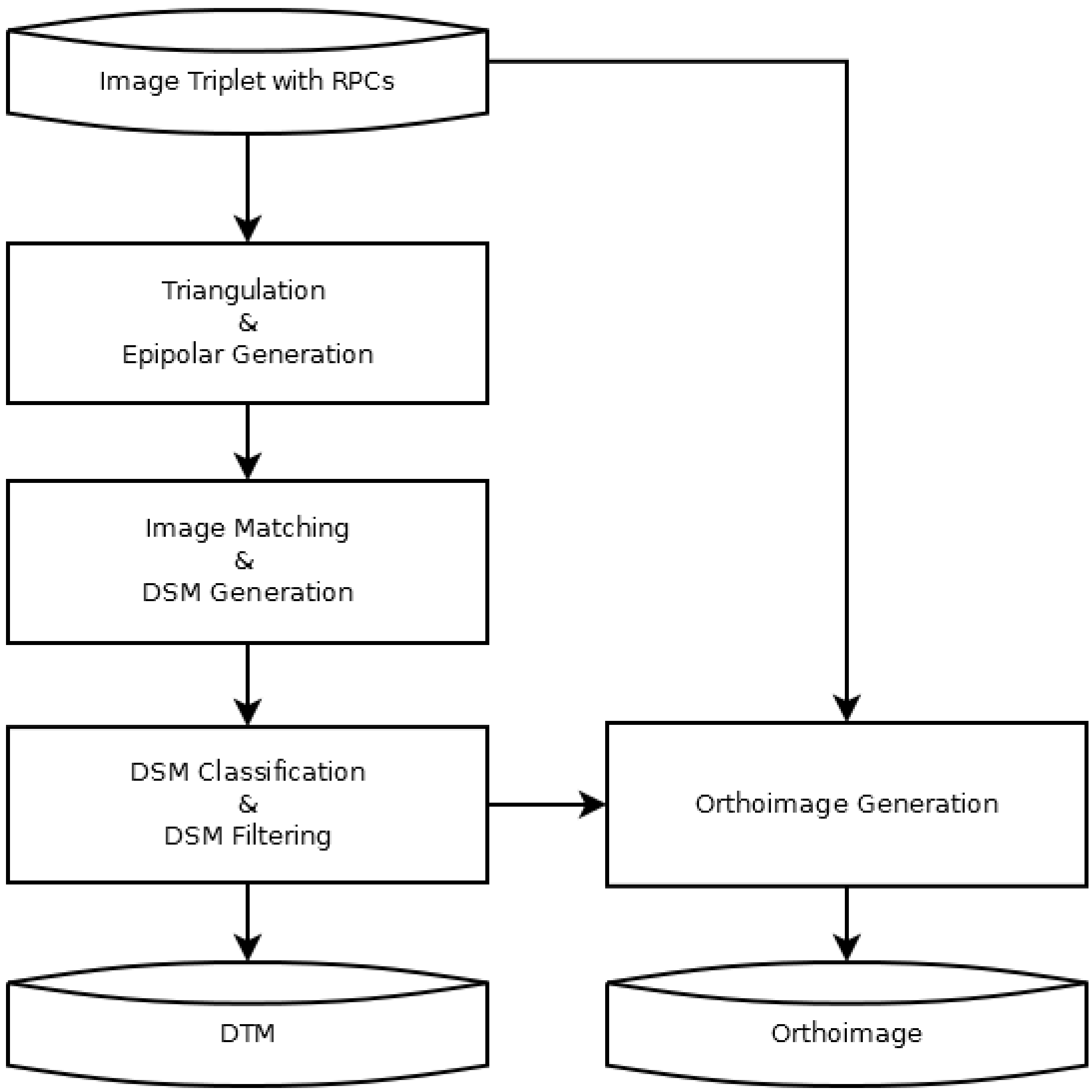
OPERATING ALOS SATELLITE			
Main data			
Name	ALOS "DAICHI"		
Constructor / Operator	JAXA	**Nationality**	Japanese
Archives	Multidates		
Delivery time	3 days to 2 weeks		
Coverage	World	**Internet On-line sale**	Yes
Resolution	2.5m (PAN) 10m (MS) 6.25 (SAR)	**Technology**	Visible and IR image SAR
Repetition	46 days 2 days with different viewing angles	**Orbit altitude**	691.65 km
Satellite history			
Name	**Date of launch**	**State**	**Sensors**
ALOS	2006	Lost	PRISM, AVNIR, PALSAR

ALOS SATELLITE SENSORS			
PRISM			
Present on :	ALOS		
Resolution	Pixel size : 2.5 meters	**Number of bands**	1 band : Panchromatic
Scene size	35 Km x 35 Km	**Bit length**	8 bits
Stereoscopy	Triplet : Backward / Nadir / Forward	**Wavelength**	0.52 to 0.77
Characteristics	Grey scale image		

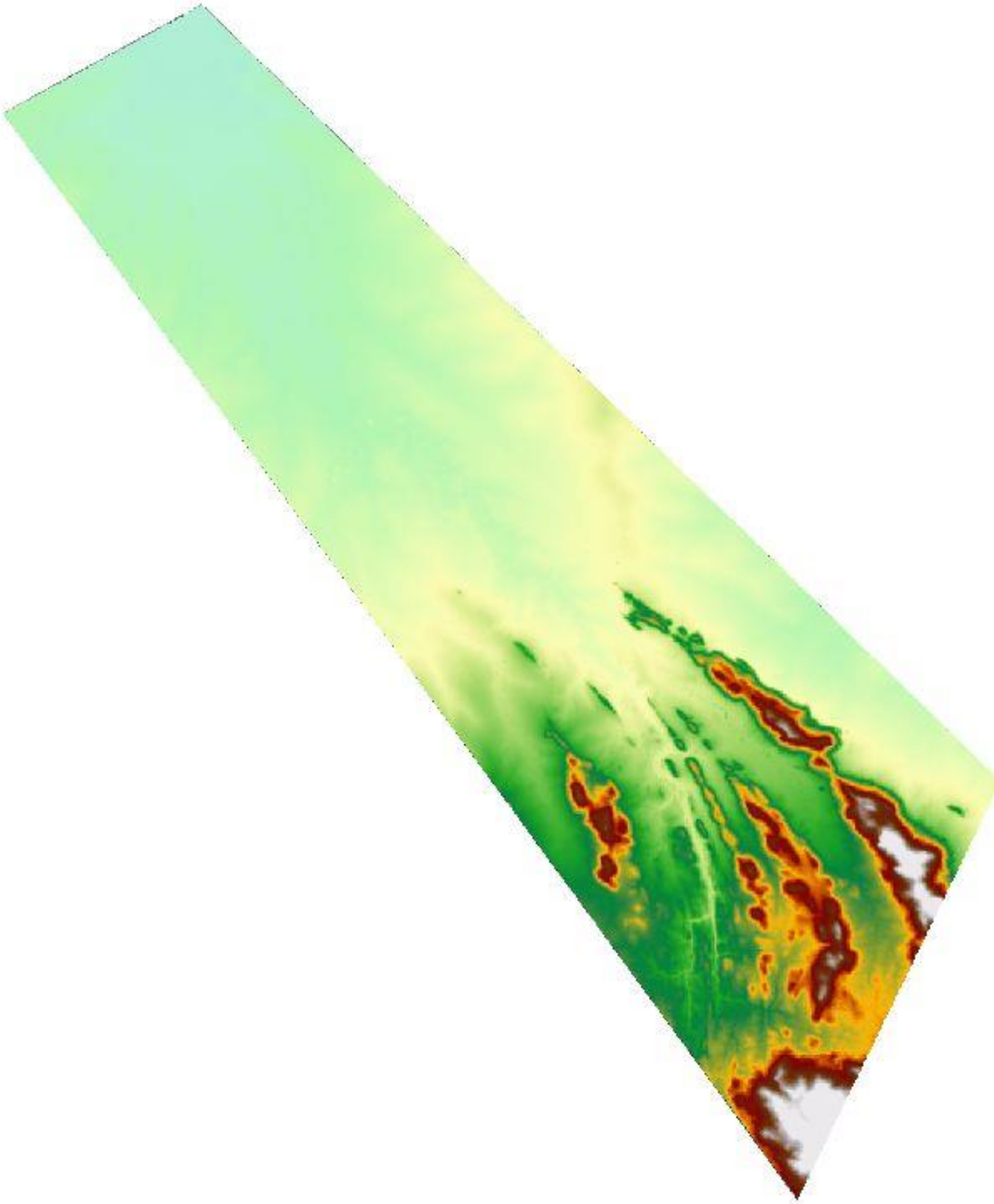
Image number	Acquisition date	Path/Row	Pixel size
ALPSMB201193510	2009-11-03	250-3510	2.5 m (1 band)
ALPSMN201193455	2009-11-03	250-3455	2.5 m (1 band)
ALPSMF201193400	2009-11-03	250-3400	2.5 m (1 band)

Image number	Acquisition date	Path/Row	Pixel size
ALPSMB097043570	2007-11-20	254-3570	2.5 m (1 band)
ALPSMN097043515	2007-11-20	254-3515	2.5 m (1 band)
ALPSMF097043460	2007-11-20	254-3460	2.5 m (1 band)
ALPSMB063493565	2007-04-04	254-3565	2.5 m (1 band)
ALPSMN063493510	2007-04-04	254-3510	2.5 m (1 band)
ALPSMF063493455	2007-04-04	254-3455	2.5 m (1 band)

III/ IMAGE PROCESSING



III/ RESULTS



DTM

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Annex 4: Meteorological and Hydrological data

CATCHMENT RAINFALL FOR THE KINYETI RIVER CATCHMENT

Year	Percentage MAP (%)												Total
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1905	1.12	1.28	3.51	10.01	12.92	11.40	11.68	15.33	13.13	12.90	5.59	3.08	101.95
1906	1.62	4.69	8.32	11.20	14.05	10.58	14.59	14.28	13.66	15.14	4.39	0.00	112.52
1907	0.00	6.32	3.58	10.61	14.49	13.13	13.75	13.18	9.64	12.00	7.85	0.00	104.54
1908	0.00	0.00	5.03	13.43	18.30	12.78	10.86	11.40	11.17	12.16	4.71	0.00	99.86
1909	1.31	1.12	6.09	13.60	13.24	10.35	12.24	11.51	11.56	9.53	5.10	3.59	99.24
1910	1.31	0.00	4.22	11.32	11.23	11.17	11.88	12.81	9.93	13.30	4.11	0.00	91.28
1911	1.06	1.30	4.55	11.72	12.40	11.49	11.02	12.19	9.84	10.14	6.47	1.29	93.47
1912	1.03	2.06	4.58	11.53	12.62	12.62	12.69	12.87	10.59	10.84	6.46	1.14	99.02
1913	0.96	2.13	3.70	12.18	12.04	11.73	11.23	11.70	9.27	10.56	4.48	1.49	91.48
1914	1.28	1.50	5.48	8.50	16.47	13.11	13.26	13.00	11.14	11.17	8.55	1.04	104.51
1915	0.00	0.83	5.95	10.21	13.14	13.15	8.87	14.74	14.21	16.16	7.43	3.33	108.03
1916	0.00	1.53	3.07	10.24	17.44	12.74	12.65	13.44	12.67	9.65	6.20	2.24	101.88
1917	1.33	2.05	1.99	15.22	13.34	14.06	12.49	13.39	12.54	10.57	3.89	1.03	101.91
1918	0.00	0.68	2.10	8.91	12.70	8.12	11.48	11.82	9.96	7.83	5.81	1.76	81.16
1919	0.00	0.81	4.10	11.68	15.25	12.84	16.54	9.84	10.53	9.18	8.63	1.44	100.85
1920	0.76	0.73	6.64	12.30	15.26	13.21	11.09	16.01	12.89	10.44	5.91	0.95	106.18
1921	0.79	1.24	2.20	8.66	11.48	10.06	10.39	12.07	11.39	13.13	3.03	1.10	85.55
1922	1.06	1.61	7.39	8.90	15.50	9.96	10.78	11.11	10.30	12.44	4.35	2.30	95.69
1923	0.00	2.22	6.57	9.96	16.55	11.41	23.07	10.18	9.03	11.24	5.86	1.40	107.47
1924	1.00	2.39	2.16	10.67	11.76	6.87	13.98	13.86	13.06	12.35	1.88	1.53	91.49
1925	0.43	0.63	3.74	8.04	12.75	12.89	10.11	12.51	6.78	11.50	8.28	1.25	88.91
1926	0.48	0.84	2.61	11.92	11.08	8.32	20.16	15.90	12.90	11.78	5.78	0.40	102.17
1927	0.34	2.45	7.75	9.27	8.12	11.09	18.53	12.02	7.21	3.61	5.43	1.56	87.38

Year	Percentage MAP (%)												Total
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1928	0.89	0.33	3.17	15.02	19.64	11.36	14.35	9.34	9.93	15.15	6.52	0.81	106.50
1929	0.84	0.48	2.33	13.03	10.58	11.19	11.46	12.20	10.08	8.96	5.83	3.88	90.87
1930	0.00	0.73	6.59	13.62	10.91	17.22	8.86	14.62	12.47	16.54	1.83	3.23	106.62
1931	1.15	0.70	10.08	8.52	16.14	11.27	13.10	18.73	10.07	12.71	4.64	1.66	108.77
1932	0.84	0.95	12.76	8.44	12.52	9.13	13.59	17.40	15.94	12.06	2.80	1.66	108.09
1933	0.54	3.03	2.88	12.57	17.27	9.55	22.62	13.99	11.60	9.05	2.94	1.53	107.56
1934	0.00	0.42	4.47	15.64	7.74	12.53	11.68	15.94	10.10	6.83	3.78	4.04	93.17
1935	0.10	2.40	3.07	7.99	15.38	13.55	10.24	15.20	13.93	10.72	3.29	2.65	98.52
1936	0.96	5.72	2.53	9.16	11.75	19.00	10.67	13.95	10.08	9.23	0.88	2.26	96.21
1937	0.86	4.57	3.97	14.45	14.21	12.32	12.01	13.90	9.36	9.99	6.57	0.52	102.72
1938	0.46	0.44	2.25	8.74	14.16	14.57	13.23	11.69	15.24	9.81	2.46	0.90	93.95
1939	0.42	3.88	5.36	10.59	13.97	8.32	12.98	11.02	7.56	7.27	7.24	1.36	89.97
1940	1.95	5.35	3.08	5.45	15.31	8.00	15.52	13.58	2.00	2.84	8.82	0.37	82.27
1941	0.00	2.06	7.28	14.72	18.73	14.30	10.47	9.88	11.35	9.45	9.11	2.16	109.54
1942	0.05	2.72	7.56	18.48	14.35	8.94	22.32	11.11	6.84	1.88	0.40	3.24	97.88
1943	0.42	0.38	9.54	6.23	9.15	13.20	12.13	10.70	7.37	2.41	0.38	0.83	72.74
1944	0.00	3.87	7.20	7.99	15.68	5.82	15.00	9.01	20.86	11.42	6.92	1.00	104.77
1945	0.06	0.09	0.56	4.81	9.15	16.48	24.50	20.55	9.65	11.11	6.72	1.92	105.61
1946	0.23	0.00	2.83	20.21	12.66	12.28	19.82	17.94	11.34	9.86	1.79	1.23	110.18
1947	0.21	0.65	9.19	11.10	8.61	12.64	22.69	11.98	19.34	3.91	0.00	2.94	103.25
1948	0.70	1.69	1.00	9.25	14.38	14.40	12.89	12.93	11.05	31.27	8.71	0.00	118.25
1949	0.54	0.13	0.55	8.66	19.55	9.15	18.71	20.48	17.41	8.66	0.89	1.75	106.48
1950	0.02	0.12	4.43	11.52	5.21	12.78	18.53	11.20	13.10	15.50	2.97	0.43	95.81
1951	2.20	2.03	3.85	15.82	8.77	7.77	20.99	7.36	10.35	14.00	10.47	5.72	109.33
1952	0.00	0.44	6.47	5.36	8.10	4.22	25.45	15.39	9.05	4.13	3.32	0.00	81.94
1953	0.69	0.08	4.27	10.08	9.19	16.35	17.54	11.96	8.66	9.05	5.26	0.36	93.49
1954	1.29	1.04	3.25	14.40	7.13	16.57	16.08	15.92	10.70	3.61	0.20	2.33	92.50
1955	1.07	0.15	5.17	10.11	10.81	17.84	15.13	16.44	13.08	5.28	5.64	2.34	103.06
1956	0.88	3.97	4.73	8.82	13.80	9.14	14.88	16.46	16.83	8.42	1.81	0.54	100.27
1957	0.55	0.29	11.83	8.72	14.58	15.26	15.06	12.76	9.78	9.88	7.12	1.95	107.79

Year	Percentage MAP (%)												Total
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1958	1.97	4.08	3.17	7.54	11.74	19.69	23.46	19.42	3.86	8.16	1.02	3.12	107.21
1959	0.00	0.92	9.32	5.19	11.21	7.15	15.61	22.75	14.08	6.84	7.76	0.16	101.00
1960	0.45	3.95	5.66	10.94	19.22	9.65	13.28	14.45	9.94	6.87	6.09	2.73	103.23
1961	0.00	1.53	3.66	7.61	12.81	6.27	13.70	7.87	17.18	17.13	15.92	4.96	108.64
1962	5.16	0.08	5.08	12.69	23.21	17.86	19.28	19.34	17.98	14.65	9.04	1.12	145.47
1963	6.08	3.46	5.04	17.84	13.26	9.55	9.23	19.05	5.14	2.55	10.29	3.34	104.83
1964	1.42	1.47	0.95	14.17	6.00	5.89	20.47	18.22	14.26	6.92	3.81	7.52	101.10
1965	0.18	0.07	4.16	7.20	8.51	8.82	9.33	11.35	7.26	6.85	5.51	0.40	69.65
1966	0.00	6.88	8.39	16.16	8.38	8.25	17.38	10.16	8.80	10.67	5.88	0.36	101.32
1967	3.40	3.54	3.27	4.61	18.15	11.32	24.24	10.68	6.81	9.94	6.90	1.91	104.78
1968	3.15	2.99	4.14	5.78	12.95	8.57	16.49	8.70	4.77	10.81	0.72	3.11	82.18
1969	5.02	5.40	3.35	2.95	18.77	10.58	22.80	8.17	6.40	13.47	4.34	1.54	102.80
1970	3.93	0.10	15.67	11.71	9.86	12.70	12.92	22.08	11.72	10.95	1.01	0.00	112.65
1971	0.46	0.14	1.22	10.67	14.06	20.63	16.51	15.29	25.24	21.91	4.22	0.03	130.37
1972	0.70	0.30	4.06	8.92	5.49	10.93	11.65	12.85	12.29	12.41	10.57	0.79	90.97
1973	0.15	0.76	4.97	12.59	14.43	12.81	12.79	13.74	16.41	6.90	5.18	0.51	101.24
1974	0.62	1.34	9.07	18.70	10.41	10.90	27.60	17.28	19.81	6.54	6.26	0.50	129.01
1975	0.37	1.17	4.50	3.20	16.32	5.95	7.88	23.24	11.80	3.13	3.13	2.18	82.88
1976	0.37	4.77	6.25	10.24	15.10	13.96	17.11	18.16	5.72	4.43	8.19	1.08	105.39
1977	0.96	0.05	4.45	9.49	13.59	23.68	20.87	9.36	8.05	9.25	6.03	0.00	105.78
1978	0.57	3.39	3.26	9.59	10.11	16.85	21.84	11.57	10.00	8.93	5.43	0.81	102.34
1979	2.95	3.70	5.26	4.15	11.67	22.36	11.25	6.45	6.13	5.97	1.82	0.74	82.43
1980	0.00	0.39	3.77	16.31	13.14	14.71	10.67	14.57	12.22	10.95	10.26	0.00	106.99
1981	0.00	2.70	4.96	12.16	11.57	8.29	16.04	9.26	16.73	14.39	3.22	0.66	99.97
1982	0.00	0.40	4.28	9.19	18.14	15.09	13.04	14.44	9.25	14.05	6.85	1.33	106.05
1983	0.12	0.53	1.18	2.77	5.35	7.13	11.15	12.50	13.58	5.34	3.53	0.41	63.58
1984	0.00	1.10	3.40	6.52	10.47	13.80	14.73	12.01	7.39	6.92	3.60	3.22	83.17
1985	1.87	0.32	6.63	10.21	15.27	13.88	11.57	10.47	12.31	7.77	7.04	0.89	98.23
1986	3.09	2.33	3.63	13.95	13.10	11.80	14.51	13.91	11.80	12.36	5.78	0.87	107.12
1987	0.70	1.55	4.51	8.01	13.14	12.11	12.49	10.76	14.27	9.92	5.50	1.35	94.31

Year	Percentage MAP (%)												Total
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1988	0.78	1.12	3.17	11.35	12.36	9.65	13.35	17.25	10.89	11.40	6.77	2.59	100.67
1989	0.71	0.71	4.76	11.13	12.55	10.77	15.40	12.52	11.57	10.12	8.35	1.14	99.73
1990	1.04	1.26	5.79	12.76	12.74	11.93	14.92	14.86	12.33	11.27	5.90	1.14	105.93
1991	0.76	1.83	3.77	17.22	11.64	8.92	13.58	18.08	10.46	9.97	10.95	1.01	108.20
1992	1.85	1.01	4.38	11.43	8.52	11.00	11.99	10.77	9.12	14.38	4.86	1.17	90.50
1993	0.97	0.85	6.61	11.03	10.26	9.51	10.14	10.09	11.73	8.60	4.94	2.60	87.32
1994	0.40	0.00	3.37	15.61	10.58	11.97	19.74	17.91	10.12	10.99	6.53	1.07	108.30
1995	0.74	0.94	4.78	12.53	12.08	8.40	13.08	13.04	11.73	11.64	4.93	2.23	96.12
1996	2.17	1.49	4.68	13.65	13.05	12.81	10.77	10.12	10.80	11.24	3.18	1.35	95.31
1997	1.10	0.00	5.64	14.65	10.47	10.23	10.45	11.79	8.47	12.59	11.28	3.68	100.34
1998	3.17	1.02	2.05	12.38	11.65	14.34	13.89	15.74	9.72	14.43	4.33	0.89	103.62
1999	0.71	0.86	5.90	16.18	11.34	11.01	13.43	13.79	11.18	13.72	3.58	2.14	103.84
2000	1.28	1.21	2.47	10.16	11.43	13.29	12.34	13.52	10.60	13.08	5.24	1.62	96.23
2001	0.00	1.32	4.48	10.96	11.77	10.83	13.09	11.32	9.27	12.65	5.34	0.80	91.84
2002	1.90	1.15	7.61	9.92	10.81	15.23	10.26	11.64	11.04	13.46	9.57	3.76	106.36
2003	1.60	1.52	5.36	12.36	12.82	11.31	12.90	13.41	10.41	10.53	6.42	1.62	100.25
2004	1.94	1.13	4.69	13.52	10.86	13.08	12.00	17.37	10.33	11.37	6.84	0.00	103.14
2005	0.42	0.36	3.42	9.85	13.46	12.67	13.27	6.92	8.24	8.37	1.80	0.34	79.12
2006	0.24	1.03	12.03	13.51	13.25	8.29	8.35	26.58	14.42	7.65	5.13	4.47	114.94
2007	0.27	0.34	2.26	12.21	13.38	12.55	20.26	28.70	25.19	5.36	5.48	0.32	126.33
2008	3.88	0.29	2.89	7.05	9.25	15.04	12.06	14.62	22.68	19.55	7.69	0.04	115.05
2009	0.61	4.41	1.50	6.03	7.35	4.35	12.55	12.69	13.74	8.57	6.61	3.33	81.73
2010	1.80	3.41	4.84	9.45	11.16	14.60	19.28	17.88	9.68	10.72	4.07	3.22	110.11
2011	0.66	0.21	8.41	11.44	13.13	9.15	13.68	14.63	14.46	7.98	6.26	1.06	101.08
2012	1.29	0.36	4.46	12.70	12.16	12.20	13.68	13.55	19.26	18.88	5.16	6.93	120.64
2013	1.92	1.58	5.81	11.43	14.07	8.98	15.06	34.31	16.16	11.33	5.56	2.06	128.28
2014	0.92	1.34	3.15	10.35	11.79	12.33	15.22	14.25	11.11	9.72	6.07	2.18	98.43
Average	1.01	1.61	4.85	10.83	12.65	11.85	14.64	14.04	11.59	10.41	5.43	1.67	100.00

SIMULATED MONTHLY FLOWS FOR THE KINYETI RIVER CATCHMENT

Year	Average Monthly Flow (million m³)												Total
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1905	2.01	1.81	2.01	1.94	2.94	5.39	6.52	13.39	16.11	17.82	16.93	8.06	94.94
1906	5.26	3.47	3.19	2.52	9.30	12.06	17.30	23.34	25.90	30.84	21.51	10.76	165.45
1907	6.72	6.11	4.75	3.38	11.18	18.36	20.31	23.83	18.11	20.77	26.92	10.68	171.14
1908	6.67	4.27	3.41	2.68	19.91	21.65	16.94	18.64	19.34	21.38	18.38	8.72	162.00
1909	5.62	3.62	3.12	2.57	11.87	13.29	14.71	17.15	18.89	14.79	16.32	7.44	129.39
1910	4.93	3.27	2.91	2.42	5.93	11.59	12.60	17.88	15.29	20.94	15.93	8.07	121.76
1911	5.27	3.44	3.01	2.47	7.73	12.70	11.80	16.19	14.28	13.69	18.52	7.82	116.93
1912	5.13	3.48	2.95	2.44	7.84	14.53	15.59	19.77	17.70	17.09	20.64	8.79	135.94
1913	5.65	3.63	3.13	2.53	7.91	13.34	12.58	15.87	13.17	14.11	13.81	6.69	112.43
1914	4.53	3.07	2.78	2.35	10.79	17.34	18.34	21.84	20.15	19.24	27.78	10.78	159.00
1915	6.73	4.17	3.46	2.70	8.02	16.34	10.23	20.83	25.83	33.16	31.10	13.29	175.85
1916	8.08	4.99	3.84	2.90	15.40	19.94	19.36	24.22	25.31	18.42	21.88	9.30	173.65
1917	5.93	3.77	3.21	3.94	14.11	21.33	19.56	24.33	25.14	20.57	16.22	8.21	166.31
1918	5.34	3.48	3.03	2.48	6.22	7.53	9.52	14.09	13.31	8.65	14.08	6.09	93.83
1919	4.20	2.91	2.68	2.30	10.91	16.15	23.32	17.79	17.28	13.45	24.77	9.32	145.09
1920	5.94	3.89	3.19	2.57	13.25	18.99	15.64	27.33	26.67	20.90	22.09	9.69	170.15
1921	6.14	3.88	3.28	2.61	4.55	9.44	9.02	14.25	16.11	20.34	12.90	7.28	109.78
1922	4.84	3.23	2.88	2.40	9.78	11.80	11.03	13.82	14.08	18.07	15.13	7.51	114.58
1923	4.97	3.29	2.92	2.42	12.19	15.32	36.21	24.93	18.05	19.32	20.82	9.06	169.49
1924	5.80	3.82	3.15	2.54	6.34	6.08	12.32	19.79	22.49	22.39	11.17	7.19	123.08
1925	4.80	3.21	2.86	2.39	5.51	13.67	10.77	15.97	8.81	13.11	22.08	8.59	111.77
1926	5.55	3.58	3.10	2.51	5.90	7.03	22.49	29.15	27.06	24.05	22.73	10.28	163.44
1927	6.46	4.04	3.38	2.66	2.41	7.35	21.90	21.24	11.87	7.12	4.63	3.52	96.57
1928	2.82	2.29	2.25	2.99	21.27	19.16	22.06	16.57	15.77	26.32	25.08	10.86	167.44
1929	6.77	4.19	3.47	2.71	6.89	11.97	12.22	16.62	15.07	11.77	16.23	7.02	114.93
1930	4.70	3.16	2.84	2.43	7.67	22.46	12.58	22.29	23.02	33.08	15.16	9.43	158.81
1931	6.00	3.81	3.23	2.59	12.03	15.95	17.98	35.14	23.64	25.88	20.54	9.87	176.67
1932	6.24	4.05	5.90	3.65	7.12	10.17	15.64	30.43	35.36	28.77	16.87	9.54	173.74

Year	Average Monthly Flow (million m³)												Total
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1933	6.06	3.84	3.25	2.60	17.84	15.03	37.38	34.80	28.61	19.32	13.41	7.46	189.60
1934	4.94	3.28	2.91	4.26	5.88	13.61	13.83	25.71	19.38	10.29	10.39	5.47	119.96
1935	3.87	2.74	2.58	2.24	9.19	17.46	13.08	23.36	26.60	21.04	14.64	7.94	144.75
1936	5.20	4.82	3.80	2.88	5.46	25.86	17.24	24.01	19.03	14.78	8.05	5.44	136.57
1937	3.85	2.74	2.58	2.89	14.00	17.63	16.72	23.44	17.09	15.59	20.85	8.61	145.99
1938	5.56	3.59	3.10	2.52	7.98	18.36	18.56	19.30	28.02	19.39	11.76	7.06	145.18
1939	4.72	3.17	2.84	2.38	9.41	9.26	13.32	15.10	9.59	6.17	16.35	6.28	98.60
1940	4.31	3.81	3.19	2.56	7.65	8.07	15.92	20.88	10.10	6.54	11.37	5.20	99.61
1941	3.72	2.67	2.54	2.90	19.16	23.29	16.62	15.04	17.78	14.08	26.63	9.82	154.25
1942	6.21	3.91	3.30	7.91	19.39	14.72	37.17	27.86	14.81	8.82	5.52	4.02	153.65
1943	3.09	2.35	2.34	2.12	2.11	9.69	12.13	13.28	8.40	5.21	3.62	2.95	67.29
1944	2.52	2.14	2.16	2.02	7.84	5.70	11.60	10.17	30.97	23.10	24.53	10.69	133.43
1945	6.68	4.15	3.44	2.70	2.43	13.06	34.54	46.85	28.09	24.66	26.55	11.28	204.43
1946	6.99	4.30	3.54	10.44	17.86	20.51	35.32	44.00	31.72	23.27	12.05	7.69	217.70
1947	5.06	3.34	2.95	2.44	2.37	13.27	35.10	28.44	44.96	20.32	11.46	7.36	177.07
1948	4.89	3.35	2.87	2.40	8.80	18.96	18.48	22.04	20.19	69.19	50.02	21.80	243.00
1949	12.65	7.13	5.28	3.66	18.33	15.12	29.06	46.13	47.87	26.38	14.08	8.83	234.53
1950	5.68	3.65	3.14	2.54	2.34	6.82	22.97	20.20	23.94	31.02	17.53	9.77	149.58
1951	6.19	3.90	3.29	8.32	14.60	6.34	29.84	16.15	12.05	27.71	19.56	11.48	159.42
1952	6.53	4.19	3.37	2.66	2.41	2.15	24.90	30.36	21.38	11.47	6.91	4.80	121.14
1953	3.51	2.56	2.47	2.19	3.33	16.49	25.82	21.65	15.05	14.65	8.68	5.45	121.86
1954	3.86	2.74	2.58	5.11	4.90	18.83	24.49	30.41	23.60	12.20	7.26	5.00	140.97
1955	3.62	2.62	2.65	5.34	5.53	21.84	22.27	33.53	29.54	14.95	8.70	5.81	156.38
1956	4.05	2.93	2.92	2.34	6.95	10.79	17.96	27.99	34.99	22.03	11.17	7.20	151.32
1957	4.80	3.21	3.98	2.83	9.97	22.35	26.45	29.62	16.92	17.94	8.47	5.68	152.20
1958	3.98	2.80	2.61	2.26	8.19	25.33	46.53	51.03	23.54	14.00	8.24	5.55	194.06
1959	3.91	2.76	2.59	2.25	3.48	3.01	18.90	35.66	33.38	24.02	13.62	8.05	151.63
1960	5.26	3.54	2.99	3.16	16.53	16.09	21.64	21.88	21.70	12.30	7.05	4.88	137.01
1961	3.55	2.58	2.48	2.19	4.13	4.19	11.55	9.45	26.19	24.95	37.39	15.66	144.32
1962	9.35	5.48	5.08	9.36	34.20	43.92	50.19	53.29	57.93	48.18	45.34	18.57	380.89

Year	Average Monthly Flow (million m³)												Total
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1963	16.25	7.86	7.38	21.23	23.05	17.29	13.86	37.25	16.65	10.20	13.40	6.34	190.78
1964	4.34	3.07	2.71	8.55	6.10	4.08	21.67	34.12	34.58	21.11	10.68	15.45	166.47
1965	7.23	4.42	3.61	2.79	2.48	3.69	7.08	8.36	7.02	4.76	3.39	2.82	57.65
1966	2.44	3.13	2.68	5.84	6.59	5.71	18.60	14.53	13.35	18.94	7.70	5.22	104.73
1967	3.74	2.68	2.54	2.22	11.16	14.85	41.17	24.52	15.01	12.76	19.64	7.90	158.16
1968	5.18	3.50	2.96	2.44	6.14	8.34	19.15	12.02	8.08	8.50	5.18	3.83	85.32
1969	4.48	3.72	3.07	2.50	12.81	13.08	31.89	20.99	13.37	20.65	8.93	5.93	141.44
1970	4.12	2.87	14.31	15.09	10.36	19.37	20.81	43.23	34.90	28.28	13.55	8.53	215.40
1971	5.52	3.57	3.09	2.51	11.72	32.22	35.01	32.65	62.83	76.87	34.84	18.17	318.99
1972	10.70	6.33	4.63	3.32	2.78	4.83	10.71	17.01	19.78	25.77	20.70	10.61	137.18
1973	6.64	4.12	3.72	6.92	15.63	19.29	21.91	21.93	34.31	27.96	12.16	7.75	182.34
1974	5.10	3.36	4.64	14.07	14.74	17.79	52.61	48.96	60.11	27.14	17.01	10.02	275.55
1975	6.32	3.96	3.33	2.64	11.81	6.51	4.80	33.28	30.66	14.80	8.66	5.78	132.55
1976	4.04	2.92	2.62	2.26	9.70	19.37	30.75	36.80	19.55	10.84	6.58	4.62	150.06
1977	3.41	2.51	2.44	2.17	6.02	34.84	48.39	24.48	17.14	17.43	11.93	6.62	177.38
1978	4.49	3.05	2.77	2.34	2.86	22.80	34.38	28.56	20.74	18.15	8.67	5.79	154.60
1979	4.04	2.83	3.18	2.53	3.30	30.58	23.56	11.54	6.95	4.82	3.42	2.84	99.60
1980	2.46	2.11	2.14	6.34	11.00	18.92	16.89	21.78	23.02	18.98	19.05	8.69	151.38
1981	5.60	3.61	3.11	3.08	9.77	9.23	20.21	13.36	28.97	38.34	14.65	9.15	159.09
1982	5.85	3.73	3.19	2.74	20.27	24.44	29.88	21.66	18.86	29.96	17.78	9.52	187.87
1983	6.05	3.83	3.25	2.60	2.37	2.14	2.74	10.55	16.19	8.51	5.23	3.85	67.30
1984	3.00	2.39	2.31	2.10	2.10	9.42	14.24	16.20	11.65	10.59	5.44	3.97	83.40
1985	3.07	2.34	4.79	3.44	12.70	18.56	16.19	15.00	20.54	11.40	18.56	7.61	134.19
1986	5.02	3.32	2.93	3.63	13.46	14.08	20.03	21.80	25.12	27.89	11.85	7.57	156.71
1987	5.00	3.31	2.93	2.83	12.32	13.79	18.08	16.19	24.83	20.36	12.02	7.23	138.88
1988	4.82	3.32	2.85	2.98	8.54	9.13	15.66	28.42	20.33	21.71	18.04	8.81	144.60
1989	5.67	3.64	3.13	4.86	8.05	12.42	22.31	19.14	25.00	23.16	9.85	6.45	143.68
1990	4.40	3.01	2.74	2.86	10.16	17.64	20.41	24.40	26.41	24.74	12.57	7.57	156.91
1991	5.00	3.31	2.93	9.36	14.75	12.76	18.73	31.45	26.88	16.81	24.88	10.21	177.05
1992	6.42	4.14	3.34	6.31	4.15	10.82	14.09	15.97	10.34	22.26	13.94	7.35	119.13

Year	Average Monthly Flow (million m³)												Total
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1993	4.88	3.25	3.92	7.12	5.58	9.08	9.03	10.08	14.80	13.21	6.55	4.60	92.10
1994	3.40	2.51	2.44	6.89	10.96	14.98	30.60	35.73	25.50	22.86	12.04	7.25	175.16
1995	4.83	3.22	2.87	9.06	13.54	10.33	16.40	19.13	20.89	24.37	12.93	7.46	145.04
1996	4.94	3.38	2.89	3.39	12.54	16.90	17.52	12.89	15.78	23.21	10.99	6.50	130.93
1997	4.42	3.02	2.75	9.33	4.82	9.39	11.40	13.69	14.18	14.52	23.17	10.13	120.82
1998	6.38	4.00	3.35	4.77	7.07	17.37	20.10	27.16	20.30	29.99	12.65	8.03	161.16
1999	5.25	3.43	5.12	7.31	12.21	13.39	21.05	22.73	21.27	29.00	11.69	7.49	159.93
2000	4.96	3.39	2.90	2.41	6.01	13.89	16.80	20.64	18.29	30.09	11.75	7.52	138.64
2001	4.97	3.29	2.92	3.96	6.71	14.20	14.26	14.80	12.25	18.36	12.10	6.78	114.60
2002	4.57	3.09	2.80	2.94	6.32	18.19	12.86	16.75	16.58	28.40	17.32	9.40	139.22
2003	5.98	3.80	4.37	7.26	14.74	15.64	18.34	22.79	20.15	24.84	11.06	6.96	155.94
2004	4.67	3.24	2.81	8.24	13.85	18.30	17.66	32.18	22.39	21.72	20.40	9.34	174.82
2005	5.95	3.78	3.22	2.58	7.64	14.02	19.13	9.85	7.59	15.11	6.34	4.48	99.70
2006	3.34	2.48	3.57	3.90	12.50	10.03	6.41	41.57	35.66	18.88	19.42	9.84	167.60
2007	6.02	3.82	3.24	2.59	10.38	16.41	31.84	67.63	79.50	35.13	24.98	13.06	294.61
2008	7.96	4.93	3.80	2.88	2.54	15.92	15.84	24.56	49.28	54.17	42.69	18.71	243.28
2009	11.00	6.30	4.77	3.39	2.82	2.37	4.82	13.23	19.71	12.61	18.38	7.73	107.13
2010	5.08	3.35	2.95	2.44	4.33	16.00	27.99	37.58	24.12	21.36	17.11	8.56	170.88
2011	5.53	3.57	3.09	2.51	9.63	10.75	15.97	24.32	28.79	15.91	20.85	8.81	149.74
2012	5.67	3.75	3.11	2.52	8.93	14.92	17.97	22.93	39.39	47.17	31.20	22.81	220.36
2013	11.34	6.47	4.88	3.45	12.75	12.34	20.55	77.13	57.55	39.45	31.91	14.73	292.56
2014	8.85	5.23	4.11	3.05	7.18	16.06	22.54	27.85	23.54	18.24	21.63	9.18	167.45
Average	5.44	3.60	3.34	3.98	9.43	14.52	20.21	24.54	23.34	21.29	16.35	8.41	154.46