UNIVERSITY OF NAIROBI

SCHOOL OF ENGINEERING

DEPARTMENT OF ENVIRONMENTAL AND BIOSYSTEMS ENGINEERING

MSC. THESIS RESEARCH: ESTIMATION OF A SAFE RESERVOIR YIELD USING WEAP: A CASE STUDY OF THWAKE MULTIPURPOSE RESERVOIR

By

CHRISTINE NYANCHOKA OCHENGO, (F56/74756/2014).

A thesis submitted to the Department of Environmental and Biosystems Engineering, University of Nairobi, in partial fulfilment of the requirements for the Degree in Masters of Science in Environmental and Biosystems Engineering

2021

DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

Christine N. Ochengo Signature:

F56/74756/2014 Date: **02nd July 2021**

SUPERVISORS

This thesis has been submitted for examination with our approval as University Supervisors.

Mr Stephen Ondieki Signature:

Date: **2nd July 2021**

Dr. John P. O Obiero, PhD Signature:

Date: 02/07/2021

Chairman: Department of Environmental and Biosytems Engineering Signature:

Date: 2nd July 2021

DECLARATION OF ORIGINALITY

Name of student:	Christine Nyanchoka Ochengo
Registration:	F56 /74756/2014
College:	College of Architecture and Engineering
Faculty/School/Institute:	School of Engineering
Department:	Environmental and Biosystems Engineering

1) I declare that this thesis is my original work and has not been submitted elsewhere for examination, award of a degree or publication. Where other works or my own work has been used, this has properly been acknowledged and referenced in accordance with the University of Nairobi's requirements.

2) I have not sought or used the services of any professional agencies to produce this work

3) I have not allowed, and shall not allow anyone to copy my work with the intention of passing it off as his/her work.

4) I understand that any false claim in respect of this work shall result in disciplinary action in accordance with University of Nairobi anti-plagiarism policy.

Signature:

Date: 02nd July 2021

DEDICATION

I dedicate this research work to my loving dad and mum Mr & Mrs Ochengo, my dear husband Bernard Mageto, daughter Gabriella and son Darren Ben. Many thanks for the support you have given me, God bless you all.

ACKNOWLEDGEMENT

I would like to thank the Lord, without whom it could be impossible to even start this programme. He has walked with me throughout and shown me his unconditional love. All the honour and glory belongs to you Lord. I wish to express my sincere gratitude to my supervisors Mr. Stephen Conrad Ondieki and Dr. John P.O Obiero for their unwavering assistance and guidance throughout the entire programme.

I wish to acknowledge other staff members at the Department of Environmental and Biosystems Engineering, University of Nairobi for their assistance.

Finally I would wish to thank the faculty of Engineering University of Nairobi for every assistance accorded to me through to the end of the programme.

ABSTRACT

Reservoir operation in this case multi-purpose reservoir involves several competing uses like irrigation, hydropower, flood control and water supply. This study aimed at using a simulation model, WEAP model to estimate the maximum, reliable continuous and dependable reservoir yield at a particular time. WEAP model schematic was set to develop current and reference scenarios. Parameters used were a GIS map of the sub-catchment, hydrological and water demand data from WRA.

To achieve the objective, 1000 years' synthetic flows were generated using SWAT Model, and 60 years (1952-2012) historical flows were used and the projected flows input into the WEAP model. The monthly reservoir balance for the base scenario and upstream dams' development scenario were simulated. The performance of the Thwake Reservoir under different scenarios was assessed for base case and upstream development dams. The sets were tuned to the operational rules of the Thwake reservoir. The safe yield of the Reservoir is at 30% of the effective storage (488Mm^3), when setting the demands on high priority and low priority. The zone totally available for Galana Kulalu flow requirement at 80% of the remaining effective storage for the high priority demands. For low priority demands, the zone totally available for Galana Kulalu is the storage between the 897M.a.s. l and 900.7 M.a.s.l. There are also different priorities for filling/storing water in the reservoir when setting the reservoir at base scenario and at upstream development.

CONTENTS

Chapter	Description	Page

TABLES

FIGURES

List of abbreviations

A1	Irrigation area 1,
A2	Irrigation area 2
AWSB	Athi Water Services Board
CASSH	CAS/ Saleh-Hegab joint venture
CWR	Crop Water Requirement
DWS	Domestic water supplies,
EF	Environmental flow requirement,
ETo	Evapotranspiration
FDR	Final Design Report
FSR	Feasibility Study Report
GDFL	Galana downstream flow requirement,
GIS	Geographical Information System
GoK	Government of Kenya
GPS	Geographical Positioning System
HP	Hydropower Production,
IWRM	Integrated Water Resources Management
Km	kilometres
L/ha/s	Litres per hectare per second
m.a.s.l	metres above sea level
MCM	Million Cubic meters
MW	mega watts
MWI	Ministry of Water and Irrigation
PV	Permanganate Value
RGS	Regular Gauging Station
SWAT	Soil and Water Assessment Tool
TARDA	Tana and Athi Region Development Authority

TAWSB	Tana Athi Water Services Board
TMWDP	Thwake Multi-Purpose Water Development Project
UN	United Nations
WRA	Water Resources Authority
WEAP	Water Evaluation and Planning

1 INTRODUCTION

1.1 Background to the Study

The Thwake Multi-Purpose reservoir has a number of competing users that it has to meet. The uses include hydropower generation, water supply and irrigation development in Kitui and Makueni Counties. The counties are well known as semi-arid hence the key objective of the study is to estimate the safe yield of the reservoir to enhance effective allocation of the water for different competing demands (Esho, 2019).

It is also important to note that the designed storage capacity of 681MCM with a dead storage of 231MC and a live storage of 450MCM.The design life is 50years, a submerged area of 2900ha with a minimum operating level of 862 Masl (CASSH, 2014). The reservoir should meet the different demands with different priorities and still fill to provide continuous withdrawal for the demands. A safe zone that will ensure safe yield of the reservoir under different operation rules needs to be established (Zeraebruk, *et al*. 2017). This will give guidance of the respective safe yield for a given operation rule and the priority of meeting the competing uses including water supply, hydropower, environmental flow, Galana demand requirement, and irrigation.

Amit (2014) defined Safe yield as the maximum continuous release from a reservoir that is possible during a particular drought period. In estimating the safe yield of water supply manual by Christie & Martin (2011) safe yield is a projected characteristic of impending reservoir circumstances. These circumstances cannot be real or actual due to the projected future conditions.

Estimation of safe yield of reservoir gives an indication of how sufficiently reliable the reservoir is. The water supply dependability is dependent upon the diversion of water sources and other features of water supply systems like physical infrastructure, operating logic and criteria and system draft patterns. (Christie & Martin, 2011).

Simulation models have been widely used to estimate the safe yield of reservoirs. (Amit, 2014)in his study stated that detailed routing (simulation) using historic streamflow sequences, modified for expected non-project changes as a measure of what may occur in the future was used to determine the safe yield of reservoirs in the United States.

1.2 Problem statement.

The Thwake multi-purpose dam is a flagship Project in the National Water Master Plan 2030. Its main use being irrigation and water supply. The release of the two uses will be used for hydropower generation. The dam thus has to satisfy water demands for irrigation demand, environmental flow demand and the hydropower demand.

From the previous studies, the different demands for the Multi-purpose dam have been estimated (CASSH, 2014). However, the safe yield of the dam is unknown. In the recent past, dams (reservoirs) have failed to meet the intended demands even before half of their lifetime (Christie & Martin, 2011). (Hoff *et al*., 2007), stated that in the Tana Basin in Kenya, all water demands (Municipal water utilities, hydro-power and irrigation) have substantial un-met demands This has caused major deficiency in the demands and hence affected the reliability.

1.3 Justification

Safe yield is the maximum, sustainable, continuous withdrawal that can be made from a reservoir at any given time (Leib and Stiles, 1998). Given the many competing demands from the Thwake Reservoir, estimating the reservoir safe yield will aid in knowing the general reliability of the reservoir to supply the different competing demands at a particular time. Christie and Martin (2011) in their guidance manual, defined “safe yield” as the sustainable yield of water from a surface or ground water source or sources which is available continuously during projected future conditions, including a repetition of the most severe drought of record, without creating undesirable effects In this regard, the study is motivated by the fact that at the end of the study the safe yield of the reservoir under a range of hydrological and catchment management conditions will be identified which will guide in the reservoir operation to meet the different competing demands.

1.4 Objectives

1.4.1 Main objective

The main objective is to estimate the safe yield for Thwake Multi-Purpose Dam reservoir using WEAP model, in Thwake-Athi River catchment in Kitui and Makueni Counties. Kenya.

1.4.2 Specific objectives

The specific objectives of this research were to: -

i. To assess the inflow and demand requirement for Thwake reservoir;
ii. Analyse trends of synthetic flows in Thwake River;
iii. To model the monthly reservoir balance of Thwake reservoir and the future upstream reservoirs under synthetic flows;
iv. To establish safe reservoir yield of Thwake Dam through inflow -outflow modelling.

1.4.3 Research Question

1. What are the potential effects of the upstream development to the safe yield of Thwake reservoir?

2 LITERATURE REVIEW

2.1 Establishing inflow and outflow demand requirement of a reservoir

2.1.1 Streamflow (Inflow) to the Reservoir

Reservoirs are designed to provide the balance between the flow brought by the river which is high variable in time and volume of water required for some usage purposes of the flow (H. Alrayess, U. Zeybekoglu & A. Ulke, 2017). The storage required on a reservoir to meet a specific demand depends basically on three factors; the magnitude and the variability of the river flows, the size of the demand and the degree of reliability of this demand being met. (Alrayess *et al* 2017), estimated the reservoir capacity of Sami Soydam Sandalcık Dam using mass curve.

Stream flow data for a sufficiently long period at proposed reservoir site is normally used in planning of reservoir inflow. In the absence of such data, the records from a station located upstream or downstream of the site on the stream or on a nearby stream should be adjusted to the reservoir site. If the run off records are too short, it can be difficult to include a critical drought period. In such a case the records should be extended by comparison with longer stream flow records in the vicinity or by the use of rainfall run off relationship

2.1.2 Demand requirement of a Reservoir

Demand for water is steadily increasing throughout the world. Currently, there is a growing number of multipurpose dams. Multipurpose dams provide many services, including water storage for irrigation, water supply, hydropower, flow regulation, flood protection among others (Kohli & Frenken, 2015). Some of the demands considered in the demand requirement include the environmental flow (which is the minimum flow to maintain downstream of the dam) and the evaporation losses which is the water loss due to exposure of water to air and direct sunlight. This loss is referred to as consumed because it is removed from the system reservoir (Kohli & Frenken, 2015).

(Branche, 2016) stated that in order to achieve proposed Sustainable Development Goals (SDGs), there is need to find 35% more food, 40% more water and 50% more energy.

To achieve the above statistics, irrigation water demand, water supply demand and hydropower water demand have to be estimated respectively.

2.2 Simulation of synthetic flows

Simulation has been an important tool for planners in many fields of knowledge. In the field of water resources, the uncertainties due to unknown data, population and the short length of the records work together to make the simulation especially important. The major utilization of water resources at the level needed in modern society makes water storage essential for satisfying the demand. Therefore, the need to reduce the uncertainty in the design of water storage capacity is an important problem in the field of water resources utilization. This problem can only be satisfactorily solved with the aid of simulation (R. Guimaraes & E. santos, 2011).

A brief review of literature shows different methods of generating the synthetic flows. For example (Silva & Portela, 2011) generated synthetic flows using the method of fragments. This procedure involves generating synthetic series of annual and monthly flows that combines two models, a probabilistic one, applied at an annual level, and at a monthly level, a deterministic disaggregation mode. (Arselan, 2012) used the modified Thomas Fiering Model to calculate streamflow simulation and synthetic flow.

United States Department of Agriculture (USDA) produced SWAT model ,which is a nonstop-time, partial-disbursed, method-related model, developed to evaluate the effects of alternative management decisions on water resources and nonpoint-source pollution in large river basins (Jeong *et al.*, 2010). (Dlamini *et al.*, 2017) used SWAT model to simulate the hydrological processes of Bernam River Basin in Malaysia.

2.3 Simulation of Monthly Reservoir Balance using WEAP Model

Simulation is a tool to evaluate the performance of a system, existing or proposed, under different configurations of interest and over long periods of real time (Maria, 1997). Maria (1997) in her paper added that simulation is used before an existing system is altered or a new system built, to reduce the chances of failure to meet specifications, to eliminate unforeseen bottlenecks, to prevent under or over-utilization of resources, and to optimize system performance.

WEAP (Water Environment And Planning) is a practical tool for water resources planning which incorporates not only water supply-side and water demand-side issues, but also water quality and ecosystem preservation issues, by its integrated approach to simulate water systems and by its policy orientation (Saxena & Yadav, 2016). In Kenya WEAP has been applied in various ways. WEAP was used for water demand simulation a case study of Mara River (Metobwa *et al*, 2018).In their study, different methods and strategies were assessed to mitigate the overuse practices from the Mara river. Water resources and demands were modelled using Water Evaluation and Planning system.

(Nyika, *et al* 2017) also Modeled Water Demand and Efficient Use in Mbagathi Sub-Catchment Using Weap. The study aimed at using WEAP model to forecast demand and analyze scenarios on efficient water use in Mbagathi sub-catchment. WEAP model schematic was set to develop current and reference scenarios.

WEAP also has an integration nature where the dam and the water demands (upstream and downstream) can be all schematized as an interconnected system ruled by allocation priorities (e.g., dam operation rules, priority for competing demands such as water supply, irrigation, hydropower, environmental flow, water storage in the reservoir) (SEI US, 2009).

2.4 Assessment of Model Performance

The process of simulation produces more accurate results due to a close representation of the actual system. In a simulation model, evaporation losses calculation is more specific so the yield obtained from the simulation model is more accurate (Ghassan, 2013).

Simulation is a representation of a system used to predict the behavior of the system under a given set of conditions. Alternative runs of a simulation model are made to analyze the performance of the system under varying conditions, such as for alternative operating policies (Ghassan, 2013).The performance measures used in assessment of the model performance were: the reservoir storage, percentage of monthly demands, supply and compliance of relevant demands.

2.5 SWAT MODEL

SWAT (Soil and Water Assessment Tool) model is a which is a nonstop-time, partial-disbursed, method-related model, (Neitsch *et al*., 2002). The SWAT model is hydro-dynamic and physically-based model for application in complex and large basins. Model inputs are as follows: rainfall, air temperature, soil characteristics, topography, vegetation, hydrogeology and other relevant physical parameters. The model is based on five linear reservoirs as follows: reservoir of the vegetation cover, snow accumulation and melting, surface reservoir, underground reservoir and surface runoff reservoir. The model uses GIS tools for preprocessing and post-processing. The basic modeling unit is the hydrologic response unit (HRU), defined as the network of elementary hydrologic areas with the selected discretization, measure of which is dependent upon the desired accuracy, as well as upon data accuracy. The total runoff on the exit profile of the catchment is computed by convolution of the sum of runoffs (surface and base runoffs). The model can be applied at the daily and hourly level of discretization and used for multiannual simulations, (Simić *et al*. , 2009).

SWAT has been widely used in river basin models world-wide. (Almendinger *et al*, 2011) applies SWAT in Use of pond, wetland, and USLE P functions to depict sediment trapping in landscape depressions. (Mango *et al*, 2011) applied SWAT to investigate the response of the headwater hydrology of the Mara River Kenya, to scenarios of continued land use change and projected climate change. Obiero *et al*, (2011) applied SWAT in predicting stream flow on the Naro Moru river catchment in Ewaso Ng'iro river basin, Kenya.

2.6 ARCH-GIS

ArcGIS is an integrated geographic information system (GIS) for managing a digital data-base, working with maps and geographic information. It provides an infrastructure for making maps, analysis, presentations of geographic information available for organizations, communities and openly on the Web, (Sadoun *et al*, 2012). It comprises four key software parts: a geographic information model for modeling aspects of the real world; components for storing and managing geographic information in files and databases; a set of out-of-the-box applications for creating, editing, manipulating, mapping, analyzing and disseminating geographic information, (Maguire, 2008).

2.7 MIKE 11

MIKE 11 is a powerful hydrological modeling system which can be used in water resources management. The system, developed by Danish Hydraulic Institute (DHI), was designed to simulate water flow in rivers and open channels. It is composed by several modules namely rainfall-runoff (RR), hydrodynamic (HD), advection-dispersion (AD) among others, (Doulgeris *et al*, 2011). Kamel, (2008), applied MIKE 11 for simulation of streamflow for Euphrates River in Iraq. The results of the study explained that the MIKE 11model gave good simulation of the flow according to a comparison between the estimated and observed stage hydrograph; also, the comparison between MIKE 11 and the U-day model that was used for the same river explained that the MIKE 11 model gave better simulation.

2.8 Analysis of trends in hydrologic and climatic parameters

In arid and semi-arid regions, assessment of the trends of hydrologic variables related to hydrological processes facilitates accurate water resources forecasting (Instanbulluoglu *et al*. 2012). Traditionally, models assumed stationary conditions, but since 2005 there has been progress on model parameter estimation under unknown or changed conditions and on techniques for modelling in those such conditions (C. Murray & G. Bloschl, 2011). Patle & Libang, (2014) used non-parametric Mann-Kendall test to analyze temporal trends in annual and seasonal rainfall. The duo, also analyzed the daily time series rainfall data for the period of 36 years statistically.

The non-parametric Mann-Kendall was also used by (Gedefaw *et al*. 2019) to analyze trends of precipitation and temperature on two eco-regions in Ethiopia. However, they in-cooperated the Sen's slope estimator test and Innovative Trend Analysis Method (ITAM) in their analysis. (Hu, *et al* 2019) used modified Mann- Kendall and Sen's slope estimator the annual and seasonal trends in precipitation, temperature, potential evapotranspiration, and river discharge for Kamo River Basin in Japan.

2.9 Determination of safe yield of a reservoir

Safe yield is the maximum, sustainable, continuous withdrawal that can be made from a reservoir at any given time (Stiles & Leib, 1998). Christie & Martin, (2011) used the basic mass balance equation as below:

$I - O = \Delta S$ ………………………………………………………………. Equation (i)

Where:

I = total inflow (Million Cubic Meters, MCM)

O = total outflow (MCM)

ΔS = change in storage of the reservoir (MCM)

Safe yield simulation models perform calculations and logical functions on a daily time step. Equation (1) above can be converted to a form that can analyze the cumulative effects of inflows and outflows over consecutive time steps as:

$\Delta St = St - St - 1$…………………………………………………………. Equation (ii)

Where:

ΔSt = change in storage (MCM) of the reservoir control point during time step t,

St = storage of the reservoir (MCM) at the end of time step t,

St - 1 = storage of the reservoir control point in volume (MCM) at the end of time step t – 1. By substituting, equation (2) is converted to:

$It - Ot = St - St – 1$…………………………………………………………Equation (iii)

Where:

It = the total inflow (MCM) to the reservoir during time step t.

Ot = the total outflow (MCM) from the reservoir during time step t.

Equation (iii) can be improved by rearranging terms:

St = St - 1 + It - Ot…………………………………………………………...Equation (iv).

In cases where supply is a general governing criteria, different ways of determining safe yield have been developed (Singhs, 2016). Hill's method which is based on draft and change in ground water elevation, Harding's method which is based on annual retained inflow and change in the water table elevation and Darcy;s law. For the above methods the equilibrium equation below applies (Singhs, 2016)

Surface inflow + subsurface inflow + precipitation + imported water + decrease in surface storage + decrease in ground water storage] = [Surface out flow +subsurface out flow +consumptive use + exported water + increase in surface storage + increase in ground water storage.

2.10 Model Evaluation

(D.N. Moriasi, *et al*., 2007) researched on the recommended model evaluation techniques. In their analysis, they recommended 3 quantitative statistics, Nash-Sucrcliffe efficieny (NSE), percent bias (PBIAS) and ration of the root mean square error to the standard deviation of measured data (RSR). According to Moriasi *et al* (2007), model simulation can be judged as satisfactory if NSE > 0.50 and RSR < 0.70.

3 METHODOLOGY

Thwake Multipurpose dam will be developed in Kitui and Makueni Counties. The dam site will cover more than a kilometer downstream of Athi and Thwake Rivers extending to both Kitui and Makueni Counties. These counties are in the eastern part of Kenya, and are known to be semi- arid counties. The programme is thus aimed at changing the counties into agriculturally productive counties.

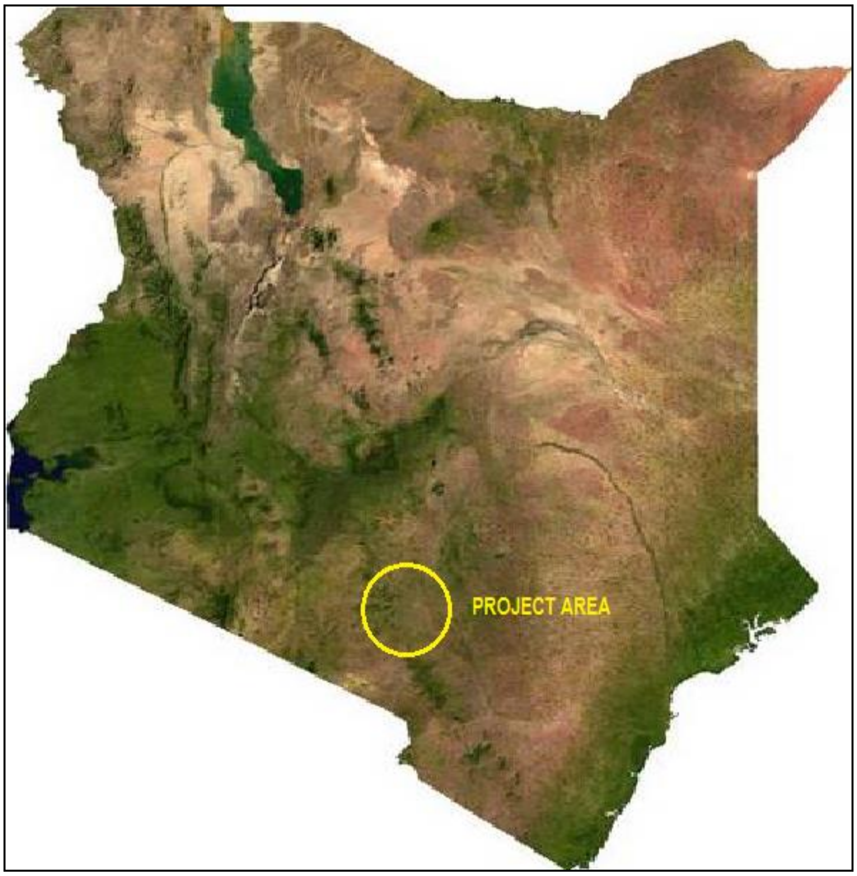


Figure 1: Map showing the General Project Location in Kenyan context

Table 1: Location of study area

LOCATION	Description
Counties	Makueni / Kituiv (Perenially dry)
Source	Athi and Thwake Rivers (Confluence)
Drainage	Athi River 3F

Purpose	Water Supply, Irrigation and Hydropower

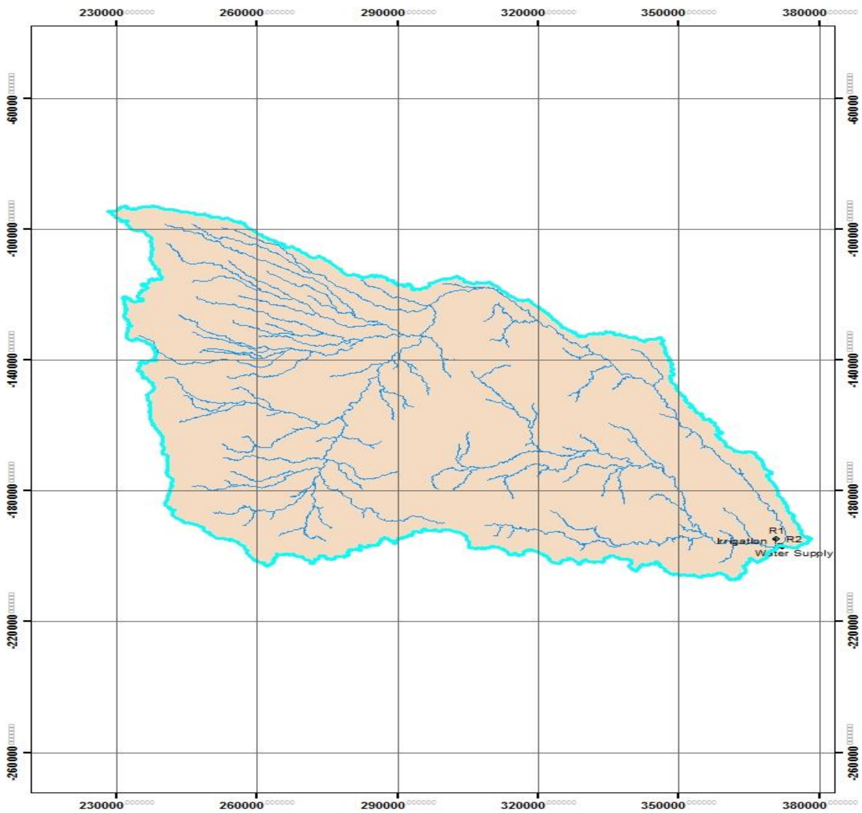


Figure 2: Thwake Catchment

3.1 Data Collection

The data needed for the model was collected and analysed as below:

3.1.1 Establishing inflow and outflow Requirement

To establish the inflow and outflow requirement for Thwake Reservoir, the following data was necessary and hence was collected and analysed accordingly.

3.1.1.1 Stream Flows (Inflow) Requirement

The daily river flow data at River gauging station 3F02 (Athi River at Mavindini) which is within the dam site was collected from the Water Resources Management Authority (WRMA), for 60 years (1952 to 2012). This data however showed some gaps which were filled using MIKE 11 rainfall runoff model, using the data obtained from WRA. MIKE 11 rainfall runoff model application was divided into three (3) stages. The first stage was the calibration process to determine optimal values of the model parameters. The second stage was the validation of the model parameters using a different set of data not used in calibrating the model. The third stage was stream flow simulation using the estimated optimal model parameters obtained during the calibration process. A simplified flow chart of the methodology adopted for filling of the gaps is presented in figure 3 below.

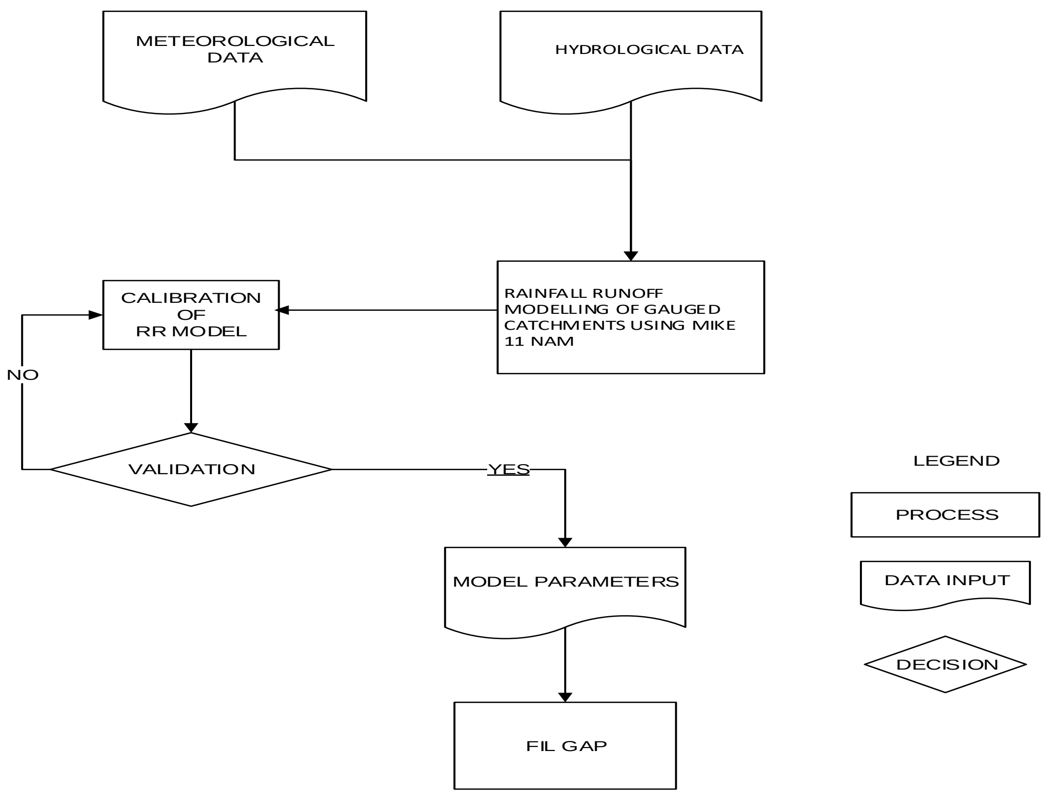


Figure 3: Simplified flow chart for filling gaps using MIKE 11

The trend analysis of flow at RGS 3F02 to test for any major changes in the flow regime due to catchment changes was also undertaken. The analysis was undertaken through mass curve analysis and normal trend observation of the average mean discharge for the three rainy months of March, April and May for each year. The analysis did not indicate any major changes in the Flood Regimes in the Athi/Thwake River catchment

3.1.1.2 Water Demand data (Outflow Requirement)

(a) Domestic water demand

This included domestic water for extended Wote system, Konza city and its environs. This data was collected from previous reports (CASSH 2014)

(b) Hydropower water demand

The demand is to facilitate the electricity production to activate the water pumps required for the Konza domestic water supply. This data was collected from previous reports provided by the Ministry of Water and Irrigation. (CASSH, 2013).

(c) Environmental flow water demand

This is the flow released for the downstream users. Under this study the environmental flow was set at 95% exceedance probability.

(d) Galana flow requirement

This is the irrigation requirement for Galana Kulalu irrigation project. Part of the project will be supplied by Thwake Reservoir. Thus Thwake dam will release water for this downstream scheme to satisfy what will be referred in this thesis as the "Galana flow requirement". This data was collected from previous reports provided by the Ministry of Water and Irrigation (Amiran, 2014)**.**

(e) Irrigation water Requirement

This includes irrigation requirement for irrigation area I (Net irrigation area 2,377ha) and irrigation area II (Net irrigation area 9,065ha). The irrigation requirement was in l/ha/s. These areas are located downstream of the Thwake Reservoir and crops under irrigation include beans, food-crops fruits and vegetables. This data was collected from previous studies (CASSH, 2013).

3.2 Simulation of synthetic flow

Generation of correlated synthetic time series of monthly inflows for Thwake Dam was done using SWAT Model. This was done in 17 series for a period of 60 years to get streamflow for 1000 years. The methodological framework followed for the simulation of synthetic flow is as shown in Figure 4 and involved:

(i) the preparation of spatial and climate data into SWAT format;

(ii) model setup, including watershed delineation and Hydrologic Response Units (HRUs) definition;

(iii) model calibration and validation;

(iv) downscaling of climate variables; and

(v) Application into the hydrologic model.

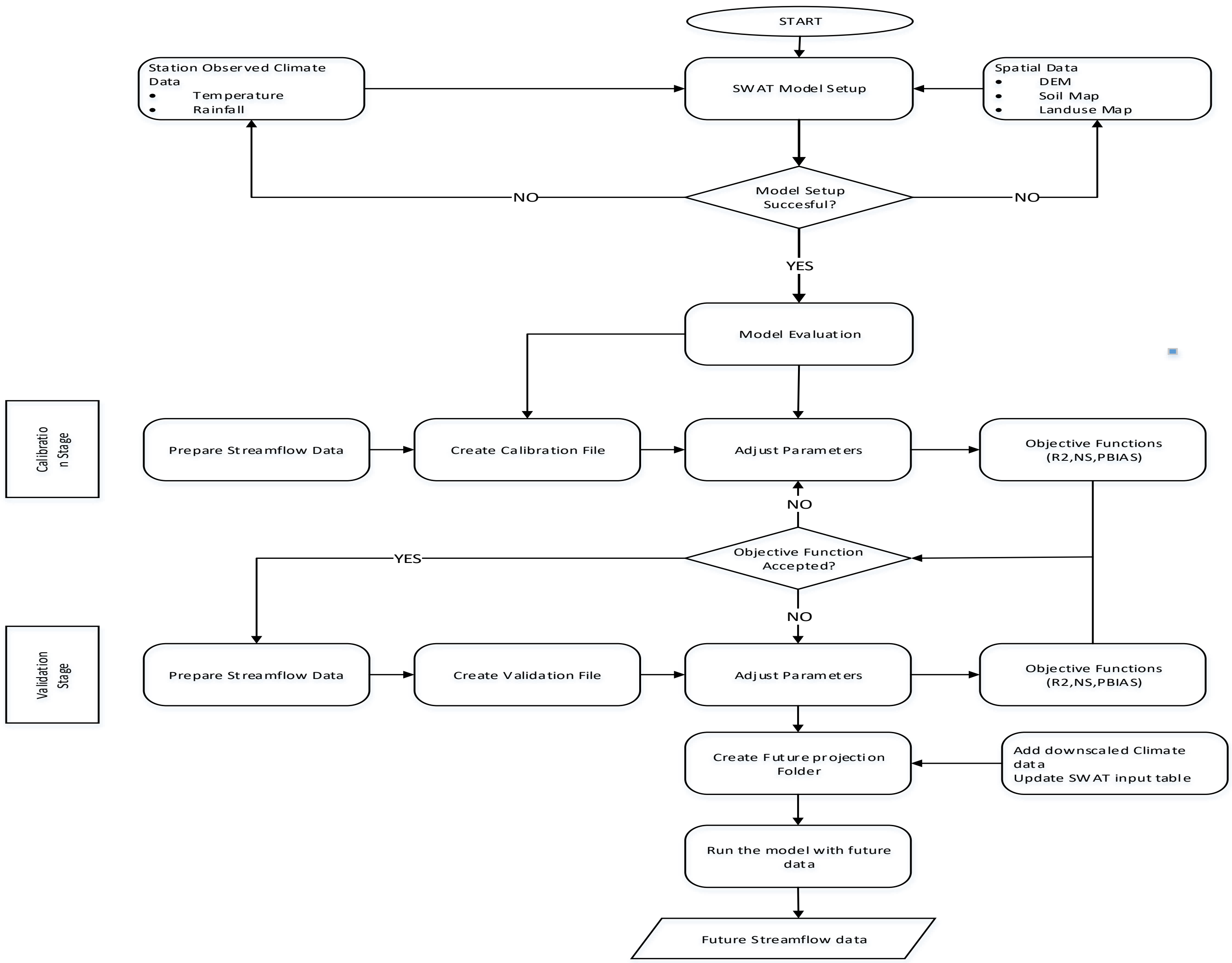


Figure 4: Framework of the study for the generation of future flows

The SWAT model requires observed climate and spatial data to force the rainfall-runoff simulation process. The results of model performance for stream-flow at 3FO2 gauging station were given in terms of the 2 objective functions for both calibration and validation periods. The data used for calibration was data from 1976 to 1979, while for validation the data from 1980 to 1984 was used. Model performance was evaluated using the Sequential Uncertainty Fitting algorithm (SUFI-2) component within SWAT-CUP tool version 5.1.6. The parallel processing option of the SWAT-CUP helped to expedite the calibration process by reducing the overall processing time.

Detailed information about the data used, including the data type and their source, is presented in table 2.

Table 2: Data Requirement and source

Data	**Data Source**	**Data Description**
Digital Elevation Model	USGS	Elevation, Overland, Channel, Slopes, Boundary
Soils Map	MWI	Soils Classification and Properties
Landuse Map	MWI	Land use classification; Cropland, forests, pasture etc
Climate Data	KMD	Daily Rainfall, Maximum and Minimum temperature
Streamflow	WARMA	Daily Streamflow (1976-2005)

Daily streamflow records (m^3/s) at the Thwake River River gauging station No. 3FO2 were obtained from the Water Resources Authority. The station has long enough flow records (60 years), but only the segment from January 1976 to December 2005, corresponding to the climate data, was used. Missing values of discharge were filled by Mike-11 NAM lumped hydrological model.

Table 3: SWAT parameters fitted during calibration and their final value ranges

				Final Parameter Range	
S/No	**Parameter Description**	**Parameter Code**	**File**	**Min**	**Max**
1	SCS curve number	CN2	.mgt	-0.3	0.3
2	Baseflow alpha factor	ALPHA_BF	.gw	0	1
3	Soil evaporation compensation factor	ESCO	.hru	0	1
4	Groundwater revap coefficient	GW_REVAP	.gw	0	0.4
5	Manning's value for main channel	CH_N2	.rte	0	0.3
6	Soil bulk density	SOL_BD	.sol	-0.027	0.3
7	Groundwater delay	GW_DELAY	.gw	30	450
8	Threshold water depth in the shallow aquifer for flow	GWQMN	.gw	0	1.88
10	Channel effective hydraulic conductivity	CH_K2	.rte	4	130

The 1000 years' synthetic stream-flow for 3F02 were used in the WEAP model.

(a) River Network

The GIS shapefile of the river network was generated using the GIS ArcMAP application.

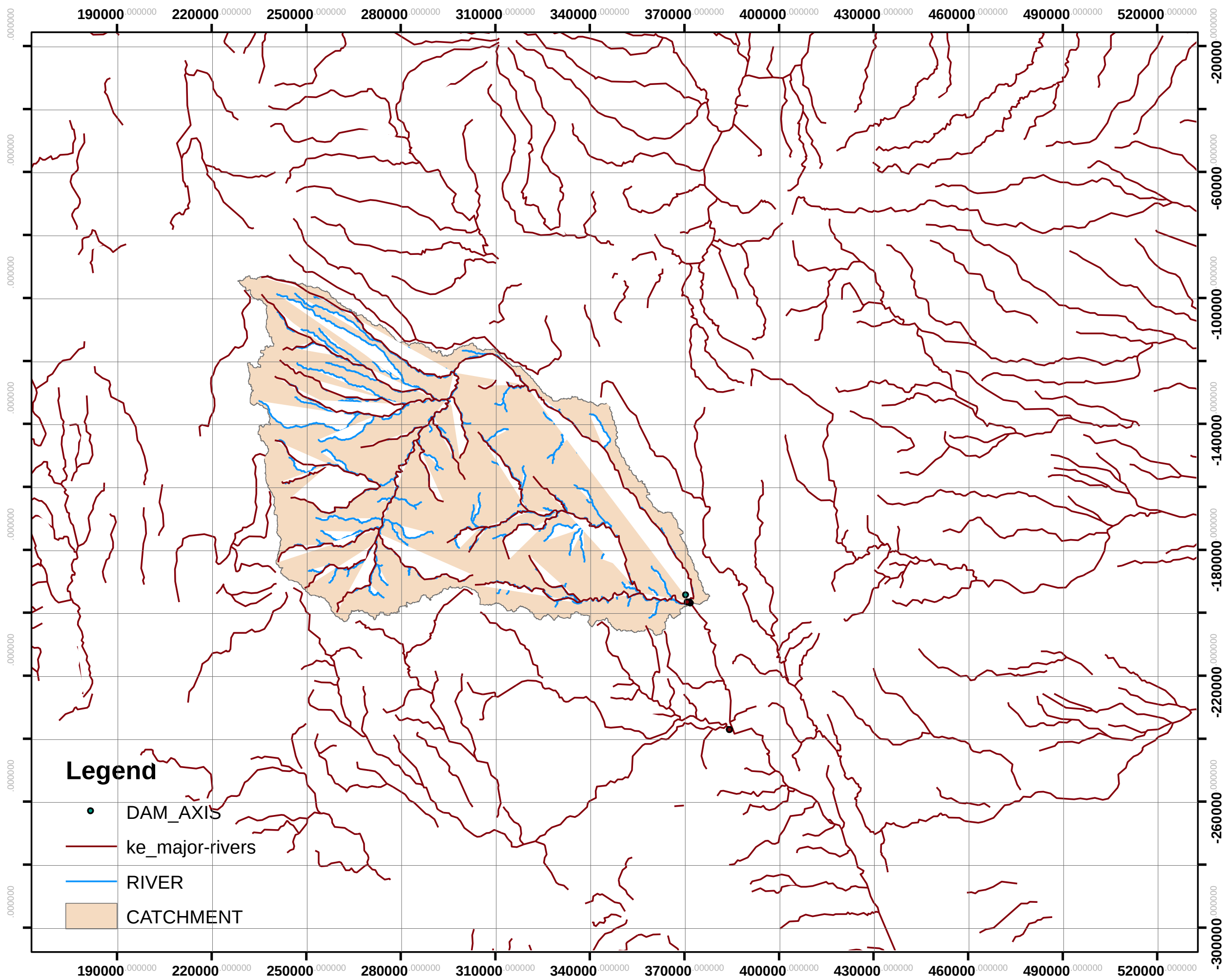


Figure 5 River network generated by GIS

(b) Thwake Reservoir data

Thwake reservoir data was collected from previous studies (CASSH, 2014) which were provided by the Ministry of Water and Irrigation. The data collected included Storage capacity, Volume-Elevation curve, Evaporation from reservoir, Inactive zone / Dead zone, Spillway capacity and Location of the reservoir.

(c) Upstream Reservoirs data

From the previous studies (D. Electricite & J.France, 1993), upstream reservoir data was collected. For all the upstream reservoirs, Storage capacity and location of the reservoir were collected. Proposed dams upstream of Thwake dam is as shown in table 4 below:

Table 4: Upstream dams

Dam	Capacity (Mm^3)
Rwabura	4.1
Thiririka	7.9
Ndarugu	225.0
Mwachi	16.0
Stony Athi	23.0
Munyu	625.0
Total	**901.0**

Since few technical parameters were available on these dams and the objective here was to assess the potential impact on Thwake dam, all these possible future dams were aggregated into one single virtual dam of a capacity of 901 Mm^3. This virtual dam was represented in the model as a water demand abstracting water upstream of Thwake: the volume of abstracted water which is consumed will reduce the inflow to Thwake reservoir.

3.3 Simulation of Monthly Reservoir balance

The behaviour of the Thwake system under the 1000's year of synthetic stream-flows has been explored in the model. The objective is to explore how this system will behave once fully developed under the synthetic flows. The fully developed Thwake system is characterised below.

3.3.1 Fully developed Domestic Water Demand

The demand on the reservoir was equal to the water supplied augmented by 5% to account for losses during the water treatment process before it is supplied to Wote and Konza.

3.3.2 Fully developed Hydropower Demand

The purpose of the electricity production is first to activate the water pumps required for the Konza domestic water supply.

3.3.3 Environmental flow requirement

This was calculated from the monthly streamflow data for 60 years (1952-2012) for 3F02 gauging station. The data was set at 95% exceedance probability The environmental flow requirement was placed immediately downstream the dam. This requirement will have high priority so that the dam releases water to comply with this environmental requirement.

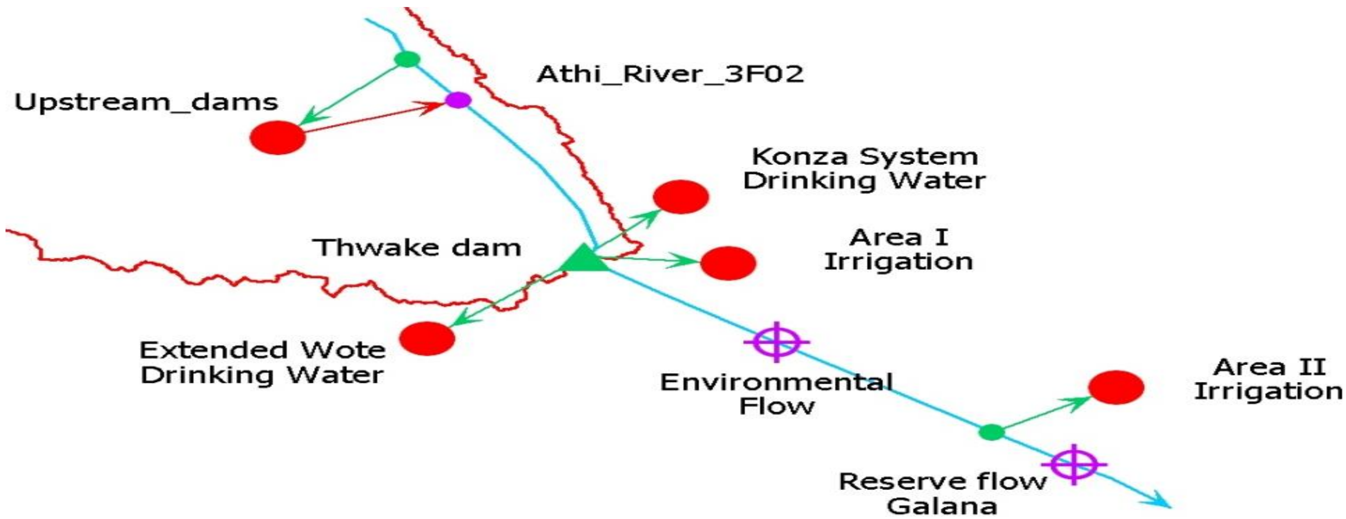


Figure 6: Schematic of the Thwake system in WEAP.

3.3.4 Galana flow requirement

The development of the large Galana Kulalu Irrigation Project has been considered in the model as a high priority. The Thwake dam should release water for this downstream scheme to satisfy what will be referred in this thesis as the "Galana flow requirement". This flow requirement was placed downstream of the intake for Irrigation Area II, as illustrated in Figure 6 above.

3.3.5 Fully developed Irrigation Water Demand

The details of net irrigation area, crops and respective irrigation requirements will be explored for the two irrigation areas, (area I and II).

3.4 Assessment of Model Performance for the Base Case and the upstream dams' scenarios.

This performance of the Thwake dam with the advised set of operation rules, under the Base Case and upstream dams' scenarios was gauged. The performance was assessed for; supply of domestic water to Wote and Konza systems, electricity production, compliance with environmental flow, satisfaction of the Galana flow requirement, water level in the Thwake reservoir and satisfaction of irrigation demand from Area I and II.

3.4.1 Case of the Base scenario

Identifying the alternative sets of operation rules of Thwake reservoir

There were four types of water usages represented in the model; (***1***) Water demands for domestic water supplies and irrigation (consuming usages), (***2***) Water demands for producing electricity (non-consuming), (***3***) Water demands to maintain an environmental flow requirement downstream of Thwake dam (environmental flow requirement) and after the water intake for Irrigation Area II (Galana flow requirement) and (***4***) Filling and storing water in Thwake reservoir.

Except for Irrigation Area II demand, which use the turbined water, all these usages are competing.

In the WEAP model the priority was chosen as a rank, starting from 1. The model first allocated water to the water usages having the rank 1, then to usages having the rank 2 etc. The lower the value of the priority rank, the higher the priority.

There were two options for setting the priority. ***Option 1*** was; (*1*) *Environmental flow requirement*, (*2*) *Domestic water supplies, Hydropower production and Galana downstream flow requirement*. (Hydropower and domestic water supply had the same priority since electricity production was necessary to supply the water to the Konza system), (*3*) *Possible specific rank for storing water in Thwake reservoir* and (*4*) *Irrigation to Area I & II. Area II* can use the water released by hydropower, however it is constrained by the flow requirement for Galana: only the flow above the flow requirement is available for Area II

The possible values for the reservoir priority rank in Option 1 were: (*5*): in this position, there will be unrestricted water supply to all water demands, including irrigation Area I and Area II (complementary to the water turbined minus the Galana flow requirement), (*4*): in this position, the reservoir will supply without restriction water to the environmental flow requirement, two domestic water supplies, hydropower and the Galana flow requirement. Concerning irrigation area, I and II (for Area II complementary to the water turbined minus the Galana flow requirement), there is a compromise between releasing water to irrigation and filling/storing water in the reservoir, (*3*): in this position, the reservoir will supply without restriction water to the environmental flow requirement, two domestic water supplies, hydropower and the Galana flow requirement. The Irrigation Area I will only get water if the reservoir is full. The Irrigation Area II will get the water turbined minus the Galana flow requirement; in case this is not enough, it would only get water from the reservoir if it is full and (*2*): in this position, the environmental flow gets its requirement without restriction. For the rest, the reservoir will balance (i) supply to the two domestic water supplies, hydropower and the Galana flow requirement with (ii) filling/storing water in the reservoir. The situation for Irrigation Area I and II is the same as for the rank 3. The option for this rank attempts to minimise the risk that the reservoir empties, which would entail a failure in delivery. It is indeed advisable to restrain supply, hence to reduce satisfaction of water demands, but therefore to reduce the occurrence of a failure, instead of supplying without restraint until reaching a failure.

In the ***Option 2***, the priorities were: (***1***) Environmental flow requirement, (***2***) Domestic water supplies and hydropower production, (***3***) Galana downstream flow requirement: the rank is lower than hydropower as the idea is to first get water which went through the turbines. If this flow is not enough (in some month the flow requirement is greater than the turbine capacity of 31 m3/s), additional water can be released from the dam, (***4***) Possible specific rank for storing water in Thwake reservoir, and (***5***) Irrigation to Area I & II.

The possible values for the reservoir priority rank were: (*6*): in this position, there will be unrestricted water supply to all water demands, including Irrigation Area I and Area II (complementary to the water turbined minus the Galana flow requirement), (*5*): in this position, the reservoir will supply without restriction water to the environmental flow requirement, two domestic water supplies, hydropower and the Galana flow requirement. Concerning Irrigation Area, I and II (for Area II complementary to the water turbined minus the Galana flow requirement), there is a compromise between releasing water to irrigation and filling the reservoir, (*4*): in this position, the reservoir will supply without restriction water to the environmental flow requirement, two domestic water supplies, hydropower and the Galana flow requirement. The irrigation scheme Area I will only get water if the reservoir is full. The scheme Area II will get the water turbined minus the the Galana flow requirement; in case this is not enough, it would only get water from the reservoir if it is full, (*3*): in this position, the reservoir will supply without restriction water to the environmental flow requirement, two domestic water supplies and hydropower. It will balance supply to Galan Flow requirement (in case turbined flow is not enough) with filling the reservoir. The situation for irrigation Area I and II is the same as for the rank 4, and (*2*): in this position, the environmental flow requirement gets its requirement without restriction. For the rest, the reservoir will balance supply (i) to the two domestic water supplies and hydropower with (ii) filling the reservoir. It will supply water to Galana Flow requirement (in case turbined flow is not enough) only if it is full. The situation for irrigation Area I and II is the same as for the rank 4. The option for this rank attempts to minimise the risk that the reservoir empties.

In both options, the values of the reservoir priority were chosen at each calculation time-step (monthly) as a function of the volume of water in the reservoir. The different volume zones of the water in the reservoir can be schematised as shown in Figure 7.

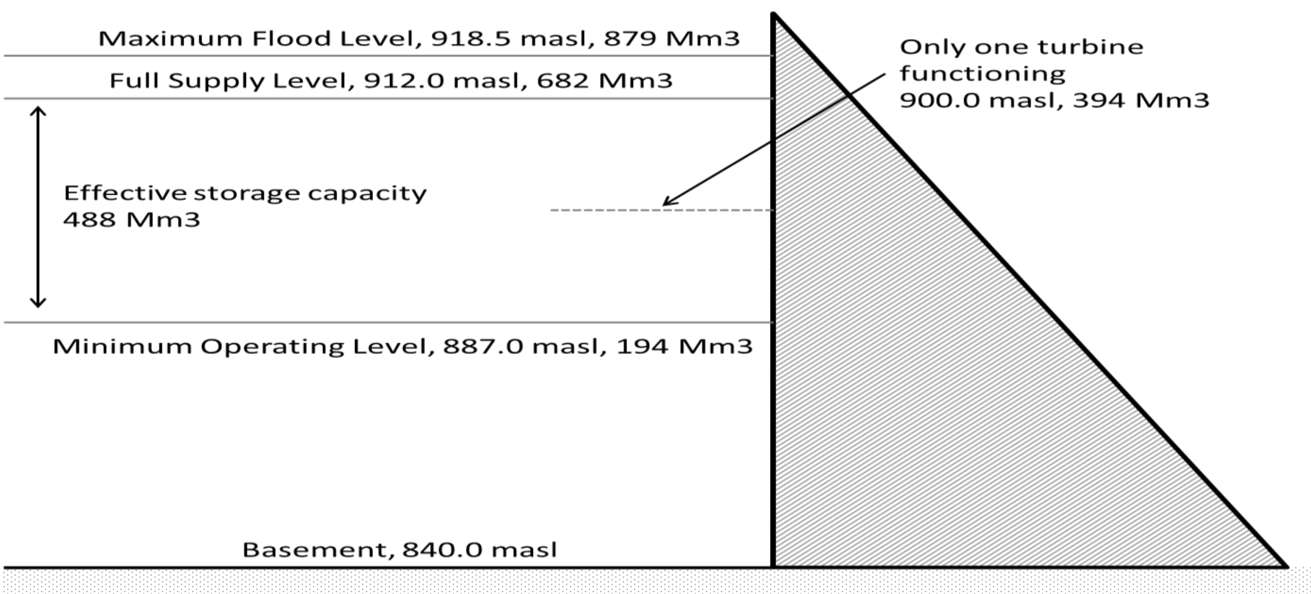


Figure 7: Different volume zones of water in the reservoir

3.4.1.1 Satisfaction of high priority demands

The first step to tune the operation rules of the reservoir was to satisfy the high priority demands, namely the environmental flow requirement, the domestic water supplies, the hydropower production and the Galana downstream flow requirement. A safe zone of the reservoir was defined, below which the priority of storing water in the reservoir will be of first rank (ie water releases will be balanced with filling/storing water in the reservoir) to avoid emptying the reservoir and hence a failure in water releases. Different thresholds were explored for this safe zone for Option 1 and Option 2 as shown in table 5 below

Table 5: Different values considered for the safe zone of the reservoir (below which releases are restrained)

Safe zone of the reservoir, as a percentage of the effective storage capacity (488 Mm3)	Top of the safe zone (masl)	Total volume (Mm3)
10%	890.8	245
20%	894.1	290
30%	897.0	341
35%	898.5	367

The curves which were examined were the monthly duration curves: the curves indicated the percentage of chance (read on the x-axis) that a value (read on the y-axis) is exceeded in a given month. The details are placed in the results and Appendixes section.

3.4.1.2 Satisfaction of low priority demands

The next step was to explore the operation of the reservoir for the low priority demands, namely irrigation to Area I and II. The remaining storage capacity above 900.7 masl is about 273 Mm3. Different options were explored. The criterion for selecting the best setting was to maximise the coverage of the irrigation demands during the crucial months for irrigation, corresponding to the developmental phase of the crops. This phase for the seasonal crops (fruit trees excluded) in Area I and II were chosen as shown in table 6.

Table 6: Development periods requiring irrigation for crops of Area I and II.

Crop	Development period with irrigation
Food crops	September and October
Beans	January and February, September and October
Vegetables	January and February, July and August

The crops being the most important in the region are the food crops then beans. Irrigation in September and October is important for both crops, hence irrigation requirement of Area I and II was examined in these two months.

3.4.1.3 Operation rules for the Base Case

Eventually the priority rank for the water demands of the Thwake system was established and is discussed in the results.

3.4.2 Case of upstream dams' development scenario

Once upstream dams are developed, it was assumed in the model that they withdraw the water before it reaches the Thwake reservoir. The amount of inflow into the Thwake reservoir will thus be reduced.

3.4.2.1 Identifying the alternative sets of operation rules of Thwake reservoir

Similar sets of scenarios to those defined for the Base Case were explored to tune the operational rules of Thwake reservoir. The fundamental difference is that, in the model, water abstracted by the upstream dams had first priority, to account for the fact that these dams abstract water before it reaches the Thwake system.

3.4.2.2 Satisfaction of high priority demands

Similar to the Base Case, two options were considered. ***Option 1*** was: (*1*) Upstream dams, (*2*) Environmental flow requirement, (*3*) Domestic water supplies, hydropower production and Galana downstream flow requirement, (*4*) Possible specific rank for storing water in Thwake reservoir. and (*5*) Irrigation to Area I & II.

and Option 2 was: (*1*) Upstream dams, (*2*) Environmental flow requirement, (*3*) Domestic water supplies and hydropower production, (*4*) Galana downstream flow requirement, (*5*) Possible specific rank for storing water in Thwake reservoir and (*6*) Irrigation to Area I & II.

3.4.2.3 Satisfaction of low priority demands

The steps followed were the same as for the Base Case.

3.4.2.4 Operation rules for the upstream dams' development scenario

Eventually the priority rank for the water demands for the Thwake system was: (*2*) Environmental flow requirement, Wote and Konza domestic water supplies, and hydropower production, (*3*) Galana downstream flow requirement, (*4*) Irrigation to Area I & II and (*5*) Possible specific rank for storing water in Thwake reservoir. The 1st rank in this scenario was occupied by the demand representing the upstream dams.

The priority for filling/storing water in the reservoir was: (*2*) when water levels in the reservoir $\leq$ 897.0 masl (ca 341 Mm3); (*3*) when water levels $\leq$ 900.7 masl (ca 409 Mm3) and (*5*) otherwise.

4 RESULTS AND DISCUSSION

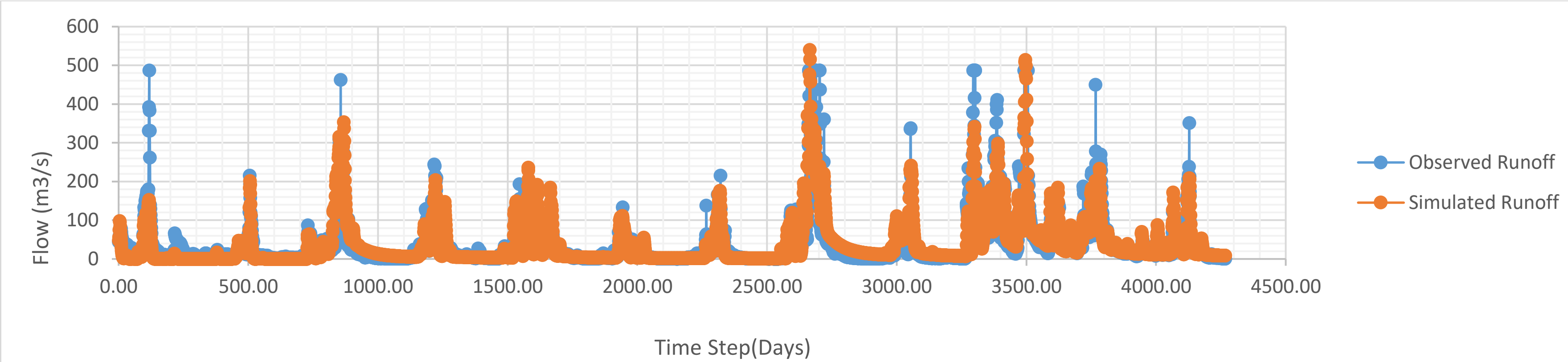
4.1 Model Calibration and Validation

Monthly streamflow data for the 3FO2 gauging station was divided into two periods: 18 years was used for model calibration (1968-1979), and the remaining 7 years (1980-1984) for validation. The results for calibration and validation for model performance is as represented in table 7 below.

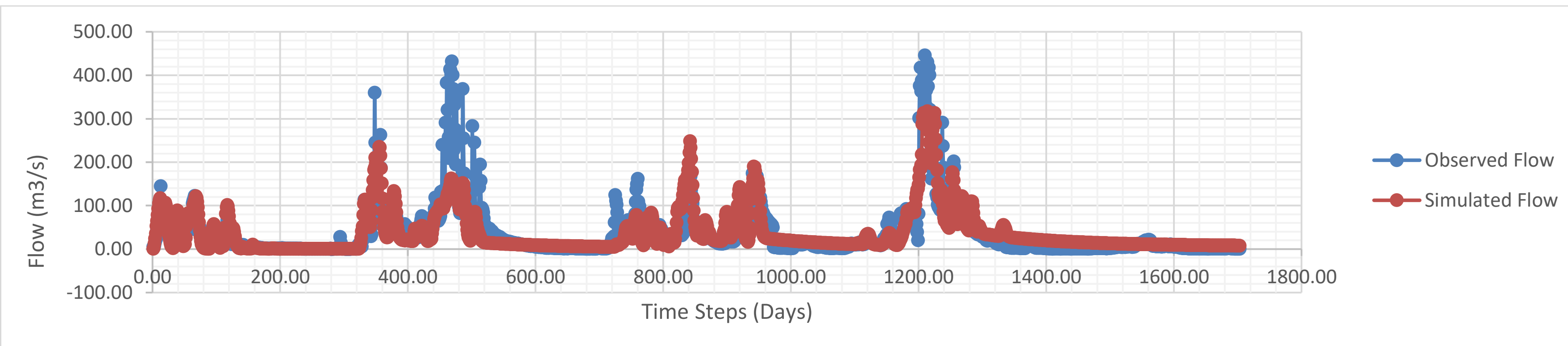
Table 7 Calibration and validation values

Model Performance	R^2	NSE	Results
Calibration	0.67	0.62	Acceptable
Validation	0.62	0.61	Acceptable

In the model, the current figures provide an actual picture of the situation hence it is viewed as a calibration step. The validation procedure was undertaken using the PEST routine within the WEAP system. PEST is a nonlinear parameter estimator and considered a unique calibration tool. The adjustment of sensitive parameters was done through trial and error to determine the best value for a specific parameter. PEST utilizes a nonlinear estimation technique.



(a)



(b)

Figure 8**.** Plots of daily observed and simulated time series of streamflow with 95% prediction uncertainty during; (a) calibration period (1968-1979), and (b) validation period (1980-1984).

4.2 Inflow and outflow requirement for Thwake Reservoir

4.2.1 Inflow to Thwake Reservoir

The gap-filled mean monthly discharges for Athi River at RGS 3F02 for each year and the long-term mean monthly discharges are depicted in table 8. These results are graphically depicted on figure 9. The results showed that Athi River at RGS 3F02 has an annual mean discharge of 34.04 m^3/sec, maximum annual discharge of 218.887m^3/sec and the minimum annual discharge of 1.299m^3/sec.

Table 8: Mean daily flow in a month for RGS 3F02

	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean Annual	Max	Min
1	1952			28.973	66.818	77.516	24.865	14.115	8.972	5.985	4.923	7.677	8.567	24.841	77.516	4.923
2	1953	2.950	0.174	4.517	13.729	14.750	5.399	2.089	2.251	1.645	0.725	40.356	33.705	10.191	40.356	0.174
3	1954	3.306	0.388	0.059	51.659	99.797	26.501	9.557	6.105	2.615	3.778	25.111	13.157	20.169	99.797	0.059
4	1955	0.922	29.565	4.596	23.153	20.130	5.650	2.586	2.159	1.792	3.392	20.515	32.177	12.220	32.177	0.922
5	1956	46.613	11.847	6.432	13.454	37.384	9.136	8.997	5.423	3.063	2.623	56.052	20.313	18.445	56.052	2.623
6	1957	26.086	27.239	11.103	57.125	89.303	47.929	16.266	9.131	6.386	2.948	19.111	50.166	30.233	89.303	2.948
7	1958	7.772	65.630	16.444	29.900	143.490	48.742	30.798	19.326	10.549	6.642	8.729	19.636	33.972	143.490	6.642
8	1959	7.944	3.675	9.695	13.640	35.212	18.181	6.617	4.568	3.604	1.941	45.123	14.348	13.712	45.123	1.941
9	1960	0.919	0.668	23.423	64.015	37.290	12.893	8.581	5.700	3.902	6.562	15.073	10.949	15.831	64.015	0.668
10	1961	1.798	0.820	0.544	50.384	31.073	8.502	3.811	3.265	5.164	75.021	432.084	442.737	87.934	442.737	0.544
11	1962	394.224	44.226	26.372	37.331	85.695	35.196	20.869	14.687	10.319	13.582	18.036	21.497	60.169	394.224	10.319
12	1963	23.834	16.752	35.454	59.383	106.591	60.400	27.575	18.885	11.505	6.860	48.508	121.993	44.812	121.993	6.860
13	1964	60.063	22.579	35.432	87.580	66.027	40.963	24.716	26.397	15.888	11.784	15.460	39.902	37.233	87.580	11.784
14	1965	30.007	9.279	7.180	37.201	37.863	16.923	10.206	7.776	4.347	24.336	69.001	35.307	24.119	69.001	4.347
15	1966	17.645	20.243	40.771	75.672	76.365	25.788	14.680	9.366	8.385	4.434	33.907	7.770	27.919	76.365	4.434
16	1967	2.650	2.141	1.296	79.908	121.419	44.147	28.752	13.796	10.183	24.542	71.501	45.889	37.185	121.419	1.296
17	1968	15.662	21.233	110.298	145.846	126.106	44.398	25.516	16.730	9.563	8.514	130.480	138.077	66.035	145.846	8.514
18	1969	43.298	39.848	50.576	32.182	55.177	28.656	16.231	14.335	7.947	5.897	78.515	47.396	35.005	78.515	5.897
19	1970	16.151	8.886	17.214	125.989	71.803	47.232	22.807	13.984	8.788	5.439	10.875	9.288	29.871	125.989	5.439
20	1971	4.027	1.478	0.402	84.451	85.905	23.766	14.734	10.504	6.411	3.414	20.457	49.024	25.381	85.905	0.402
21	1972	27.477	20.877	10.347	63.954	23.067	20.235	4.952	2.873	2.506	4.840	56.674	23.210	21.751	63.954	2.506
22	1973	8.407	5.406	0.445	43.457	7.444	8.044	3.536	3.129	4.309	2.826	75.411	1.539	13.663	75.411	0.445
23	1974	8.407	5.406	22.827	184.474	26.912	5.565	34.505	13.188	4.760	2.495	13.015	4.984	27.212	184.474	2.495
24	1975	1.622	0.253	3.517	111.921	17.907	3.088	2.668	3.093	1.441	8.056	77.300	20.558	20.952	111.921	0.253

	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean Annual	Max	Min
25	1976	1.142	0.633	2.009	83.279	10.724	45.285	2.221	1.000	1.384	0.637	42.064	109.210	24.966	109.210	0.633
26	1977	38.102	13.895	24.062	386.385	238.820	41.152	18.085	22.177	15.851	3.455	101.185	45.937	79.092	386.385	3.455
27	1978	29.769	28.799	23.368	1.608	9.674	31.881	17.019	4.647	4.862	11.257	52.828	42.244	21.496	52.828	1.608
28	1979	41.939	97.819	86.834	131.270	86.688	64.943	28.797	16.339	8.460	6.743	67.509	42.089	56.619	131.270	6.743
29	1980	9.932	7.850	9.948	35.684	85.502	33.814	14.143	8.278	6.533	5.653	57.958	20.254	24.629	85.502	5.653
30	1981	8.951	4.389	58.967	230.426	170.609	36.715	21.063	13.920	8.338	8.158	11.603	10.882	48.668	230.426	4.389
31	1982	6.661	2.756	1.215	50.728	63.784	26.035	10.683	6.888	5.040	8.158	11.603	79.058	22.717	79.058	1.215
32	1983	21.315	20.715	15.371	58.456	55.046	21.561	20.832	15.872	8.170	7.340	20.243	58.774	26.975	58.774	7.340
33	1984	7.968	2.347	5.645	6.877	1.947	0.285	0.290	0.600	1.469	3.123	28.072	41.478	8.342	41.478	0.285
34	1985	2.333	79.320	7.531	34.761	46.476	21.477	14.139	8.283	5.241	4.780	19.607	22.568	22.210	79.320	2.333
35	1986	4.418	4.031	4.223	20.784	109.558	20.041	13.373	7.315	5.198	3.627	36.341	33.139	21.837	109.558	3.627
36	1987	9.460	6.170	4.171	6.983	20.955	25.030	13.373	6.354	3.833	2.245	14.218	9.245	10.170	25.030	2.245
37	1988	1.291	1.556	12.135	34.358	53.532	33.973	22.247	14.021	12.788	10.431	30.983	25.872	21.099	53.532	1.291
38	1989	45.263	24.447	34.437	58.290	58.670	42.060	27.031	19.712	14.956	18.880	35.991	45.548	35.440	58.670	14.956
39	1990	40.980	22.316	47.002	258.004	53.120	32.434	21.784	25.771	11.697	10.227	47.094	64.343	52.898	258.004	10.227
40	1991	31.195	15.213	1.862	7.266	53.120	24.605	12.867	8.285	6.086	4.960	11.033	10.181	15.556	53.120	1.862
41	1992	1.268	0.174	0.059	52.713	79.379	12.498	9.904	6.639	4.670	5.042	16.257	20.056	17.388	79.379	0.059
42	1993	97.921	93.125	14.998	7.436	1.947	8.974	6.588	4.336	1.837	0.090	7.700	42.033	23.915	97.921	0.090
43	1994	1.686	2.713	14.192	33.431	30.347	16.122	13.945	8.674	4.894	10.197	24.864	37.396	16.538	37.396	1.686
44	1995	21.505	24.565	38.566	22.576	12.562	9.405	6.803	5.851	3.279	15.787	48.471	13.130	18.542	48.471	3.279
45	1996	26.036	7.580	5.069	77.383	73.664	13.829	24.339	9.298	7.817	4.519	53.114	47.707	29.196	77.383	4.519
46	1997	32.243	19.703	23.498	69.572	74.033	27.848	16.487	11.712	8.455	75.021	432.084	442.737	102.783	442.737	8.455
47	1998	394.2243	44.22627	23.498	69.572	74.033	27.848	16.487	11.712	8.455	10.386	53.114	47.707	65.105	394.224	8.455
48	1999	32.243	19.703	23.498	69.572	74.033	27.848	4.878	4.878	3.803	2.749	53.114	47.707	30.336	74.033	2.749
49	2000	23.622	6.951	25.276	37.892	20.884	18.690	14.591	13.089	13.209	13.791	47.849	32.914	22.396	47.849	6.951
50	2001	173.361	48.449	64.978	106.736	61.538	38.133	28.747	24.157	18.537	16.978	61.115	31.382	56.176	173.361	16.978
51	2002	27.270	23.853	46.355	65.229	190.055	44.314	32.230	29.553	26.398	26.071	67.747	106.068	57.095	190.055	23.853

	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean Annual	Max	Min
52	2003	87.176	47.270	38.702	59.536	218.221	72.505	47.652	40.166	32.789	27.562	64.143	43.993	64.976	218.221	27.562
53	2004	45.030	41.365	37.843	133.268	101.301	39.655	30.778	27.067	23.198	26.088	52.796	44.088	50.207	133.268	23.198
54	2005	34.495	32.399	43.489	52.641	72.920	51.513	35.169	30.985	27.606	10.386	53.114	47.707	41.035	72.920	10.386
55	2006	32.243	19.703	23.498	69.572	74.033	27.848	16.487	8.097	7.334	5.230	217.146	162.487	55.307	217.146	5.230
56	2007	87.866	26.652	11.359	71.874	22.190	24.602	14.462	13.612	12.409	9.574	14.175	10.100	26.573	87.866	9.574
57	2008	6.403	5.147	29.890	39.172	9.863	6.137	7.099	5.558	5.096	10.161	25.603	6.278	13.034	39.172	5.096
58	2009	5.100	2.847	0.795	9.313	12.566	8.284	3.327	1.048	0.399	35.481	67.299	69.590	18.004	69.590	0.399
59	2010	90.934	70.228	98.541	64.096	156.471	35.499	19.051	13.139	9.398	7.318	31.399	30.572	52.220	156.471	7.318
60	2011	9.742	8.256	24.294	16.213	20.887	11.614	7.512	5.569	6.343	12.230	73.622	67.488	21.981	73.622	5.569
61	2012	24.580	10.512	6.348	73.111	434.969										
	Mean Flow	38.458	20.771	22.974	68.185	72.596	27.278	16.161	11.504	8.281	11.165	57.367	53.736	**34.040**	72.596	8.281
	Max	394.224	97.819	110.298	386.385	434.969	72.505	47.652	40.166	32.789	75.021	432.084	442.737	**213.887**	442.737	32.789
	Min	0.919	0.174	0.059	1.608	1.947	0.285	0.290	0.600	0.399	0.090	7.677	1.539	**1.299**	7.677	0.059
	Std dev	73.2	23.0	23.7	65.0	70.1	16.2	10.1	8.4	6.6	14.1	78.0	79.7	39.014	79.737	6.604

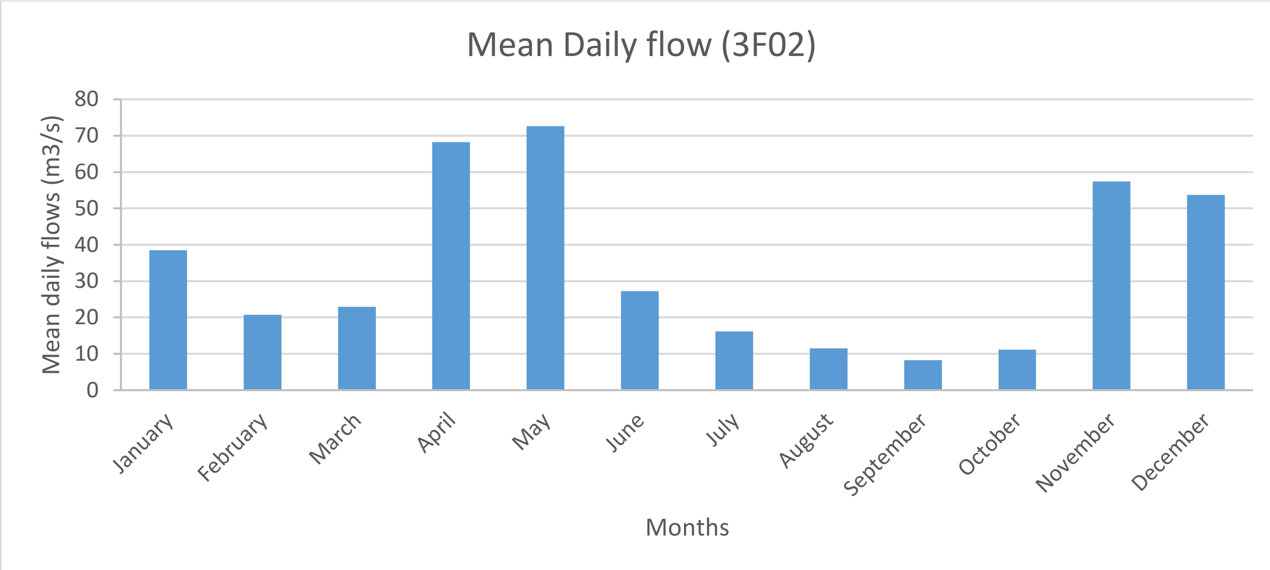


Figure 9: Mean daily flow in a month (3F02)

4.2.2 Demand Requirement for Thwake Reservoir

4.2.2.1 Fully developed domestic water demand

The domestic demand was summarised as in table 9 below.

Table 9: Water Demands (Data obtained from *(CASSH, Annex IV: Water and Sanitation Final design Report, October, 2014)*

	Water supplied				**Water demand on Thwake reservoir**	
Domestic Water Supply	Population	m3/day	Mm3/year	Equivalent l/cap/day	m3/day	Mm3/year
Extended Wote System	674,741	34,621	12.6	51	36,443	13.3
Konza City and its environs	640,000	100,320	36.6	157	105,600	38.5

4.2.2.2 Fully developed Hydropower Demand

The hydropower demand required to activate the water pumps to supply water to Konza city for which the demand is equivalent to a capacity of 17.2 MW, with respect to the total capacity of 19.9 MW. Considering this high demand, the design of the hydropower unit was designed at 900 masl and another one at 887 masl, the Minimum Operating Level of the reservoir. The capacity of the turbines is summarised in table 10 below.

Table 10: Turbine capacity (Data obtained from (CASSH, 2013)

Elevation of the turbine intake (masl)	**Capacity (m3/s)**
900	20.7 (2 turbines)
887 (MOL)	10.3 (1 turbine)

4.2.2.3 *Environmental flow requirement*

An environmental flow requirement was placed immediately downstream the dam Environmental flow was set at 95% exceedance probability. Accordingly, the 95% exceedance probability was averagely 3.5 m^3/s.

Table 11: Environmental flows

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1.142	0.253	0.402	6.983	7.444	5.399	2.221	1.048	1.441	0.725	8.729	6.278	3.505417

4.2.2.4 *Galana flow requirement*

Galana flow will restrain the supply to Irrigation Area II as it will be considered as a high priority demand. Its demand is on average 17 m^3/s annually and varies monthly

The difference between the Environmental and Galana flow requirements will be in the priority: Environmental flow will be of highest priority and Galana flow will be of slightly lower priority, being nevertheless in the high priority demands group.

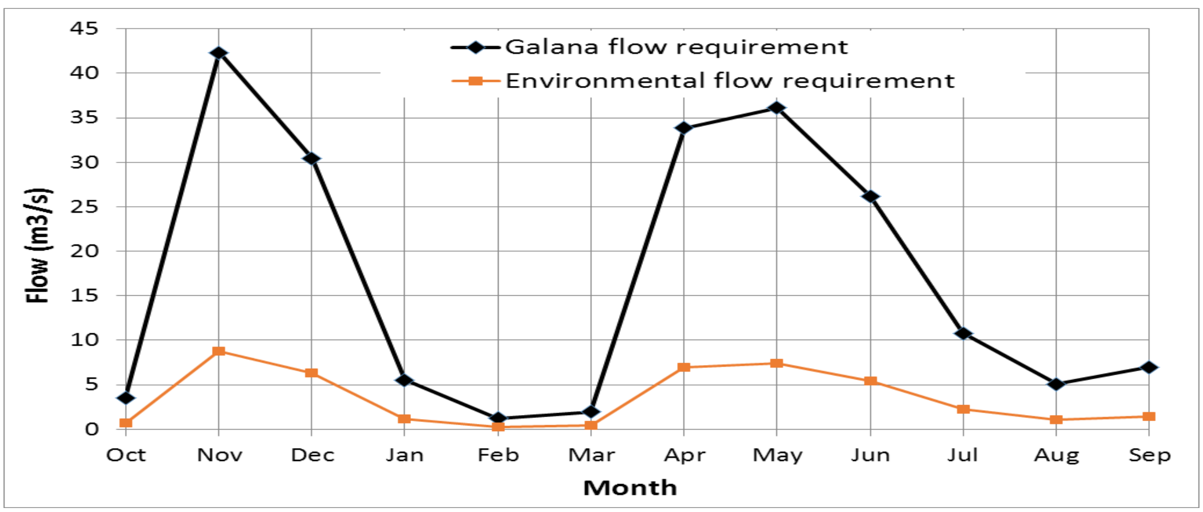


Figure 10: Environmental and Galana flow requirements.

4.2.2.5 *Fully developed Irrigation Water Demand*

The details for the two areas (Area I and II) are shown in Table 12 and Figure 11 below:

Table 12: Irrigation areas and water demands (Data obtained from *(CASSH, Annex VI: Irrigation Component final design Report., June, 2013.)*

Irrigation scheme	**Net Area (ha)**	**Crops**	**Water demands**	
			l/s/ha	**Mm3/year**
Area I	2,377		1.08	10.3

Area II	9,065	Beans, Food crops, Fruits, Vegetables		41.5

The monthly pattern of the water demands is as below:

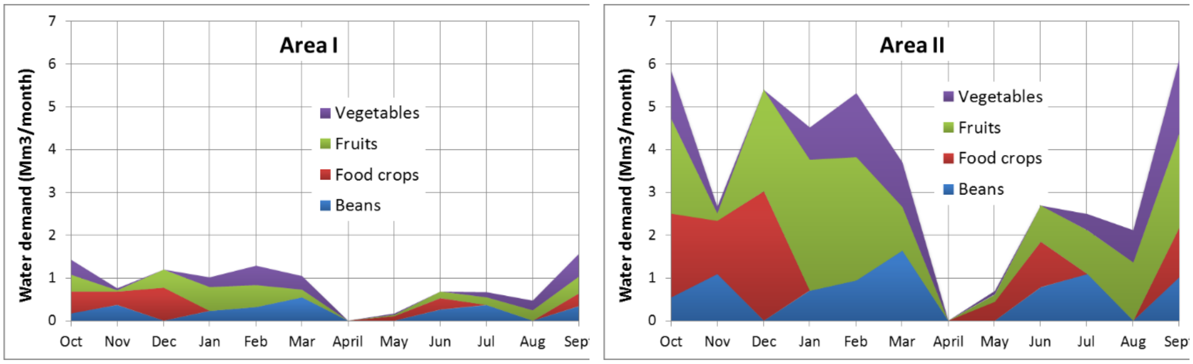


Figure 11: Irrigation water demand as a function of the different crops

4.3 Synthetic flows (1000 years)

The 1000 years' synthetic flows were generated using SWAT. Digitised soil and land use maps of 2013 were obtained from the Ministry of Water and Irrigation. The land use map distinguishes eleven land use classes. Soil properties such as soil depth, texture and water holding capacity were obtained from JICA soil survey study of 1992 for the SWAT database. Details on land use and soil distribution are shown in figure 12 below. Due to the technicality of WEAP not being able to deal with a > 2500 year, the generated synthetic flows were allocated to synthetic years for use in the WEAP model. The synthetic years started from 1500 to 2499. Thus the first flow generated was allocated year 1500 and the last flow allocated year 2499.

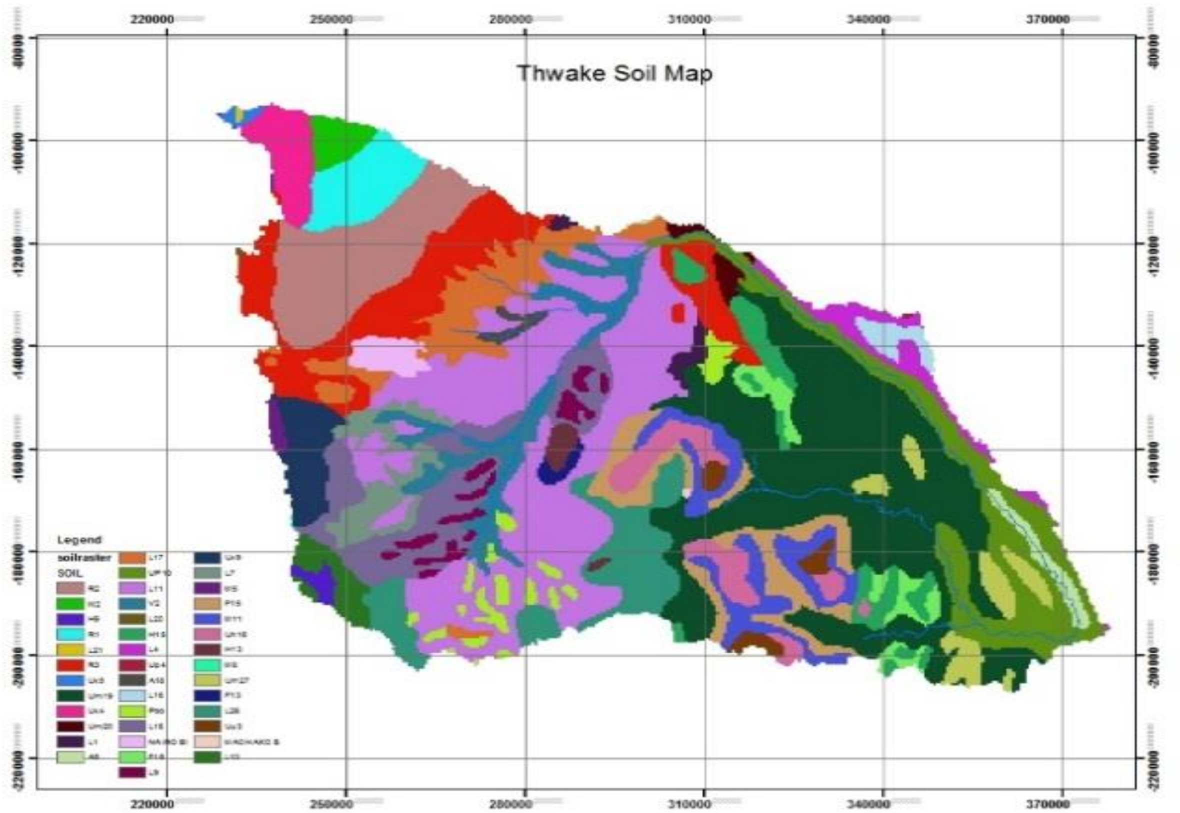


Figure 12: soils dataset from Ministry Of Water and Irrigation (MOWI)

4.4 Performance of the Thwake for the Base Case and the upstream dams' scenarios

This section gauged the performance of the Thwake dam with the advised set of operation rules, under the Base Case and upstream dams' scenarios. The performance was judged for: supply of domestic water to Wote and Konza systems, electricity production, compliance with environmental flow, satisfaction of the Galana flow requirement, water level in the Thwake reservoir, and satisfaction of irrigation demand from Area I and II.

4.4.1 Supply of domestic water

The performances are summarised in figure 12 and table 12.

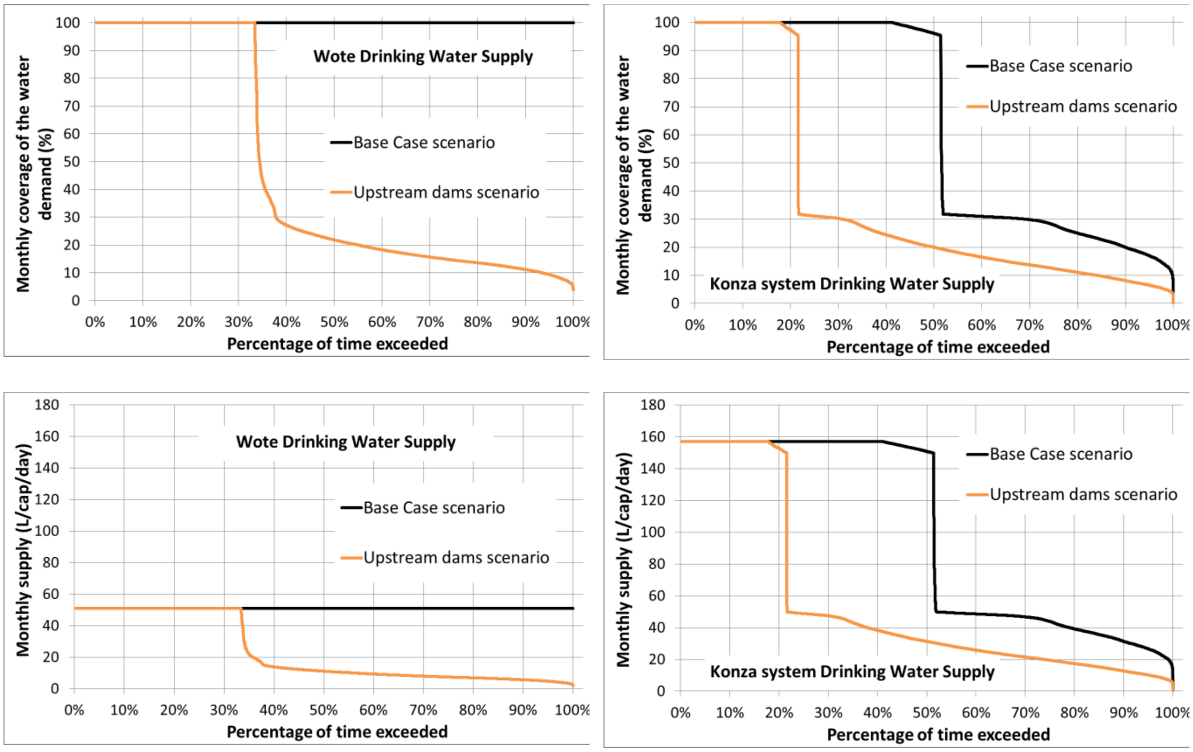


Figure 13: Supply of the domestic water demands for the Base Case and Upstream dam scenarios. Top: satisfaction of the water demand; bottom: equivalent supply in L/cap/day.

Table 13: Main performance for domestic water supply.

Domestic demands	**Wote**		**Konza system**	
Scenario	**Base Case**	**Upstream dams**	**Base Case**	**Upstream dams**
Design rate	51 L/cap/day		157 L/cap/day	
Frequency of total monthly satisfaction	100% of the time	33% of the time	41% of the time	18% of the time
Median supply (50% of the time)	100% (51 L/cap/day)	22% (11 L/cap/day)	96% (151 L/cap/day)	20% (31 L/cap/day)
Low monthly satisfaction (15 l/cap/day or less)	Never	62% of the time	Less than 0.15% of the time (about 20 months on 12,000)	16% of the time
Exceptionally low monthly satisfaction (7.5 l/cap/day or less)	Never	27% of the time	Never	2% of the time
Minimum monthly coverage over 12,000 months in the modelling	-	2 L/cap/day for 4 months	13 L/cap/day for 5 months	5 L/cap/day for 12 months

Wote domestic demand is always totally satisfied in the Base Case scenario. In the upstream dam scenario, it is severely reduced and reaches low (15 L/cap/day) and very low (7.5 L/cap/day) supply 62% and 27% of the time respectively.

The satisfaction of the demand for the Konza system is generally worse than for Wote since (i) it requires electricity production from the Thwake hydropower unit to reach a certain target, which is a severe constrain and (ii) its priority is less than supply to Wote in the Base Case scenario. The sudden fall in satisfaction is due to the fall in electricity production). In absolute value (in L/cap/day) however, the situation appears better: *the low supply (15 L/cap/day or less) is only reached 0.15% of the time (20 months over 12,000) in the Base Case, and 16% of the time in the upstream dam scenario* and *the very low supply (7.5 L/cap/day or less) is never reached in the Base Case and occurs 2% of the time in the upstream dam scenario*.

4.4.2 Electricity production

The performances are summarised in figure 13 and table 13.

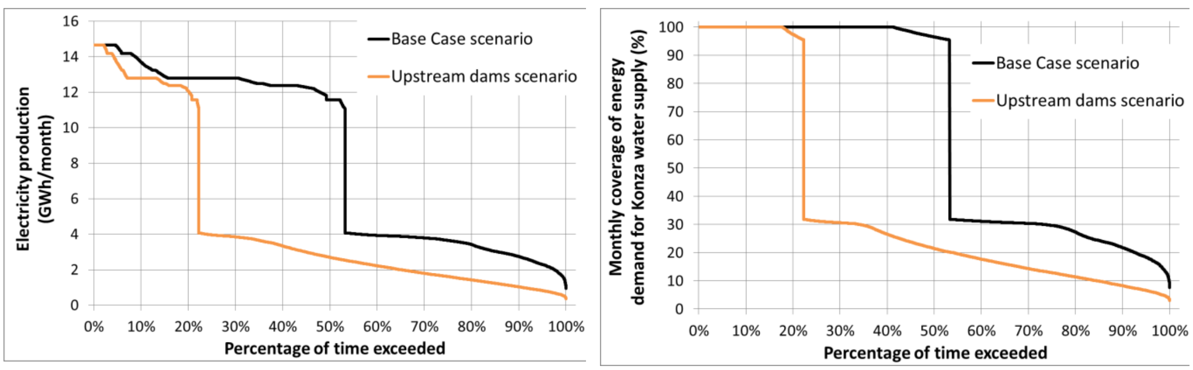


Figure 14: Electricity production for the Base Case and Upstream dam scenarios.

Table 14: Main performance for electricity production.

Scenario	Base Case	Upstream dams
Frequency of maximum production (at capacity of 19.9 MW, 14.6 GWh/month)	5% of the time	2% of the time
Frequency of total monthly satisfaction of energy demand for Konza water supply	41% of the time	18% of the time
Median production (50% of the time)	11.5 GWh/month	2.7 GWh/month
Low production (4 GWh/month or less)	44%	74% of the time
Exceptionally low production (2 GWh/month or less)	2% of the time	35% of the time
Minimum production over 12,000 months in the modelling	Slightly less than1 GWh/month, occurred for 1 month	0.4 GWh/year occurred for 13 months

In the Base Case scenario, the median (most likely) monthly and annual electricity production is 11.5 GWh/month and 103 GWh/year. The sudden fall just after the median is due to the shift from three turbines in operation (above 900 masl) to one turbine (below 900 masl).

In the upstream dams' scenario, the production is severely reduced, with a median production of 2.7GWh/month and 34 GWh/year.

In term of production to operate the Konza domestic water supply, the scheme is already not reliable in the Base Case scenario since the requirement to operate totally the supply is only satisfied 41% of the time, with a sudden fall once the water levels are below 900masl. The situation is logically worse in the upstream dams' scenario with a total power requirement only met 18% of the time.

4.4.3 Environmental flow requirement

The coverage of the environmental flow is shown in figure 14.

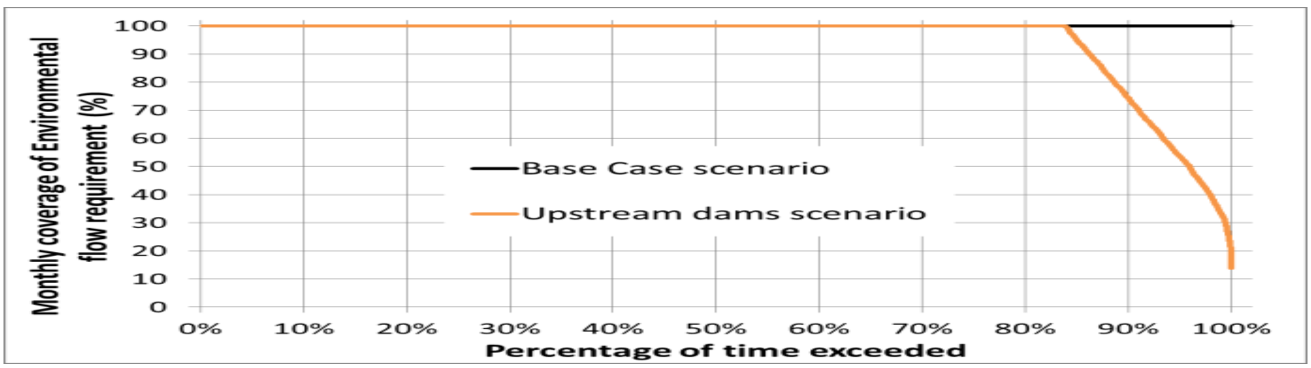


Figure 15: Compliance with environmental flow for the Base Case and upstream dam scenarios.

The environmental flow requirement is always satisfied in the Base Case while it is totally satisfied in the upstream dams' scenario 84% of the time.

4.4.4 Galana flow requirement

The coverage of the Galana flow requirement is shown in figure 15.

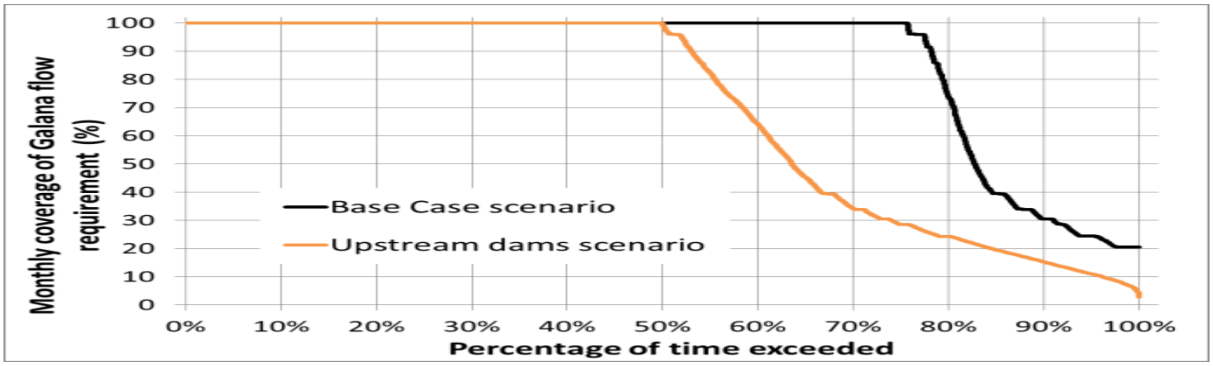


Figure 16: Satisfaction of Galana flow requirement for the Base Case and upstream dam scenarios.

Table 15: Main performance for satisfaction of Galana flow requirement.

Scenario	Base Case	Upstream dams
Frequency of total monthly satisfaction	76% of the time	50% of the time
Low monthly satisfaction (30% or less)	9% of the time	36% of the time
Minimum monthly satisfaction over 12,000 months in the modelling	Satisfaction of 21%, for 2.5% of the months.	Satisfaction of 3% occurred for 2 months

In the Base Case, the monthly flow requirement is relatively well satisfied, with a total satisfaction 76% of the time. Its minimum is 21% which corresponds to the environmental flow requirement, 3.5 m3/s on average annually, which is always satisfied. In the upstream dams' scenario, satisfaction is worse and its minimum is 3% since the environmental flow requirement is also not always satisfied.

4.4.5 Storage in Thwake reservoir

The storage in Thwake reservoir is shown in figure 16.

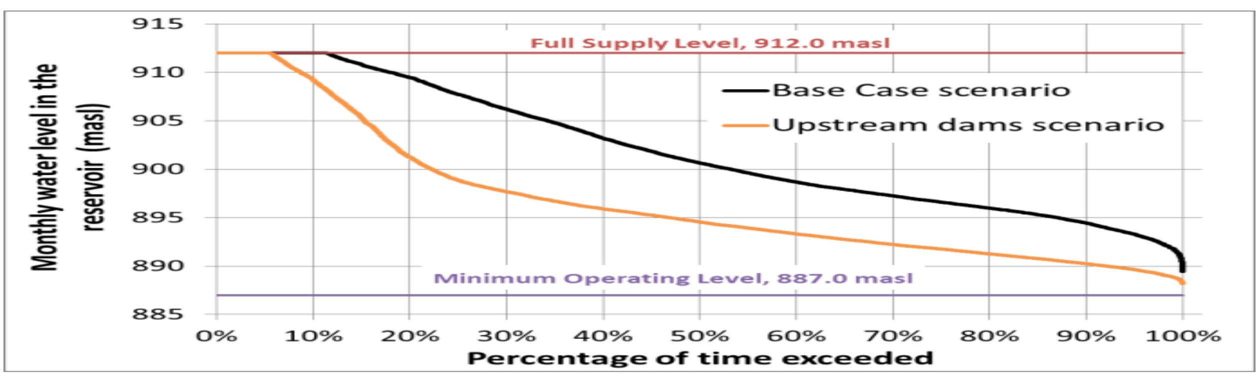


Figure 17: Water level in Thwake reservoir for the Base Case and upstream dam scenarios.

Table 16: Main performance in terms of water level in Thwake reservoir (water storage).

Scenario	Base Case	Upstream dams
Frequency of full water level (FSL)	11% of the time	6% of the time
Frequency of water level above 900.0 masl (all turbines functioning)	53% of the time	22% of the time
Median water level	900.7 masl	894.6 masl
Frequency of low water level (895 masl or less)	13% of the time	53% of the time
Frequency of exceptionally low water level (890 masl or less)	Almost never	8% of the time
Minimum water level over 12,000 months in the modelling	889.4 masl for 1 month	888 masl for 20 months

In the Base Case, the median water level in the reservoir (900.7 masl) is close to 900.0 masl, from which only one hydropower turbine is operational. The hydropower unit operates slightly more than half of the time (53%) with all its three turbines and the rest of the time (47%) with only one turbine. Moreover, the chosen operation rules are such that the water level never reaches the Minimum Operating Level which would entail a total failure of supply to the domestic water schemes.

In the Upstream dams' scenario, the water levels are significantly lower with a median water level of 894.6 masl. Most of the time (88% of the time) the hydropower only operates with one turbine. However, the operation rules are such that the water level in the reservoir never reaches the Minimum Operating Level.

4.4.6 Coverage of irrigation demands

The coverage of irrigation demand is shown in figure 17.

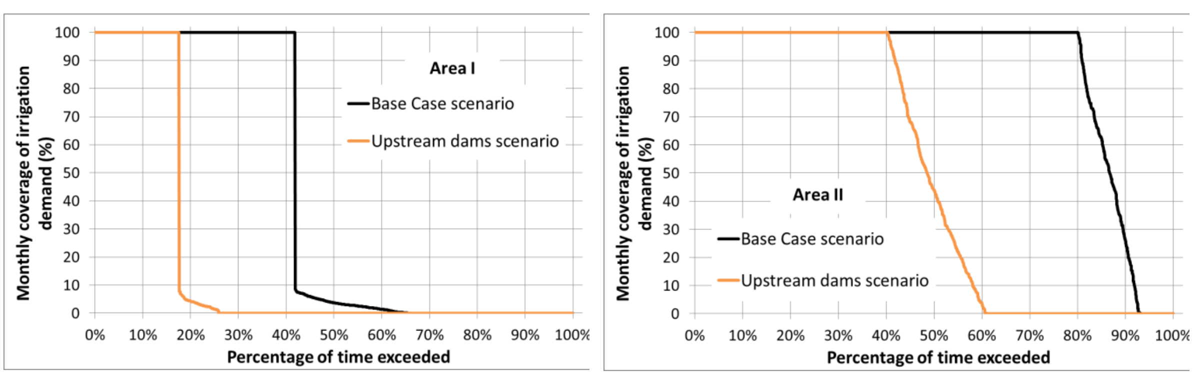


Figure 18: Satisfaction of the irrigation water demands for the Base Case and Upstream dam scenarios.

The results are summarised in table 16.

Table 17: Main performance for coverage of irrigation demands in the critical months of September and October.

Irrigation demand	Area I		Area II	
Scenario	Base Case	Upstream dams	Base Case	Upstream dams
Frequency of total monthly satisfaction	42% of the time	17% of the time	80% of the time	40% of the time
Low monthly satisfaction (10% or less)	58% of the time	83% of the time	8% of the time	42% of the time
No supply at all	37% of the time	74% of the time	7% of the time	39% of the time

The satisfaction of Area I's demand is bad in the Base Case since most of the time (58%) it gets less than 10% of its requirement in the crucial months of September and October, with 37% of the time with no water at all. The abrupt shift between 100% to less than 10% of satisfaction in the duration curve is due to the low priority to allocate water to irrigation. Area I only gets water when the water in the reservoir is above 900.7 masl. The results are even worse in the upstream dams' scenario with a full supply only 17% of the time and no supply at all 74% of the time.

This bad coverage entails that the extent proposed of 2,377 ha for Area I, appears overestimated given the allocation setting of Thwake system. The failure criterion that will be chosen for irrigation is that crops get their irrigation requirement during the critical months at least 70% of the time. The area should be revisited so as to reach a full coverage in the months of September and October 70% of the time in the Base Case scenario.

Results are better for Area II since it can use some portion of the water released for hydropower, the other part being reserved for the Galan flow requirement.

4.5 Base Case, tuning the safe zone of the reservoir and the operation of the dam for the high priority demands

This presents the options of Thwake dam operation rules explored in the Base Case to supply first water to the high priority demands, namely the environmental flow requirement, the two domestic water supplies, the hydropower production and the Galana downstream flow requirement.

The value for 50% (the median) was the most probable value occurring in a given month (one month on two).

The comparison between Option 1 and Option 2 showed that:

The satisfaction of the environmental flow requirement is always totally satisfied except for Option 1 with a safe zone of 10%;

The satisfaction of the Galana flow requirement is improved in case of Option 1 but the safe zone should be at least of 30% to ensure a better reliability (minimum percentage of satisfaction and

The satisfaction of domestic water supply, especially to Wote, is however improved in case of Option 2, so is electricity production.

Since supplying domestic water, and producing the required electricity to do so, is the main purpose of the Thwake dam, Option 2 was selected for setting the allocation priorities: (*1*) Environmental flow requirement, (*2*) Domestic water supplies and Hydropower production, (*3*) Galana downstream flow requirement, (*4*) Possible specific rank for storing water in Thwake reservoir and (*5*) Irrigation to Area I & II.

With the Option 2, there were different possibilities to operate the reservoir to satisfy the Galana flow requirement once the water level in the reservoir is above the safe zone. In this first approach the simple case explored is that 50% of the remaining effective volume is totally available for the flow requirement, the rest is balanced with filling/storing water in the reservoir The results for the various safe zones are as follows:

The environmental flow requirement is always totally satisfied in all the cases.

In terms of domestic water supply to Wote, the case with a safe volume of 10% of the effective storage yields a better satisfaction of the demand most of the time (90% of the time) but at a cost of a worse coverage 10% of the time, with total failure of supply. Hence in term of reliability, it is better to have a larger safe zone.

The results for the supply to the Konza system are different than for Wote, since the supply is function of the water available for release but also function of the hydropower production (cf. below). Its best coverage is for a safe zone equal to 30% of the effective storage.

The electricity production is the greatest with a large safe storage zone: the more water in the reservoir, the higher the water level and the more head on the turbine.

The results for coverage of Galana flow requirement are not very contrasted. Since the satisfaction of flow requirement is of less priority when the water level is below the safe zone, a smaller safe zone logically entails a slightly better satisfaction of the flow requirement most of the time (95% of the months), but at the cost of less reliability (drop in coverage 5% of the months).

In all the cases, irrigation Area I badly covered because of its low priority. Area II is better covered, due to water released for hydropower, but overall it has a low satisfaction.

From these elements, a safe zone equal to 30% of the effective storage was selected, ie below the level 897.0 masl. With this safe zone, the minimum satisfaction at Wote reaches the value of 7% which is equivalent to a supply of approximately 3.5 l/cap/day. This is below (World Health Organization, 2011) guidelines of 7.5 l/cap/day as the minimum daily requirement so it was not acceptable. Since the demand of Wote system is significantly smaller than for the Konza system, the following alternative priority setting where supply with a safe zone of 30% were explored: (*1*) Environmental flow requirement, (*2*) Wote domestic water supply, (*3*) Konza drinking water supply and hydropower production, (*4*) Galana downstream flow requirement, (*5*) Possible specific rank for storing water in Thwake reservoir and (*6*) Irrigation to Area I & II.

The supply to Wote was as a consequence always totally satisfied with an insignificant impact on supply to the Konza system. This alternative priority setting was retained.

With this alternative setting, four additional options for operating the volume of water above the safe zone with respect to Galana flow requirement were explored: 30%, 70%, 80% or 90% of the remaining effective volume is totally available for the flow requirement; the rest is balanced with filling/storing water in the reservoir. The results were:

The environmental flow requirement and domestic water demand for Wote are always totally satisfied in all the cases.

The coverage of the Galana flow requirement increases logically with the percentage of remaining effective volume being totally available for its requirement.

But this is at the cost of slight losses in coverage of domestic water supply to Konza where the tendency is the contrary.

A compromise is to have 80% of the storage above the safe zone totally available for the Galana flow requirement, which has a little impact on the domestic water supplies and on the electricity production.

Eventually, the advised setting to satisfy the high priority demands (the environmental flow, the domestic water supplies, the hydropower production and the Galana downstream flow requirement) was to have the priority rank as such: (*1*) Environmental flow requirement, (*2*) Wote domestic water supply, (*3*) Konza domestic water supply and hydropower production, (*4*) Galana downstream flow requirement and (*5*) Possible specific rank for storing water in Thwake reservoir.

The priority for filling/storing water in the reservoir is: (*3*) when water levels in the reservoir ≤ 897.0 masl (ca 341 Mm3); (*4*) when water levels ≤ 900.7 masl (ca 409 Mm3) and (*5*) otherwise.

The table below summarises the scenarios examined iteratively to identify the best operation rules and the results are presented as graphs in the Appendixes section. The best operation rule, scenario "2.3.4bis", is coloured in green in table 18 below. The table shows different scenarios explored to tune the operation of Thwake dam for the high priority demands.

Table 18: Results for base case scenario-high priority demands

Scenario	Priority for Galana flow requirement	Safe zone of the reservoir	Zone totally available for Galana flow requirement	Priority for filling/storing water in the reservoir
1.1	1 (Option 1)	10% of effective storage (891.0 masl, 243 Mm3)		• 2 when water levels ≤ 890.8 masl (ca 242 Mm3), • 3 otherwise.
1.2	1 (Option 1)	20% of effective storage (894.0 masl, 290 Mm3)		• 2 when water levels ≤ 894.1 masl (ca 291 Mm3), • 3 otherwise.
1.3	1 (Option 1)	30% of effective storage (897.0 masl, 341 Mm3)		• 2 when water levels ≤ 897.0 masl (ca 341 Mm3), • 3 otherwise.
1.4	1 (Option 1)	35% of effective storage (897.0 masl, 341 Mm3)		• 2 when water levels ≤ 898.3 masl (ca 364 Mm3), • 3 otherwise.
2.1.1	2 (Option 2)	10% of effective storage (891.0 masl, 243 Mm3)	50% of remaining effective storage	• 2 when water levels ≤ 890.8 masl (ca 242 Mm3),

				• 3 when water levels ≤ 903.2 masl (ca 462 Mm3), • 4 otherwise.
2.2.1	2 (Option 2)	20% of effective storage (894.0 masl, 290 Mm3)	50% of remaining effective storage	• 2 when water levels ≤ 894.1 masl (ca 291 Mm3 • 3 when water levels ≤ 904.4 masl (ca 488 Mm3), • 4 otherwise.
2.3.1	2 (Option 2)	30% of effective storage (897.0 masl, 341 Mm3)	50% of remaining effective storage	• 2 when water levels ≤ 897.0 masl (ca 341 Mm3), • 3 when water levels ≤ 905.4 masl (ca 510 Mm3), • 4 otherwise.
2.3.1bis*	2 (Option 2)	30% of effective storage (897.0 masl, 341 Mm3)	50% of remaining effective storage	• 3 when water levels ≤ 897.0 masl (ca 341 Mm3), • 4 when water levels ≤ 905.4 masl (ca 510 Mm3), • 5 otherwise.
2.3.2bis	2 (Option 2)	30% of effective storage (897.0 masl, 341 Mm3)	30% of remaining effective storage	• 3 when water levels ≤ 897.0 masl (ca 341 Mm3), • 4 when water levels ≤ 908.2 masl (ca 367 Mm3), • 5 otherwise.
2.3.3bis	2 (Option 2)	30% of effective storage (897.0 masl, 341 Mm3)	70% of remaining effective storage	• 3 when water levels ≤ 897.0 masl (ca 341 Mm3), • 4 when water levels ≤ 902.3 masl (ca 447 Mm3), • 5 otherwise..

2.3.4bis	2 (Option 2)	30% of effective storage (897.0 masl, 341 Mm3)	80% of remaining effective storage	• 3 when water levels ≤ 897.0 masl (ca 341 Mm3), • 4 when water levels ≤ 900.7 masl (ca 409 Mm3), • 5 otherwise.
2.3.5bis	2 (Option 2)	30% of effective storage (897.0 masl, 341 Mm3)	90% of remaining effective storage	• 3 when water levels ≤ 897.0 masl (ca 341 Mm3), • 4 when water levels ≤ 898.9 masl (ca 375 Mm3), • 5 otherwise.
2.4.1	2 (Option 2)	35% of effective storage (897.0 masl, 341 Mm3)	50% of remaining effective storage	• 2 when water levels ≤ 898.3 masl (ca 364 Mm3), • 3 when water levels ≤ 905.9 masl (ca 523 Mm3), • 4 otherwise.

* in the scenarios labelled with "bis", the priority for the water demands is as follows:

(*1*) Environmental flow requirement, (*2*) Wote Domestic water supply, (*3*) Konza Drinking Water supply and Hydropower production, (*4*) Galana downstream flow requirement, (*5*) Possible specific rank for storing water in Thwake reservoir and (*6*) Irrigation to Area I & II.

4.6 Base Case, tuning the operation of the dam for the low priority demands

This explores the operation rules in the Base Case to supply water to the low priority demands, namely the irrigation schemes Area I and II. The scenarios examined in the table below builds on the operation rule identified previously for the high priority demands. The eventual best operation rule for all the demands is scenario "2.3.4.7bis", coloured in green. Table 19 below shows different scenarios explored to tune the operation of Thwake dam for the low priority demands.

Table 19: Results for Base case scenario-Low priority demands

Scenario	Priority for Galana flow requirement	Safe zone of the reservoir	Zone totally available for Galana flow requirement	Zone available for irrigation	Priority for filling/storing water in the reservoir

2.3.4.1bis	2 (Option 2)	30% of effective storage (897.0 masl, 341 Mm3)	Storage between the safe zone and the elevation 900.7 masl	• None: 60% of remaining storage, • partly: 20% of remaining storage, • totally: 20% of remaining storage.	• 3 when water levels ≤ 897.0 masl (ca 341 Mm3), • 4 when water levels ≤ 900.7 masl (ca 409 Mm3), • 5 when water levels ≤ 907.9 masl (ca 572 Mm3), • 6 when water levels ≤ 910.1 masl (ca 627 Mm3), • 7 otherwise.
2.3.4.2bis	2 (Option 2)	30% of effective storage (897.0 masl, 341 Mm3)	Storage between the safe zone and the elevation 900.7 masl	• None: 1/3rd of remaining storage, • partly: 1/3rd of remaining storage, • totally: 1/3rd of remaining storage.	• 3 when water levels ≤ 897.0 masl (ca 341 Mm3), • 4 when water levels ≤ 900.7 masl (ca 409 Mm3), • 5 when water levels ≤ 905.0 masl (ca 500 Mm3), • 6 when water levels ≤ 908.7 masl (ca 592 Mm3), • 7 otherwise.
2.3.4.3 bis	2 (Option 2)	30% of effective storage (897.0 masl, 341 Mm3)	Storage between the safe zone and the elevation 900.7 masl	• None: 20% of remaining storage, • partly: 40% of remaining storage, • totally: 40% of remaining storage.	• 3 when water levels ≤ 897.0 masl (ca 341 Mm3), • 4 when water levels ≤ 900.7 masl (ca 409 Mm3), • 5 when water levels ≤ 903.3

					masl (ca 464 Mm3), • 6 when water levels ≤ 907.9 masl (ca 572 Mm3), • 7 otherwise.
2.3.4.4 bis	2 (Option 2)	30% of effective storage (897.0 masl, 341 Mm3)	Storage between the safe zone and the elevation 900.7 masl	• None: 10% of remaining storage, • partly: 45% of remaining storage, • totally: 45% of remaining storage.	• 3 when water levels ≤ 897.0 masl (ca 341 Mm3), • 4 when water levels ≤ 900.7 masl (ca 409 Mm3), • 5 when water levels ≤ 902.0 masl (ca 437 Mm3), • 6 when water levels ≤ 907.4 masl (ca 560 Mm3), • 7 otherwise.
2.3.4.5 bis	2 (Option 2)	30% of effective storage (897.0 masl, 341 Mm3)	Storage between the safe zone and the elevation 900.7 masl	• None: 0% of remaining storage, • partly: 50% of remaining storage, • totally: 50% of remaining storage.	• 3 when water levels ≤ 897.0 masl (ca 341 Mm3), • 4 when water levels ≤ 900.7 masl (ca 409 Mm3), • 6 when water levels ≤ 906.8 masl (ca 545 Mm3), • 7 otherwise.
2.3.4.6 bis	2 (Option 2)	30% of effective storage (897.0 masl, 341 Mm3)	Storage between the safe zone and the elevation 900.7 masl	• None: 0% of remaining storage, • partly: 25% of remaining storage,	• 3 when water levels ≤ 897.0 masl (ca 341 Mm3), • 4 when water levels ≤ 900.7

				• totally: 75% of remaining storage.	masl (ca 409 Mm3), • 6 when water levels ≤ 903.9 masl (ca 477 Mm3), • 7 otherwise.
2.3.4.7 bis	2 (Option 2)	30% of effective storage (897.0 masl, 341 Mm3)	Storage between the safe zone and the elevation 900.7 masl	• None: 0% of remaining storage, • partly: 0% of remaining storage, • totally: 100% of remaining storage.	• 3 when water levels ≤ 897.0 masl (ca 341 Mm3), • 4 when water levels ≤ 900.7 masl (ca 409 Mm3), • 6 otherwise.

The best scenario is "2.3.4.7bis". The operation rules in this scenario are equivalent to have the following priority setting for the demands:

(*1*) Environmental flow requirement, (*2*) Wote Domestic water supply, (*3*) Konza Drinking Water supply and Hydropower production, (*4*) Galana downstream flow requirement, (*5*) Irrigation to Area I & II and (*6*) Possible specific rank for storing water in Thwake reservoir.

with the following priority for filling/storing water in the reservoir:

(3) when water levels in the reservoir ≤ 897.0 masl (ca 341 Mm3); (4) when water levels ≤ 900.7 masl (ca 409 Mm3) and (6) otherwise.

4.7 Dam development scenario, tuning the safe zone of the reservoir and the operation of the dam for the high priority demands

The set of scenario explored are the same as in Base Case for Option 1 and 2, except that all the priority ranks are increased by one to account for the new upstream dams' demand withdrawing water with first priority. The scenarios for Option 3 are summarised in the table 20 below.

Table 20: Results for Upstream dam development scenario-high priority demands

Scenario	Priority for Galana flow requirement	Safe zone of the reservoir	Zone totally available for Galana flow requirement	Priority for filling/storing water in the reservoir
3.1.1	3 (Option 3)	10% of effective storage (891.0 masl, 243 Mm3)	50% of remaining effective storage	• 2 when water levels ≤ 890.8 masl (ca 242 Mm3), • 3 when water levels ≤ 903.2 masl (ca 462 Mm3), • 4 otherwise.
3.2.1	3 (Option 3)	20% of effective storage (894.0 masl, 290 Mm3)	50% of remaining effective storage	• 2 when water levels ≤ 894.1 masl (ca 291 Mm3 • 3 when water levels ≤ 904.4 masl (ca 488 Mm3), • 4 otherwise.
3.3.1	3 (Option 3)	30% of effective storage (897.0 masl, 341 Mm3)	50% of remaining effective storage	• 2 when water levels ≤ 897.0 masl (ca 341 Mm3), • 3 when water levels ≤ 905.4 masl (ca 510 Mm3), • 4 otherwise.
3.3.2	3 (Option 3)	30% of effective storage (897.0 masl, 341 Mm3)	30% of remaining effective storage	• 2 when water levels ≤ 897.0 masl (ca 341 Mm3), • 3 when water levels ≤ 908.2 masl (ca 367 Mm3), • 4 otherwise.
3.3.3	3 (Option 3)	30% of effective storage (897.0 masl, 341 Mm3)	70% of remaining effective storage	• 2 when water levels ≤ 897.0 masl (ca 341 Mm3), • 3 when water levels ≤ 902.3 masl (ca 447 Mm3), • 4 otherwise..

3.3.4	3 (Option 3)	30% of effective storage (897.0 masl, 341 Mm3)	80% of remaining effective storage	• 2 when water levels ≤ 897.0 masl (ca 341 Mm3), • 3 when water levels ≤ 900.7 masl (ca 409 Mm3), • 4 otherwise.
3.3.5	3 (Option 3)	30% of effective storage (897.0 masl, 341 Mm3)	90% of remaining effective storage	• 2 when water levels ≤ 897.0 masl (ca 341 Mm3), • 3 when water levels ≤ 898.9 masl (ca 375 Mm3), • 4 otherwise.
3.4.1	3 (Option 3)	35% of effective storage (897.0 masl, 341 Mm3)	50% of remaining effective storage	• 2 when water levels ≤ 898.3 masl (ca 364 Mm3), • 3 when water levels ≤ 905.9 masl (ca 523 Mm3), • 4 otherwise.

4.8 Dam development scenario, tuning the operation of the dam for the low priority demands

The different scenarios considered to identify the best operation rules of Thwake dam for the low priority demands in case of upstream dams' development are summarised in the table 21 below:

Table 21: Results for Upstream dam development-Low priority demands

Scenario	Priority for Galana flow requirement	Safe zone of the reservoir	Zone totally available for Galana flow requirement	Zone available for irrigation	Priority for filling/storing water in the reservoir
3.3.4.1	3 (Option 3)	30% of effective storage (897.0 masl, 341 Mm3)	Storage between the safe zone and the elevation 900.7 masl	• None: 60% of remaining storage, • partly: 20% of remaining storage, • totally: 20% of remaining storage.	• 2 when water levels ≤ 897.0 masl (ca 341 Mm3), • 3 when water levels ≤ 900.7 masl (ca 409 Mm3), • 4 when water levels ≤ 907.9

					masl (ca 572 Mm3), • 5 when water levels ≤ 910.1 masl (ca 627 Mm3), • 6 otherwise.
3.3.4.2	3 (Option 3)	30% of effective storage (897.0 masl, 341 Mm3)	Storage between the safe zone and the elevation 900.7 masl	• None: 1/3rd of remaining storage, • partly: 1/3rd of remaining storage, • totally: 1/3rd of remaining storage.	• 2 when water levels ≤ 897.0 masl (ca 341 Mm3), • 3 when water levels ≤ 900.7 masl (ca 409 Mm3), • 4 when water levels ≤ 905.0 masl (ca 500 Mm3), • 5 when water levels ≤ 908.7 masl (ca 592 Mm3), • 6 otherwise.
3.3.4.3	3 (Option 3)	30% of effective storage (897.0 masl, 341 Mm3)	Storage between the safe zone and the elevation 900.7 masl	• None: 20% of remaining storage, • partly: 40% of remaining storage, • totally: 40% of remaining storage.	• 2 when water levels ≤ 897.0 masl (ca 341 Mm3), • 3 when water levels ≤ 900.7 masl (ca 409 Mm3), • 4 when water levels ≤ 903.3 masl (ca 464 Mm3), • 5 when water levels ≤ 907.9 masl (ca 572 Mm3), • 6 otherwise.
3.3.4.4	3 (Option 3)	30% of effective storage	Storage between the safe zone and the	• None: 10% of remaining storage,	• 2 when water levels ≤ 897.0

		(897.0 masl, 341 Mm3)	elevation 900.7 masl	• partly: 45% of remaining storage, • totally: 45% of remaining storage.	masl (ca 341 Mm3), • 3 when water levels ≤ 900.7 masl (ca 409 Mm3), • 4 when water levels ≤ 902.0 masl (ca 437 Mm3), • 5 when water levels ≤ 907.4 masl (ca 560 Mm3), • 6 otherwise.
3.3.4.5	3 (Option 3)	30% of effective storage (897.0 masl, 341 Mm3)	Storage between the safe zone and the elevation 900.7 masl	• None: 0% of remaining storage, • partly: 50% of remaining storage, • totally: 50% of remaining storage.	• 2 when water levels ≤ 897.0 masl (ca 341 Mm3), • 3 when water levels ≤ 900.7 masl (ca 409 Mm3), • 5 when water levels ≤ 906.8 masl (ca 545 Mm3), • 6 otherwise.
3.3.4.6	3 (Option 3)	30% of effective storage (897.0 masl, 341 Mm3)	Storage between the safe zone and the elevation 900.7 masl	• None: 0% of remaining storage, • partly: 25% of remaining storage, • totally: 75% of remaining storage.	• 2 when water levels ≤ 897.0 masl (ca 341 Mm3), • 3 when water levels ≤ 900.7 masl (ca 409 Mm3), • 5 when water levels ≤ 903.9 masl (ca 477 Mm3), • 6 otherwise.
3.3.4.7	3 (Option 3)	30% of effective storage	Storage between the safe zone and the	• None: 0% of remaining storage,	• 2 when water levels ≤ 897.0

		(897.0 masl, 341 Mm3)	elevation 900.7 masl	• partly: 0% of remaining storage, • totally: 100% of remaining storage.	masl (ca 341 Mm3), • 3 when water levels ≤ 900.7 masl (ca 409 Mm3), • 6 otherwise.

(S. Yaykiran, *et al*. 2019) in their model for estimation the water budget components, found out that for Sakarya River Basin, runoff was 4747 MCM, flow to groundwater was 3065 MCM and evapotranspiration was 23,011MCM. The general WEAP model performace ratings indicated that model simulations represent streamflow variations at acceptable levels. According to (G. Dimova, *et al* 2013), WEAP model is very reliable where parameters require the set-up and output of a detailed water management model. This was evident in their study where analytical water balance modelling was implemented in WEAP for Vit River in Bulgaria catchment.From the results, important site specific outcomes were achieved, mainly getting a complete overview on the complex water resource and water use relations, as well as outlining measures for efficient water resource utilization at a river basin scale

WEAP being a priority driven software, was applied to assess the future water demands for Niger River (Z.M. Mounir, *et al*., 2011). According to Z. M. Mounir *et al* (2011), in 2030, there would be a deficit of 33.7 million cubic meter of water set as follows: 9.8 million m3 for the irrigation, 22.1 million m3 for Niamey city and 1.8 million m3 for Tillabéry town.

The performance of the Thwake Reservoir under different scenarios was assessed for base case and upstream development dams. The sets were tuned to the operational rules of the Thwake reservoir. The safe yield of the Reservoir is at 30% of the effective storage (488Mm^3), when setting the demands on high priority and low priority. The zone totally available for Galana Kulalu flow requirement at 80% of the remaining effective storage for the high priority demands. For low priority demands, the zone totally available for Galana Kulalu is the storage between the 897M.a.s. l and 900.7 M.a.s.l. There are also different priorities for filling/storing water in the reservoir when setting the reservoir at base scenario and at upstream development.

For assessment of the safe yield of Thwake Reservoir, failure criteria for base case and for each water demand category was defined. The failure criterion for domestic water supply was based on health standards. Referring to WHO's guidelines (WHO, 2011), the failure chosen for domestic water supply was: (a) a minimum vital supply of 7.5l.cap/day. This should be always supplied (100% of the time) and (b) a minimum comfort supply of 15l/cap/day. This should be supplied 80% of the time. Based on the design rate for Wote and Konza systems (CASSH, October, 2014), 51 l/cap/day and 157 l/cap/day respectively, the failure criteria is summarized as:

Table 22:Failure criteria for domestic water supply

Failure Criteria	Minimum vital supply that should be satisfied 100% of the time		Minimum comfort supply that should be satisfied 80% of the time	
	l/cap/day	Satisfaction demand	l/cap/day	Satisfaction demand
Wote system	7.5	15%	15	30%
Konza system		5%		10%

For hydropwer and environmental flow requirements, there’s a total satisfaction of the requirement less than 100% of the time.Galana flow requirement total satisfaction is less than 70% of the time.

The results for irrigation in the Base Case show that Area II and especially Area I do not get the irrigation supply they require. Only parts of their areas get full irrigation:

At Area I, its 2,377 ha (CASSH, June, 2013.) only get fully supplied 42% of the time in the critical months of September and October. Therefore, it can be assumed that only 42% of the 2,377 ha, equal to 998 ha, get fully supplied.

At Area II, its 9,065 ha (CASSH, June, 2013.) get fully supplied 80% of the time in the critical months of September and October. This is equivalent to say that only about 7,250 ha get fully irrigated.

The failure criterion is such that the areas fully irrigated in the Base Case (998 ha and 7,250 ha respectively at Area I and II), are fully supplied only 70% of the time. This is equivalent to say that:

Area I, with its 2,377 ha, gets full supply less than 42% x 70% = 29% of the time,

Area II, with its 9,065 ha, gets full supply less than 80% x 70% = 57% of the time.

5 RECOMMENDATION

Since water from the reservoir will be used to supply drinking water and water from Athi river might be polluted by waste water from Nairobi city, it is essential to check the water quality parameters. These parameters are advised to be: Temperature, Biochemical oxygen demand (BOD), Dissolved organic carbon (DOC), Dissolved oxygen (DO), Conductivity, pH, Turbidity, Total suspended solids (TSS), Nutrients (total Nitrogen, TN) and Total phosphorus (TP).

During impoundment and normal operation of the dam, readings should be daily in two locations just upstream of the reservoir (Athi and Thwake rivers) and within the Thwake reservoir, at several depths near intake for domestic water supply.

Another daily measurement should be carried-out downstream the dam, to monitor water quality after the dam. This reading should start during the construction period of the dam, to check the impact of construction works.

Monitoring sediment concentration is one aspect of water quality, with the parameters TSS and turbidity. Special attention is given nevertheless to sediment concentration to follow sedimentation of Thwake reservoir.

In this regard, it is recommended to establish from the impoundment period another station near or at the existing discharge station Athi Munyu (3DA02), to monitor the total suspended solids (TSS).

Besides monitoring, it is important to have a well organised data management, on two aspects: the creation and maintenance of a database and data quality verification and validation.

6 CONCLUSION

The Thwake reservoir has an estimated dependable yield when it will be in operation before and after the development of the upstream dams (termed as ‘virtual dam’).

Creating and maintaining a database have the following advantages: it allows central availability of data in case it has multiple users; data can be manipulated by several users while preserving the raw data and it provides long-term data security.

The database should store the different measured data in several thematic sections. It should also contain metadata to reference the measurement (who did it? how?), for traceability.

Provision should be made for storing raw and validated data, as will explained below. It should also be possible to input three types of entry: the value of the measurement (a number or a text); an entry to mark missing data (e.g., no measurement) and an entry to mark erroneous measurement, for validated data.

Measured data should be examined to verify its correctness. If an error is apparent, data have to be corrected in case of obvious error (e.g., typographical error) or marked as erroneous.

Measured values should be entered as raw data in the database. The validated data, verified and possibly corrected, should be saved in the database in validated category.

Analysis at regular intervals of data in the database will enable to detect changes in the reservoir hydrology (inflow and balance), water quality and/or reservoir sedimentation. This will allow flood management and support the implementation of the reservoir operation rules, follow water quality and reservoir sedimentation

7 REFERENCES

1) Almendinger JE, Murphy MS & Ulrich JS. (2011). Use of the Soil and Water Assessment Tool to Scale Sediment Delivery from Field to Watershed in an Agricultural Landscape with Topographic Depressions. *Journal Of Environmental Quality*, 9-17.
2) Amiran. (2014.). Draft Pre-feasibility report-Galana Kulalu irrigation project (Model *Farm).*
3) Amit, S. (2014). Safe Yield for Jointly Operated Reservoir System and Examination of ENSO Impacts. *Virginia Tech*.
4) Arselan. (2015). Streamflow simulation and sythetic flow calculation by modified Thomas Fiering Model. 2-11.
5) Branche, E. (2016). *International Water Power and Dams Construction.* Retrieved from Water Power Magazines: https://www.waterpowermagazine.com/features/featurea-fair-share-4868585/
6) C. Murray & G. Bloschl. (2011). Hydrological modelling in a changing world. *Sage Journals*.
7) C.B.Pedersen, H. Madsen & C.Scotner. (2007). *Real-time optimization of dam releases using multiple objectives.*
8) CASSH. (2014). *Annex 1: Dam Design Report.* Unpublished.
9) CASSH. (December, 2013). *Annex V: Hydropower Design Report.* Unpublished.
10) CASSH. (June, 2013.). *Annex VI: Irrigation Component final design Report.* Unpublished.
11) CASSH. (October, 2014). *Annex IV: Water and Sanitation Final design Report.* Unpublished.

12) Ch. Doulgeris, P. Georgiou, D. Papadimos & D. Papamichail. (2011). Evaluating three different model setups in the MIKE 11 NAM model. *Advances in the Research of Aquatic Environment,*.

13) CTCN. (2016). *Climate Technology Centre and Network.* Retrieved from Ctc-n.org: https://www.ctc-n.org/technologies/multipurpose-dams

14) D. Electricite & J.France, . (1993). *Munyu Dam feasibility study Report.*

15) D.N. Moriasi, J.G. Anorld, M.W. Van Liew, R.L. Bingner, R.D. Harmel & T.L. Veith. (2007). Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations. *American Society of Agricultural and Biological Engineers*, 885-900.

16) E. Instanbulluoglu, T. Wang, M. Wright & J. Lenters. (2012). Interpretation of hydrologic trends from a water balance perspective: The role of groundwater storage in the Budyko hypothesis. *American Geophysical Union*, 163-171.

17) Esho, L. (2019). *Government of Makueni County (2019), "Makueni County Spatial Plan".*

18) G. Dimova, E. Tzanov, P. Nonov, I. Ribarova & M. Kossida. (2013). Complementary use of the WEAP Model to underpin the Development of SEEAW physical water use and supply tables. *Elsevier Ltd*, 563-572.

19) G.T. Patle & A. Libang. (2014). Trend analysis of annual and seasonal rainfall to climate variability in North-East region of India. *Journal of Applied and Natural Science* , 480-483.

20) Ghassan, L. A. (2013). Optimization-Simulation models for yield of a single reservoir. *Journal of Indian Water Resources Society*, 9-16.

21) Governor Chris Christie & Commissioner Bob Martin. (2011). *Estimating the safe yield of surface water supply guidance manual.* New Jersey Department of Environmental Protection.

22) H. Alrayess, U. Zeybekoglu & A. Ulke. (2017). Different design techniques in determining reservoir capacity. *European Water* , 107-115.

23) Holger Hoff, Stacey Noel & Peter Droogers. (2007). *Water Use and demand in the Tana Basin: analysis using Water Evaluation And Planning tool, WEAP*. ISRIC-World soil Information.

24) J. Jeong, Narayanan K. & J Arnold. (2010). Development and Integration of Sub-hourly Rainfall–Runoff Modeling Capability Within a Watershed Model.

25) J. Nyika, G. N. Karuku & R. Onwonga. (2017). Modelling Water Demand and Efficient Use in Mbagathi SubCatchment Using Weap. *International Journal of Sustainable Water and Environmental System*, 49-57.

26) J.P.O.Obiero, M.A.Hassan & L.O.Gumbe. (2011). Modelling of Streamflow of a Catchment in Kenya. *Journal of Water Resource and Protection*, 667-677.

27) K. Frenken & A. Kohli. (2015). Evaporation from artificial lakes and reservoirs. *FAO AQUASTAT Reports*, 2.

28) K. N. Zeraebruk, A. O. Mayabi & J. M. Gathenya. (2017). Assessment of Water Resources and Analysis of Safe Yield and Reliability of Surface Water Reservoirs of Asmara Water Supply System. *Environment and Natural Resources Research*, 59.

29) Kamel, A. H. (2008). Application of a hydrodynamic MIKE11 Model for the Euphrates River in Iraq. *Slovak Journal of Civil Engineering*.

30) Kharagpur. (n.d.). Hydraulic structures for flow diversion and storage. In Kharagpur, *Hydraulic structures for flow diversion and storage* (p. 24). unpublished.

31) L. M. Mango, A. M. Melesse, M. E. McClain, D. Gann, & S. G. Setegn. (2011). Land use and climate change impacts on the hydrology of the upper Mara River Basin, Kenya: results of a modeling study to support better resource management. *Hydrology and Earth Systems Sciences*.

32) M. Gedefaw, D. Yan, H. Wang, T. Qin & K. Wang. (2019). Analysis of the Recent Trends of Two Climate Parameters over Two Eco-Regions of Ethiopia. *Creative Commons Attribution*.

33) M. Hu, T. Sayama, S. Try, K. Takara & K. Tanaka. (2019). Trend Analysis of Hydroclimatic Variables in the Kamo River Basin, Japan. *Creative Commons Attribution*.

34) Madsen, R. (2006). A Real-Time Inflow Forecasting and Reservoir Optimization System for Optimizing Hydropower Production.

35) Maguire, D. J. (2008). *Springer Link.* Retrieved from https://doi.org/10.1007/978-0-387-35973-1_68: https://link.springer.com/referenceworkentry/10.1007%2F978-0-387-35973-1_68#howtocite

36) Maria, A. (1997). Introduction To Modeling And Simulation. *Proceedings of the 1997 Winter Simulation Conference*, (pp. 1-7). New York.

37) O.G.M. Metobwa, K.A Mourad & L. Ribe. (2018). Water Demand Simulation using WEAP: Mara River, Kenya. *International Journal of Natural Resource Ecology and Management*, 9-18.

38) R. Guimaraes & E. santos. (2011). Principles of stochastic generation of hydrological time series for reservoir planning. 1.

39) S. Yaykiran, G. Cuceloglu & A. Ekdal. (2019). Estimation of Water Budget Components of the Sakarya River Basin by Using WEAP-PGM Model. *Creative Commons Attribution*.

40) S.L. Neitsch, J.G. Arnold, J.R. KIiniry, R. Srinivasan, & J.R. Williams. (2002). *Soil And Water Assessment Tool User's Manual.* Texas: Texas Water Resources Institute, College Station, Texas.

41) Sadoun B., Al-Bayari O., Al-Azizi J. & Al Rawashdeh S. (2012). Geographic Information System using ArcGIS 10 and Open Source MapWindow - Methodology and Comparative Study. *Science and Technology Publications, Lda.*

42) Singhs, D. S. (2016). *SAFE (PERENNIAL, BASIN) YIELD.* unpublished.

43) T. Silva & M.Portela. (2011). *Generation of monthly synthetic streamflow series based on the method of fragments.* Portugal: WIT Press.

44) T.Stiles & D.Leib. (1998). *Yield Estimates for Surface-water Sources.*

45) US Army Corps of Engineers. (1991, January). Optimization of multiple-Purpose Reservoirs system operations. *Research document No. 34*.

46) US, S. (2009). Retrieved from http://www.sei.org

47) WHO. (2011). *Guidelines for Drinking Water Quality-Fourth Edition.* Geneva: WHO Press.

48) Z. Simić, N. Milivojević, D. Prodanović, V. Milivojević, & N. Perović. (2009). SWAT-Based Runoff Modeling in Complex Catchment Areas. *Serbian Society for Computational Mechanics,* 38-63.

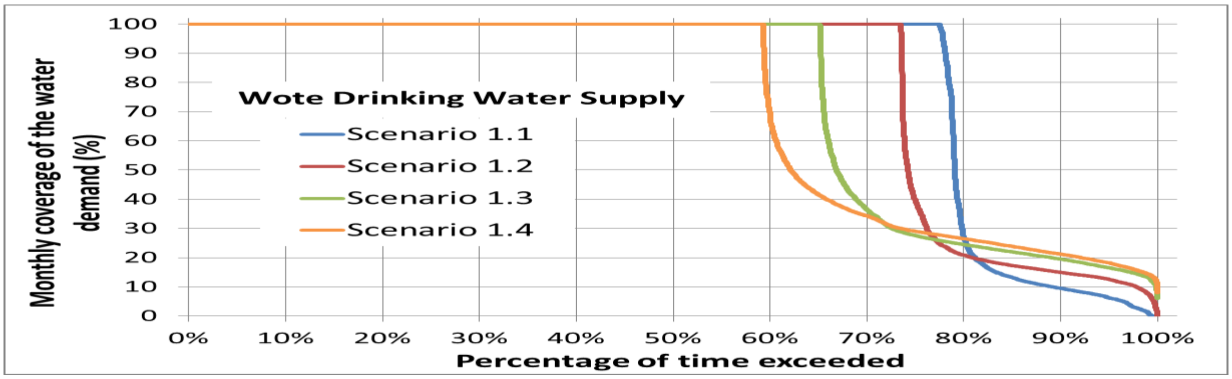
49) Z.M. Mounir, C.M. Ma & I. Amadou. (2011). Application of Water Evaluation and Planning (WEAP): A Model to Assess Future Water Demands in the Niger River (In Niger Republic). *Canadian Center of Science and Education*, 38-49.

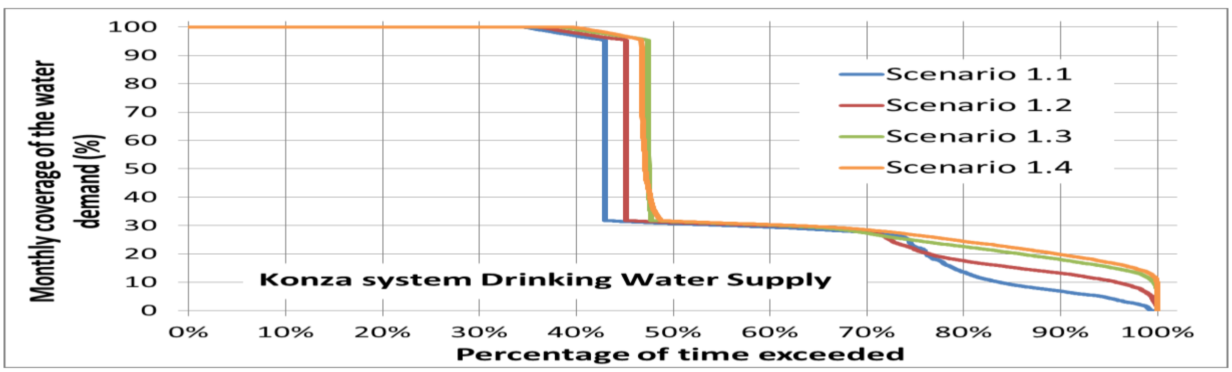
8 APPENDICES

8.1 Appendix 1 – Base Case, tuning the safe zone of the reservoir and the operation of the dam for the high priority demands

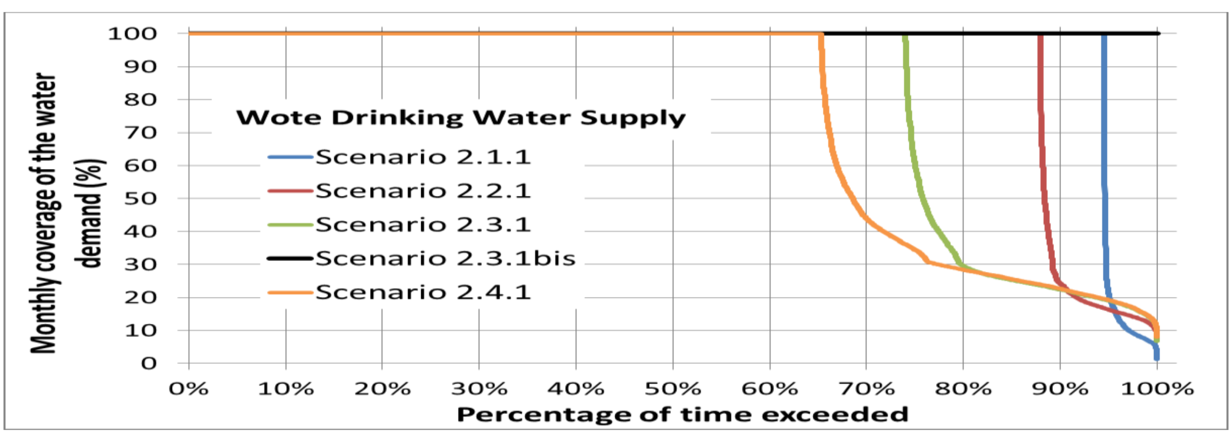
8.1.1 Monthly coverage of the domestic water demands

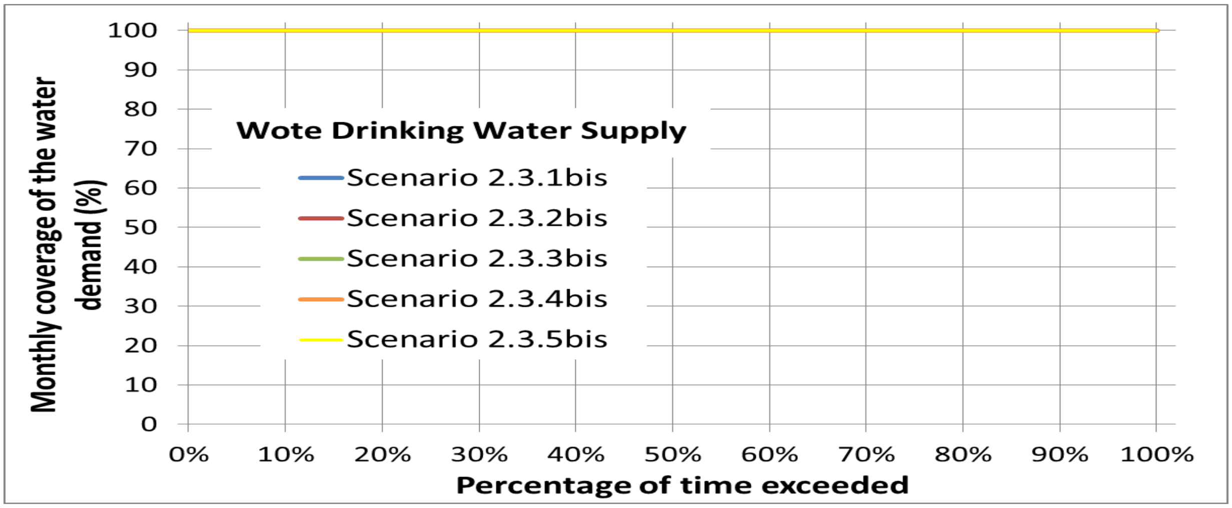
Option 1:

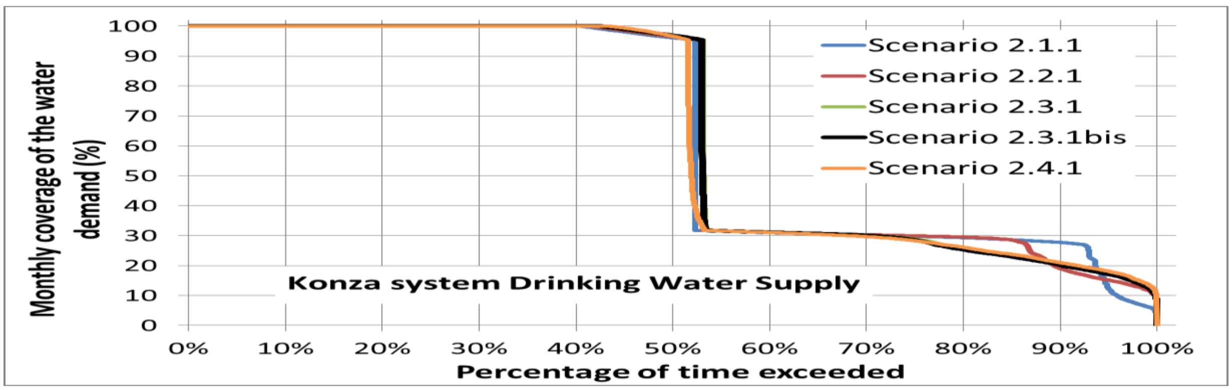


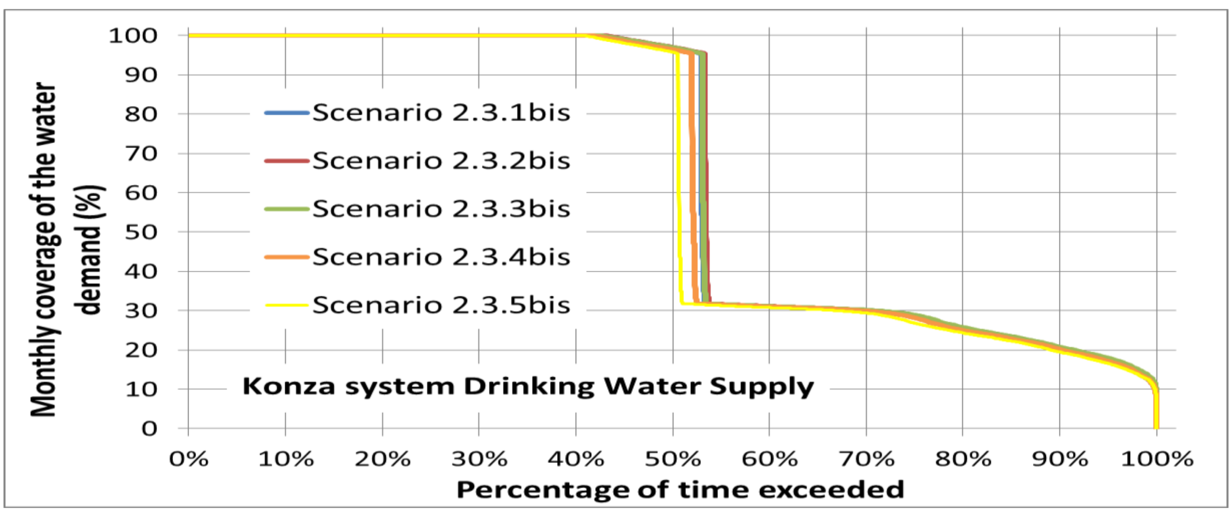


Option 2:



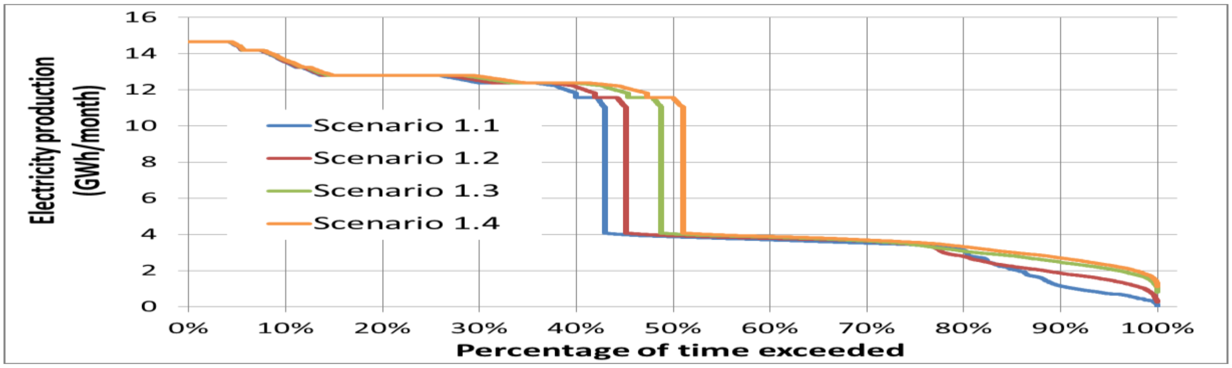

Wote Drinking Water Supply
Scenario 2.3.1bis
Scenario 2.3.2bis
Scenario 2.3.3bis
Scenario 2.3.4bis
Scenario 2.3.5bis
Monthly coverage of the water demand (%)
Percentage of time exceeded
0
10
20
30
40
50
60
70
80
90
100
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%


Scenario 2.1.1
Scenario 2.2.1
Scenario 2.3.1
Scenario 2.3.1bis
Scenario 2.4.1
Konza system Drinking Water Supply
Monthly coverage of the water demand (%)
Percentage of time exceeded

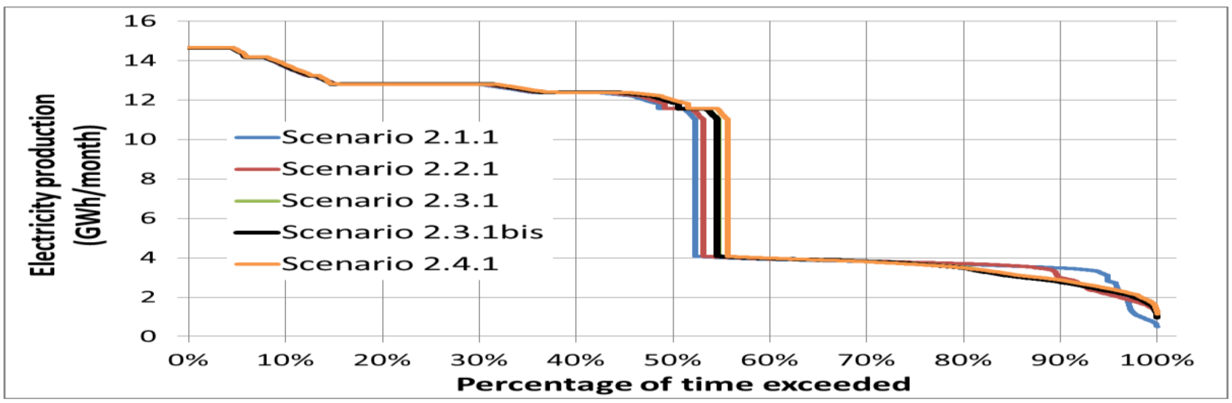

Scenario 2.3.1bis
Scenario 2.3.2bis
Scenario 2.3.3bis
Scenario 2.3.4bis
Scenario 2.3.5bis
Konza system Drinking Water Supply
Monthly coverage of the water demand (%)
Percentage of time exceeded

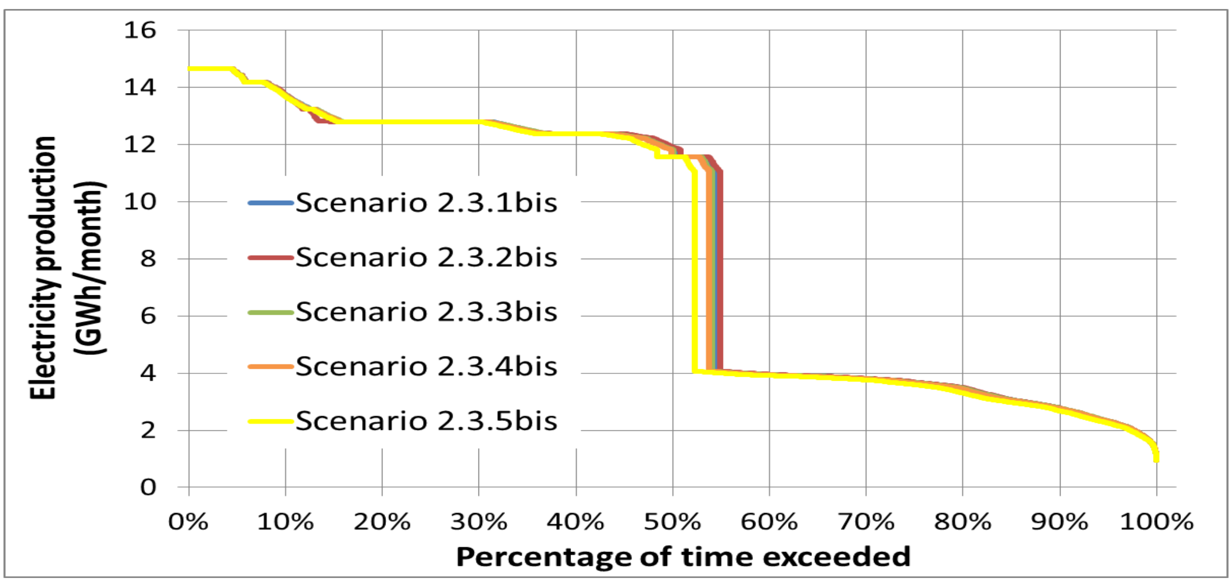
8.1.2 Monthly electricity production

Option 1:



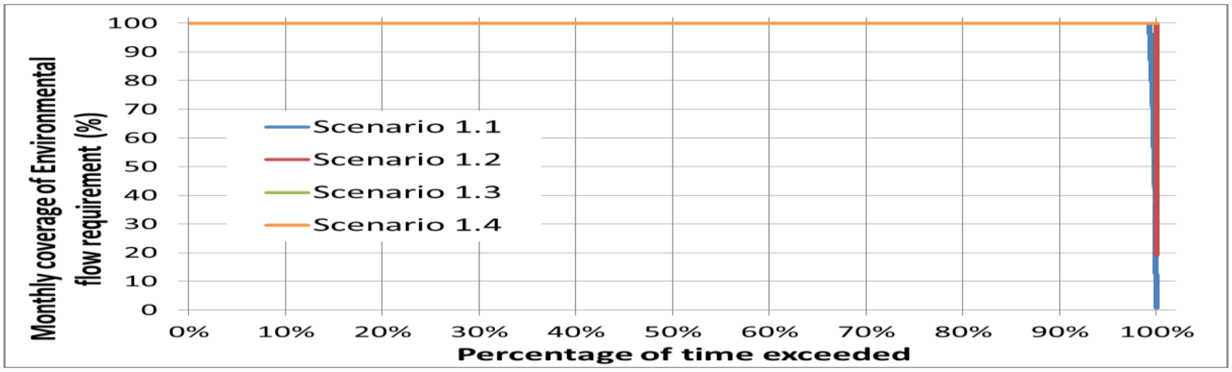
Option 2:



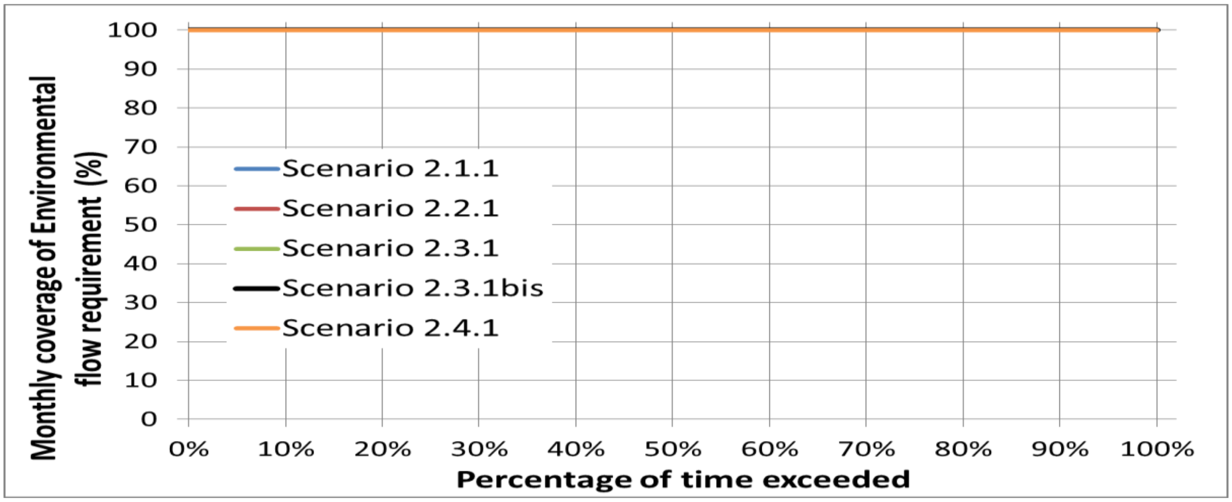


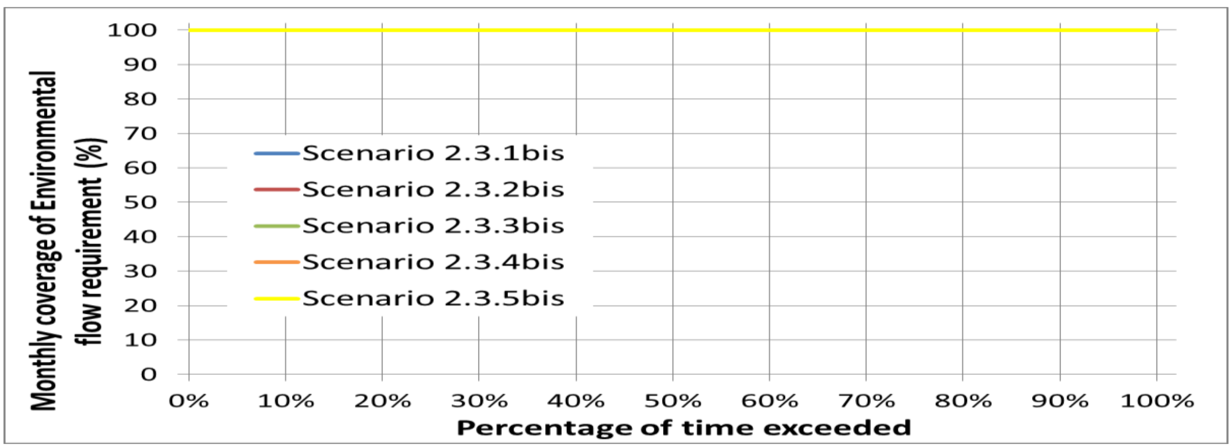
8.1.3 Monthly coverage of Environmental Flow requirement

Option 1:



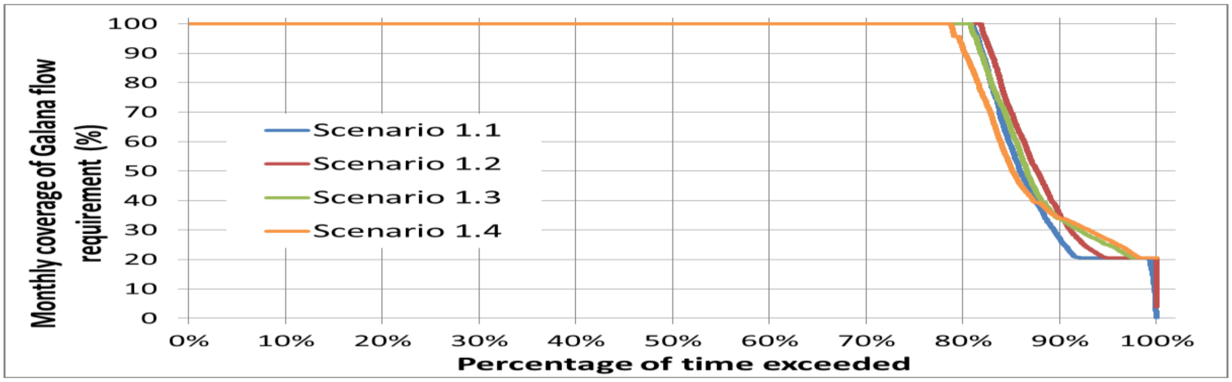
Option 2:



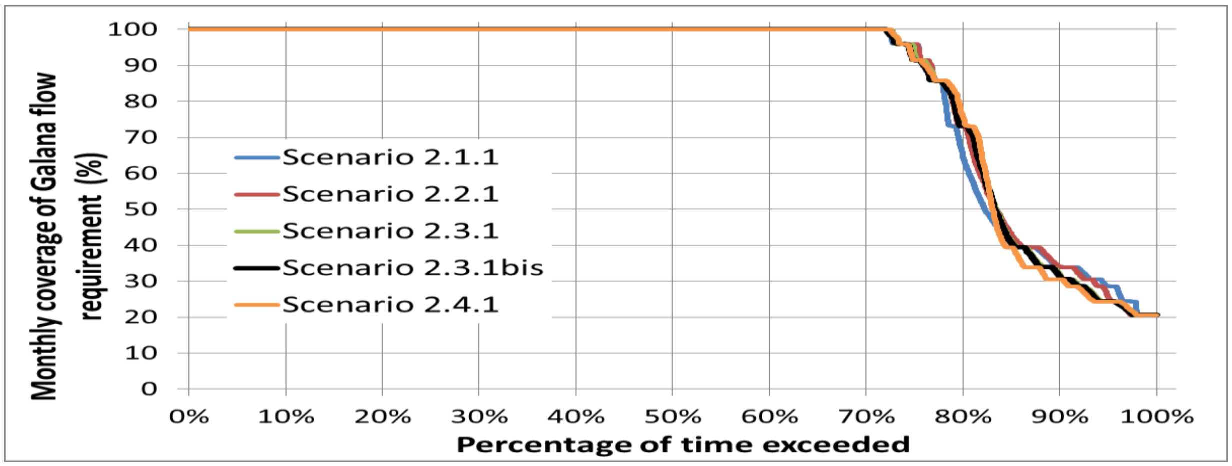


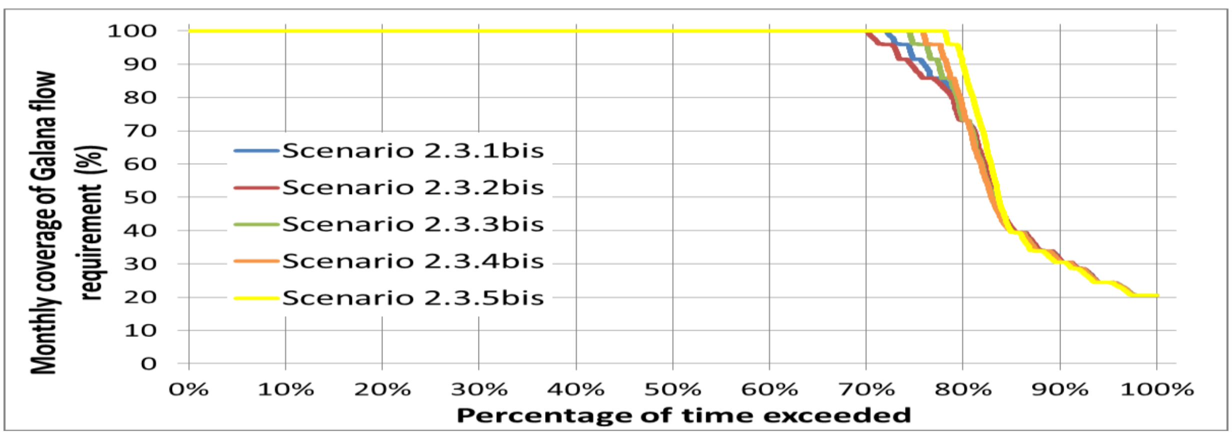
8.1.4 Monthly coverage of Galana downstream flow requirement

Option 1:



Option 2:

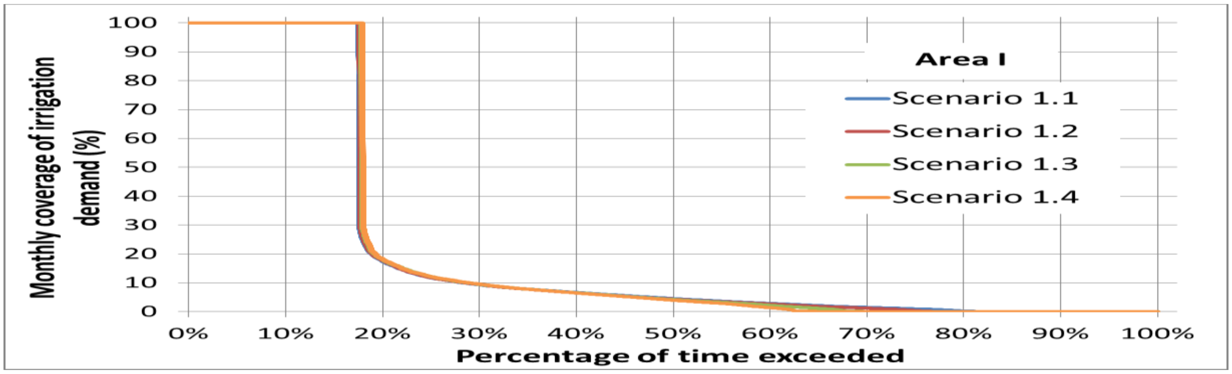


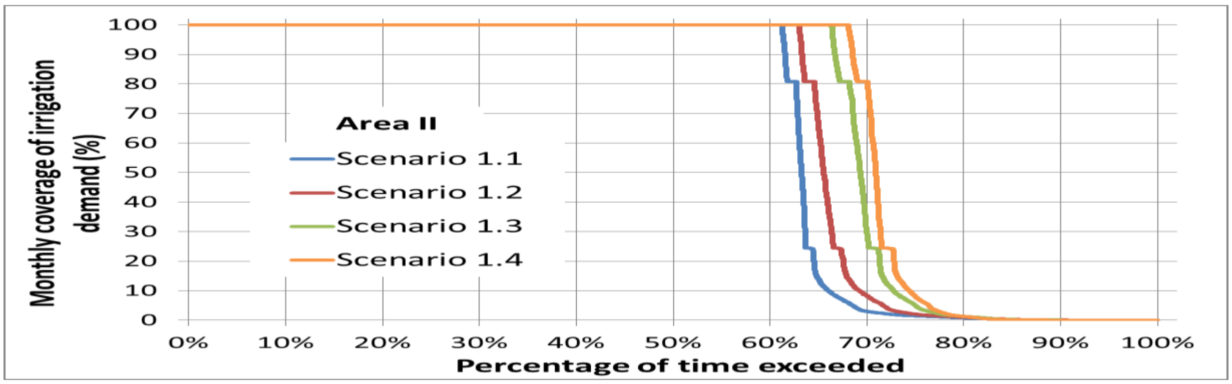


8.1.5 Monthly coverage of the irrigation water demands

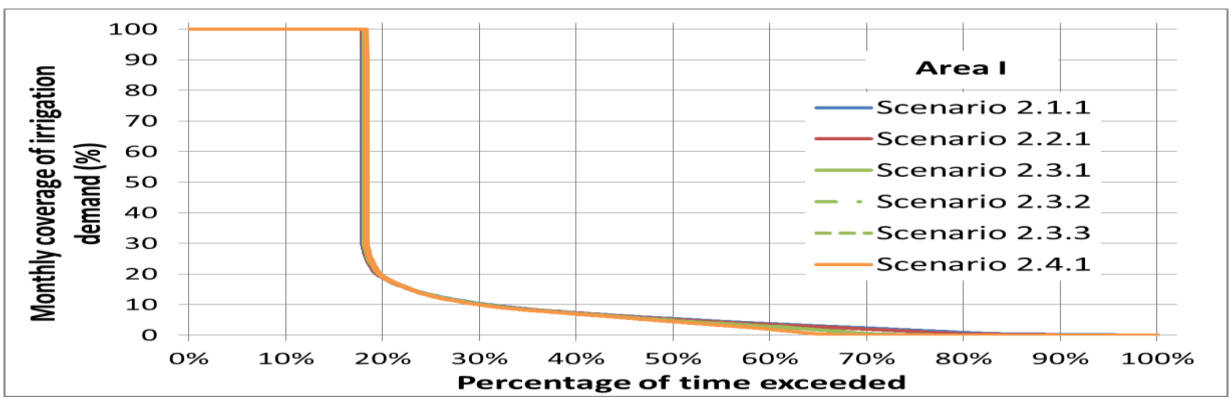
The satisfaction of irrigation at Area I and II are examined for the months of September and October.

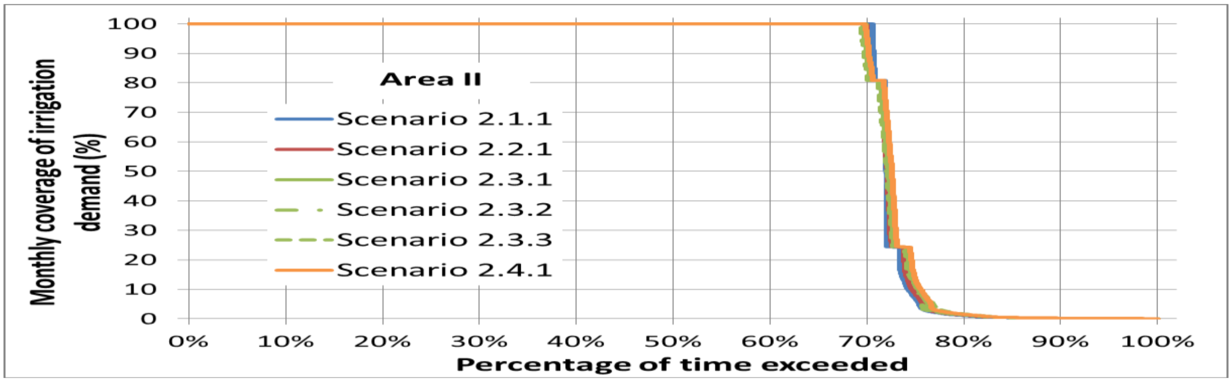
<u>Option 1:</u>





<u>Option 2:</u>

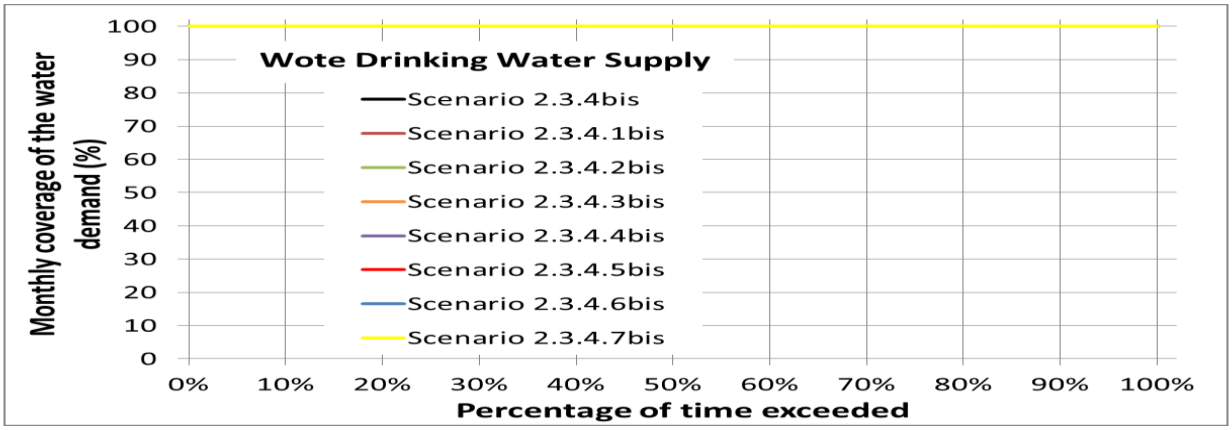


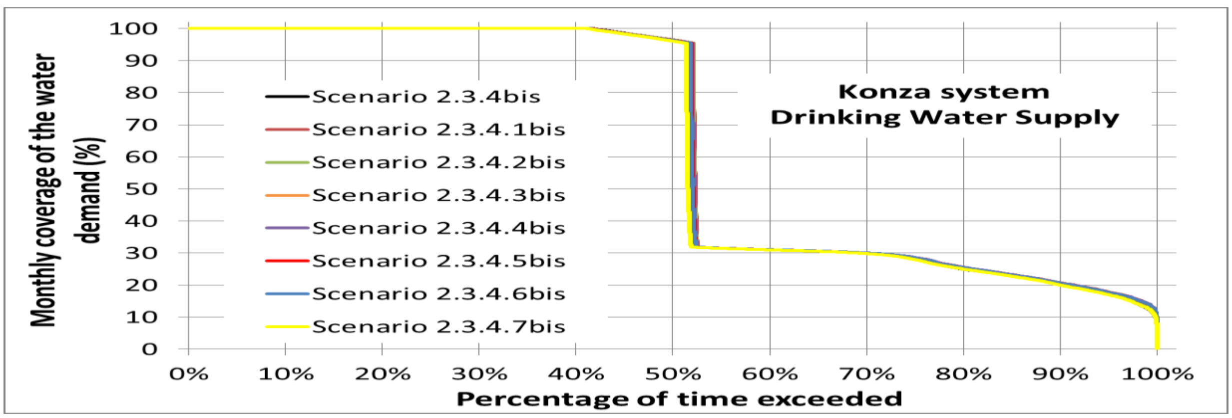


Area II
Scenario 2.1.1
Scenario 2.2.1
Scenario 2.3.1
Scenario 2.3.2
Scenario 2.3.3
Scenario 2.4.1
Monthly coverage of irrigation demand (%)
100
90
80
70
60
50
40
30
20
10
0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percentage of time exceeded

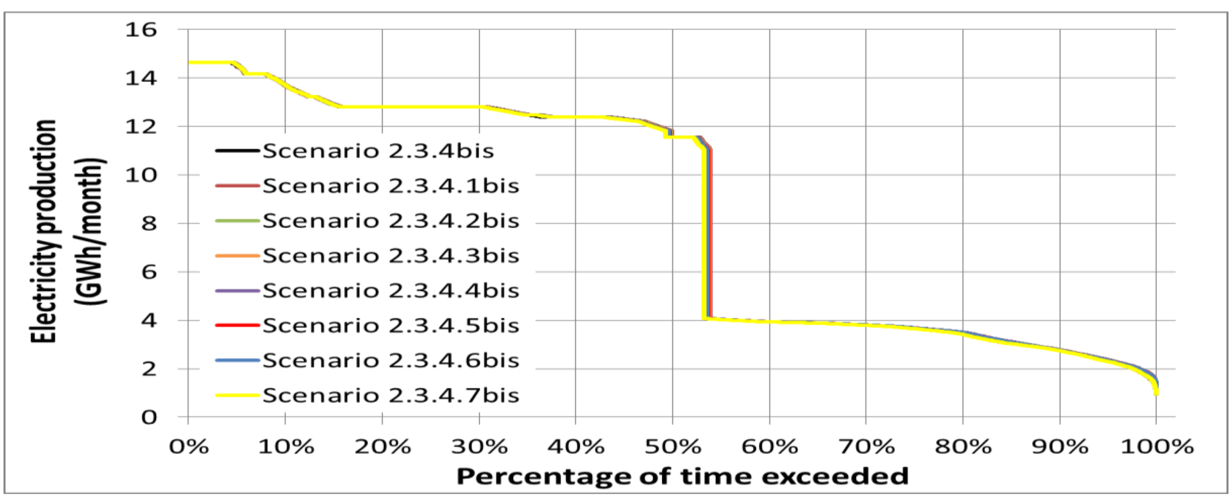
8.2 Appendix 2 – Base Case, tuning the operation of the dam for the low priority demands

8.2.1 Monthly coverage of the domestic water demands

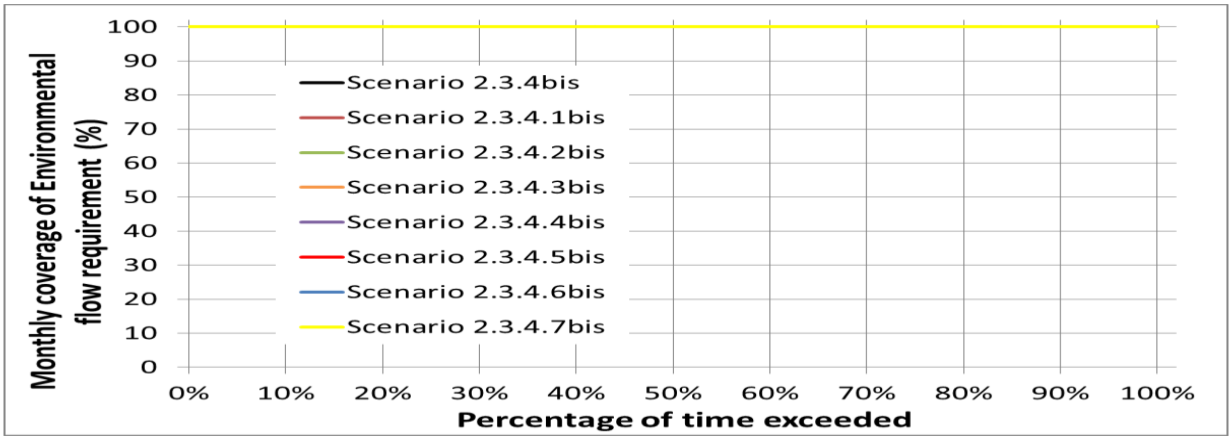




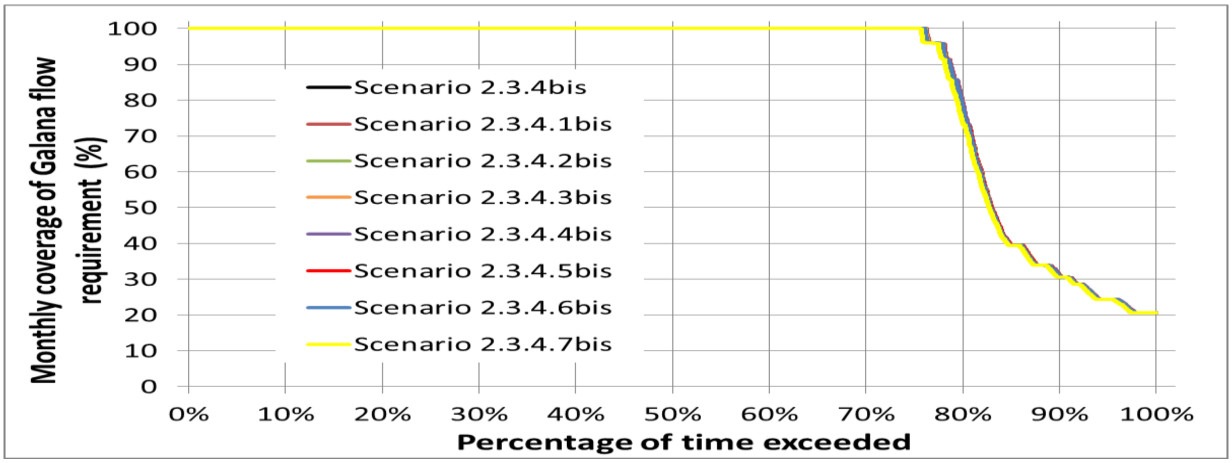
8.2.2 Monthly electricity production



8.2.3 Monthly coverage of Environmental Flow requirement

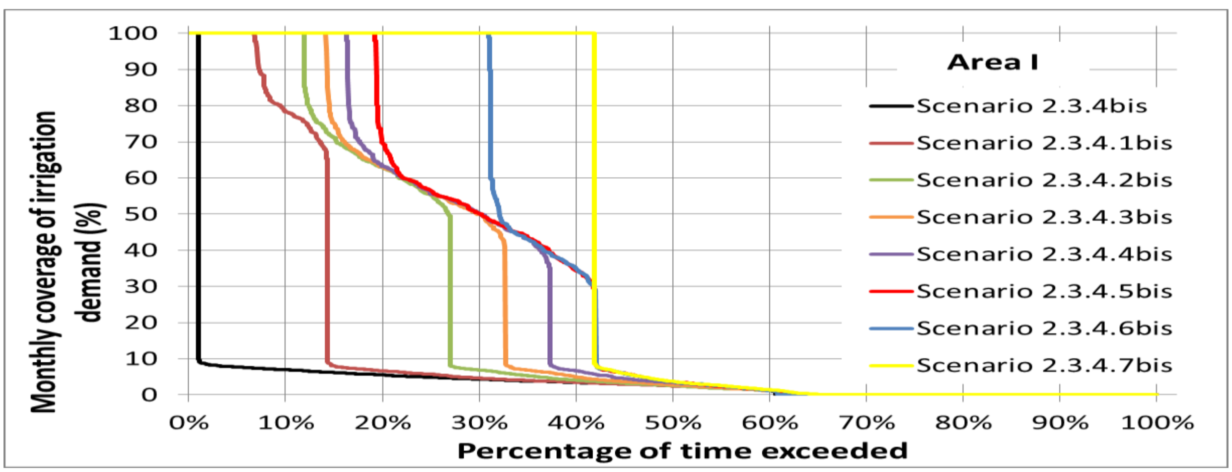


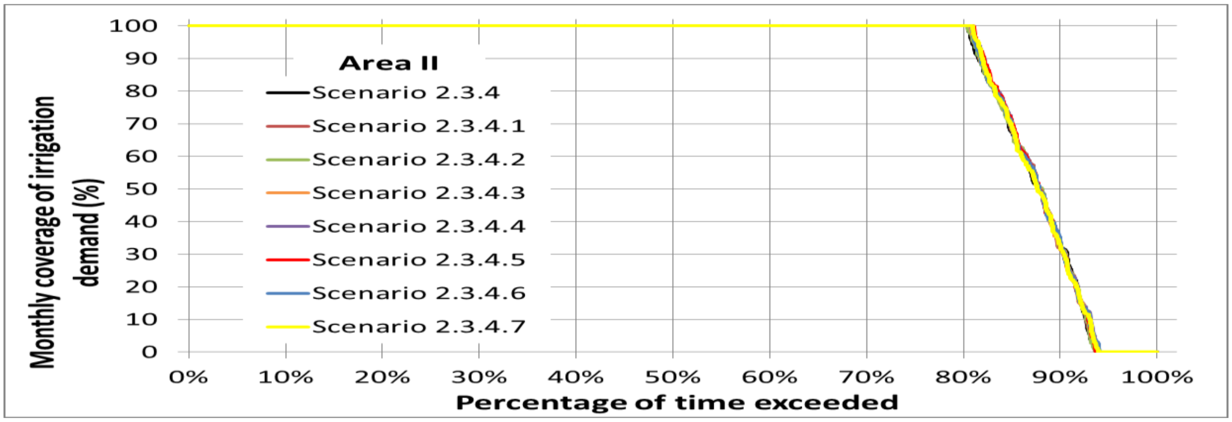
8.2.4 Monthly coverage of Galana downstream flow requirement



8.2.5 Monthly coverage of the irrigation water demands

The satisfaction of irrigation at Area I and II are examined for the months of September and October.



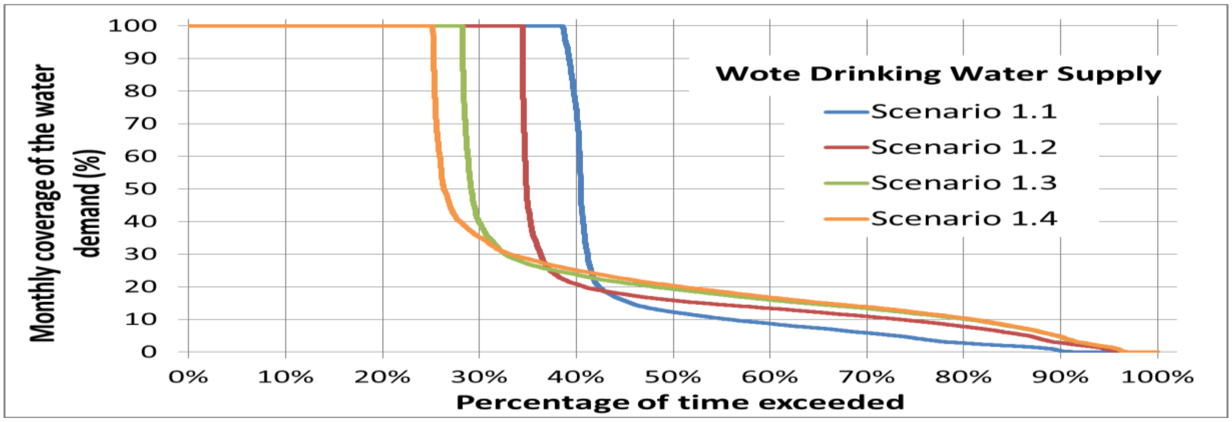


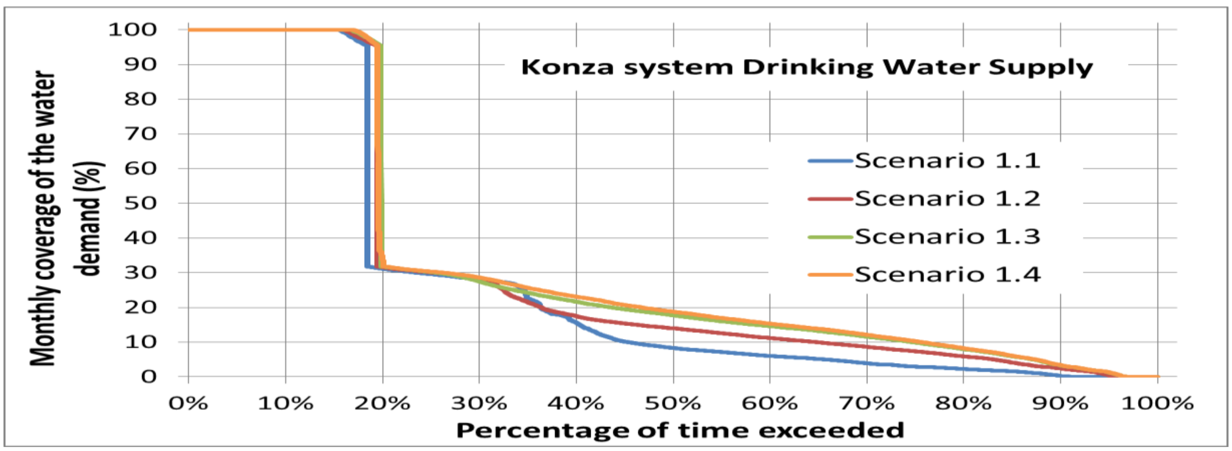
Monthly coverage of irrigation demand (%)
100
90
80
70
60
50
40
30
20
10
0
Area II
Scenario 2.3.4
Scenario 2.3.4.1
Scenario 2.3.4.2
Scenario 2.3.4.3
Scenario 2.3.4.4
Scenario 2.3.4.5
Scenario 2.3.4.6
Scenario 2.3.4.7
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percentage of time exceeded

8.3 Appendix 3 – Dam development scenario, tuning the safe zone of the reservoir and the operation of the dam for the high priority demands

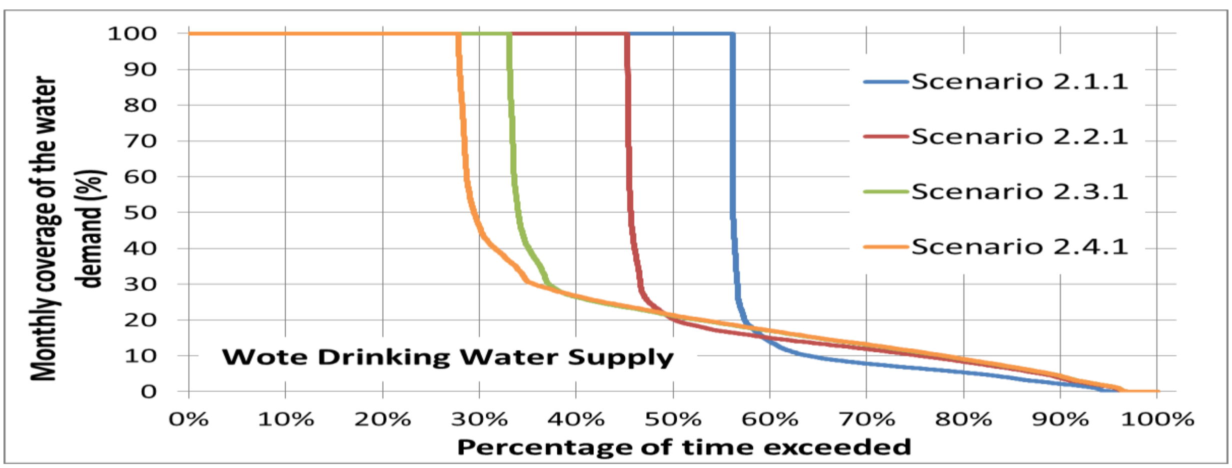
8.3.1 Monthly coverage of the domestic water demands

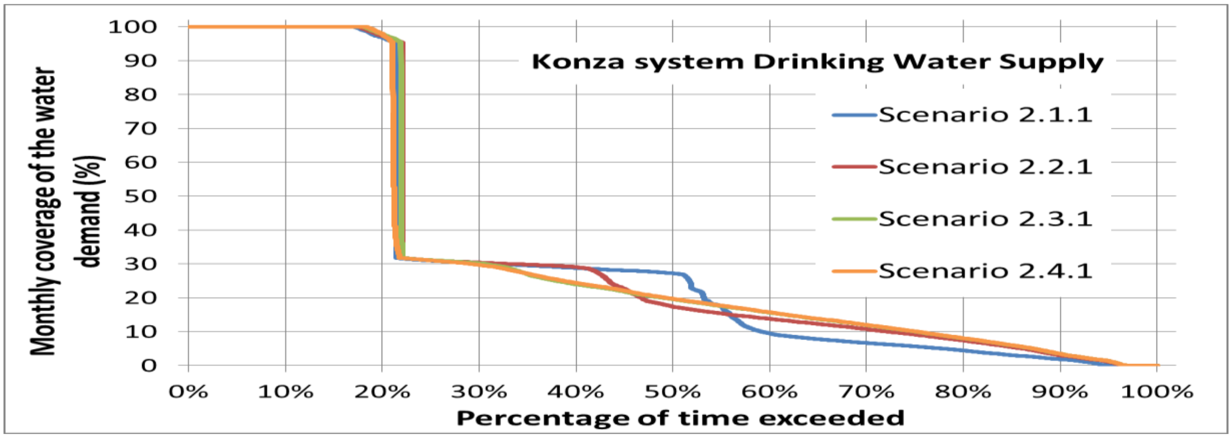
Option 1:



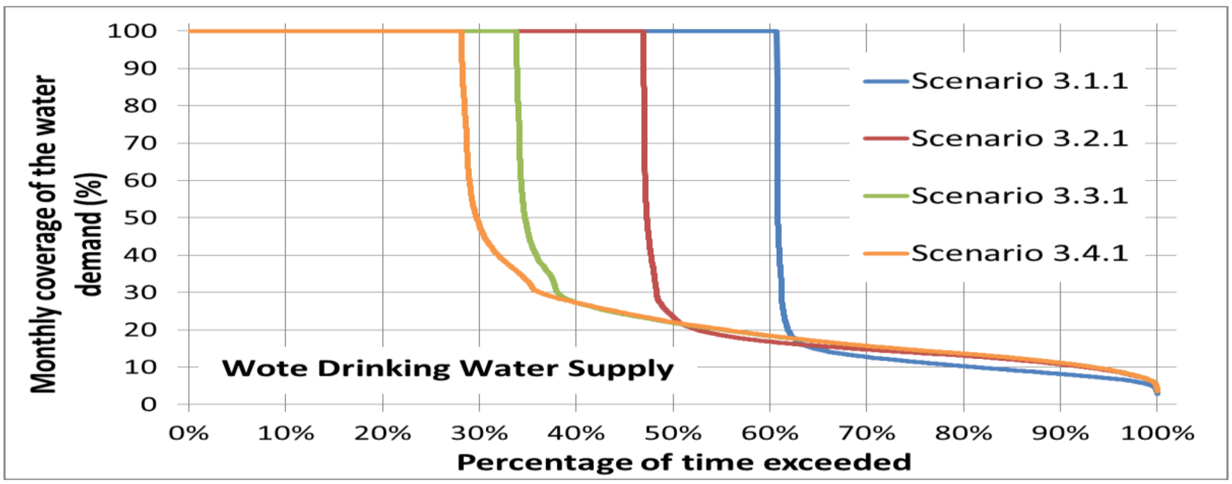


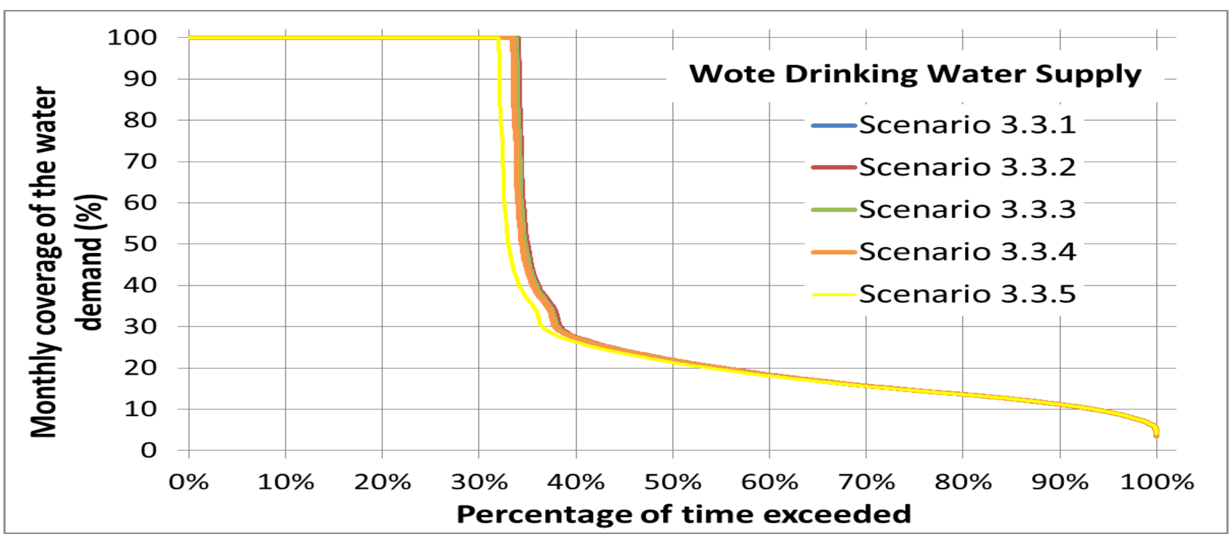
Option 2:

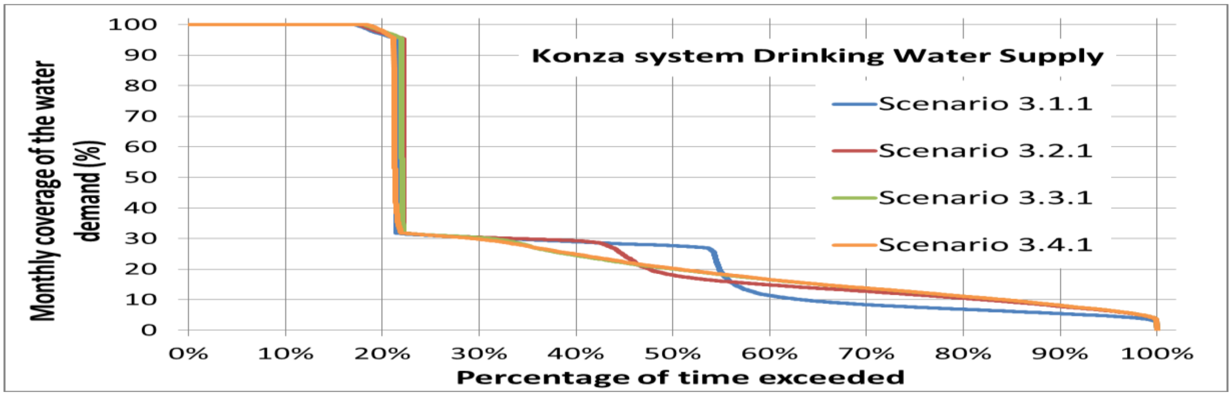


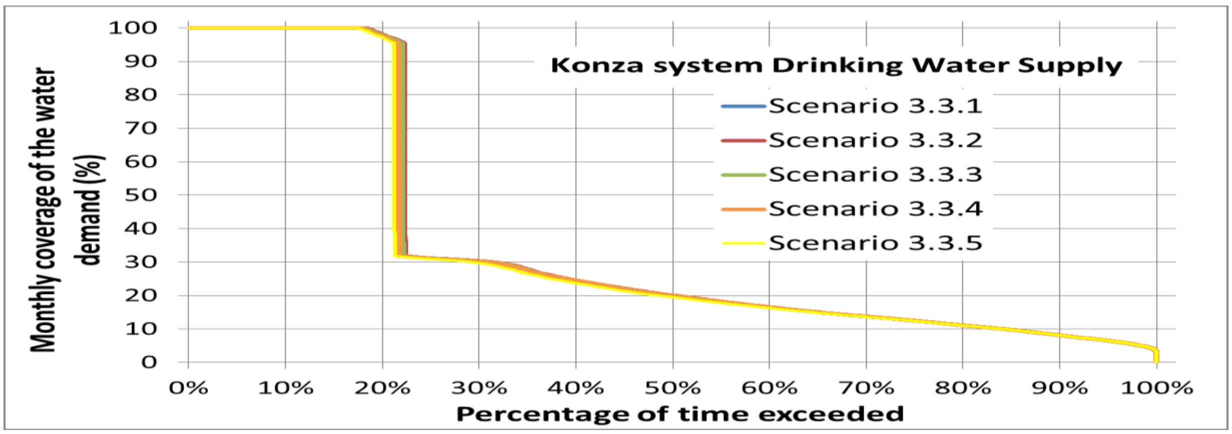

Konza system Drinking Water Supply
Scenario 2.1.1
Scenario 2.2.1
Scenario 2.3.1
Scenario 2.4.1
Monthly coverage of the water demand (%)
Percentage of time exceeded
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
0
10
20
30
40
50
60
70
80
90
100

Option 3:


Wote Drinking Water Supply
Scenario 3.1.1
Scenario 3.2.1
Scenario 3.3.1
Scenario 3.4.1
Monthly coverage of the water demand (%)
Percentage of time exceeded

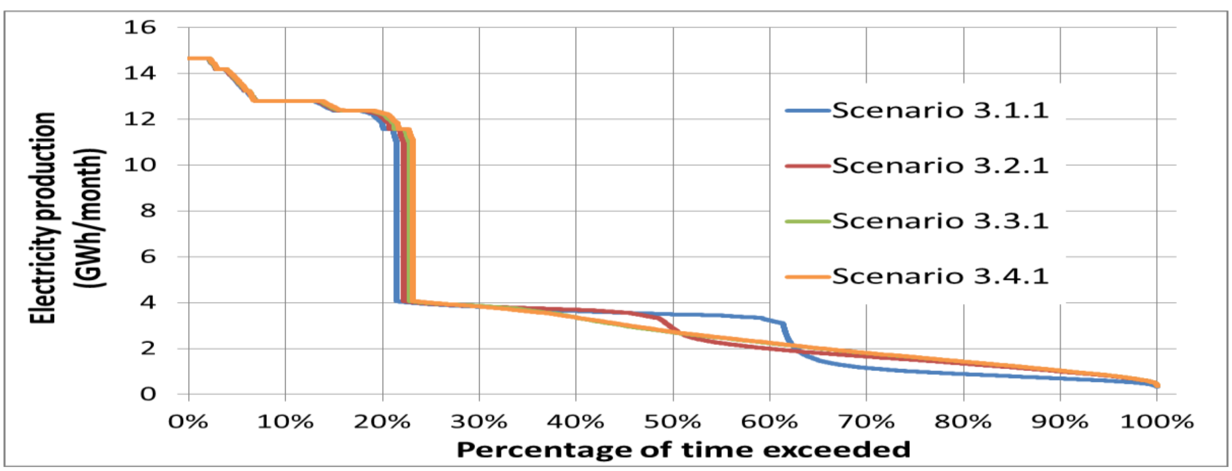

Wote Drinking Water Supply
Scenario 3.3.1
Scenario 3.3.2
Scenario 3.3.3
Scenario 3.3.4
Scenario 3.3.5
Monthly coverage of the water demand (%)
Percentage of time exceeded

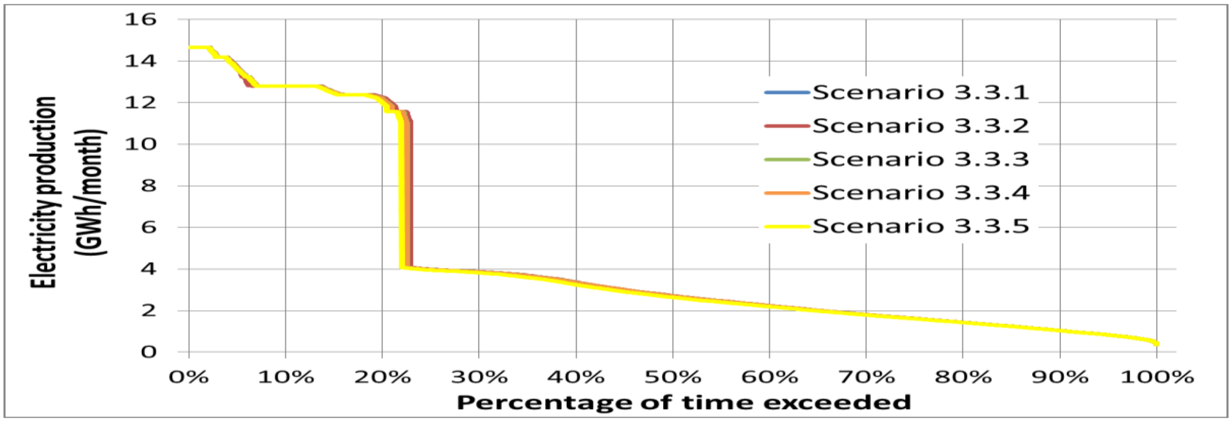




8.3.2 Monthly electricity production

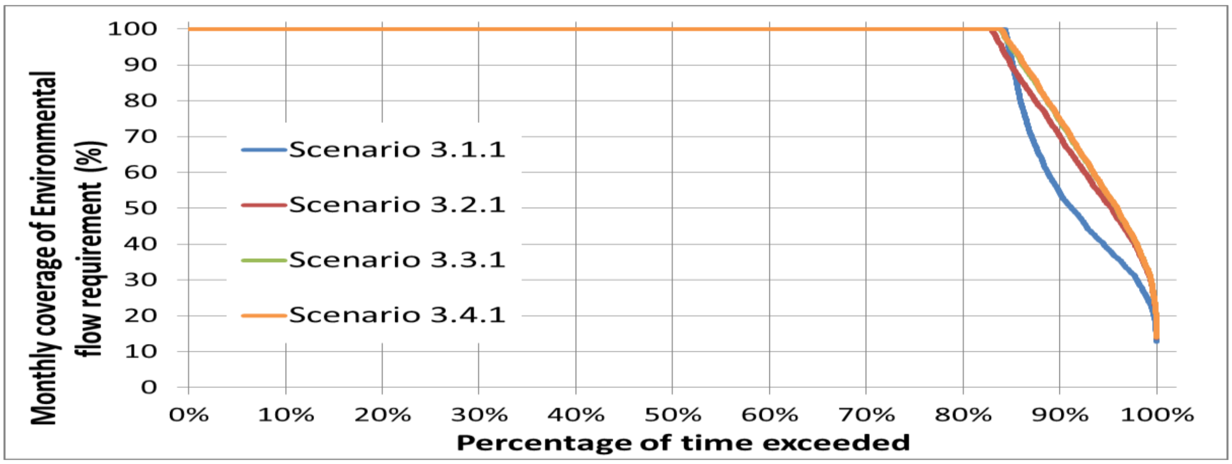
<u>Option 3:</u>

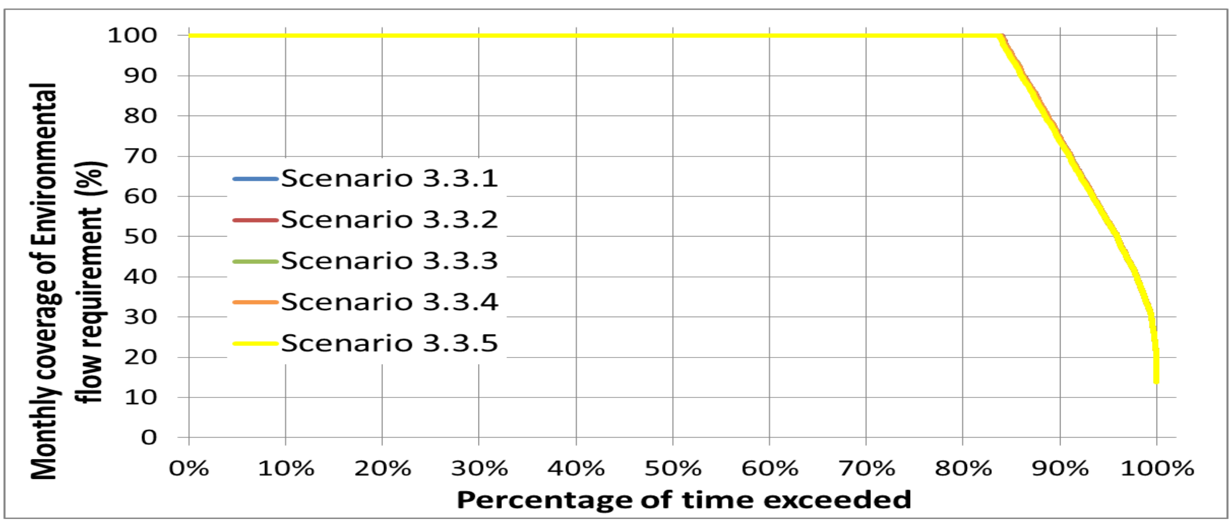




8.3.3 Monthly coverage of Environmental Flow requirement

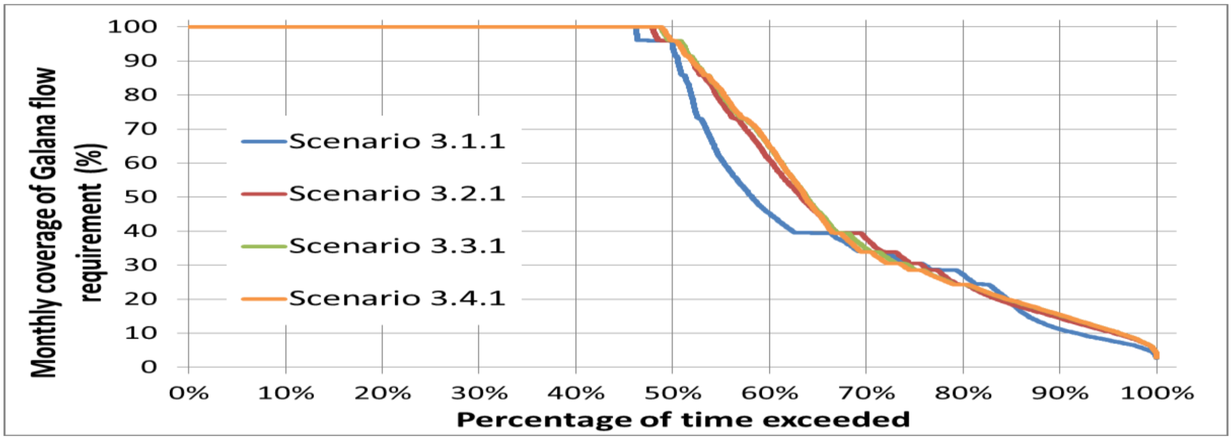
<u>Option 3:</u>

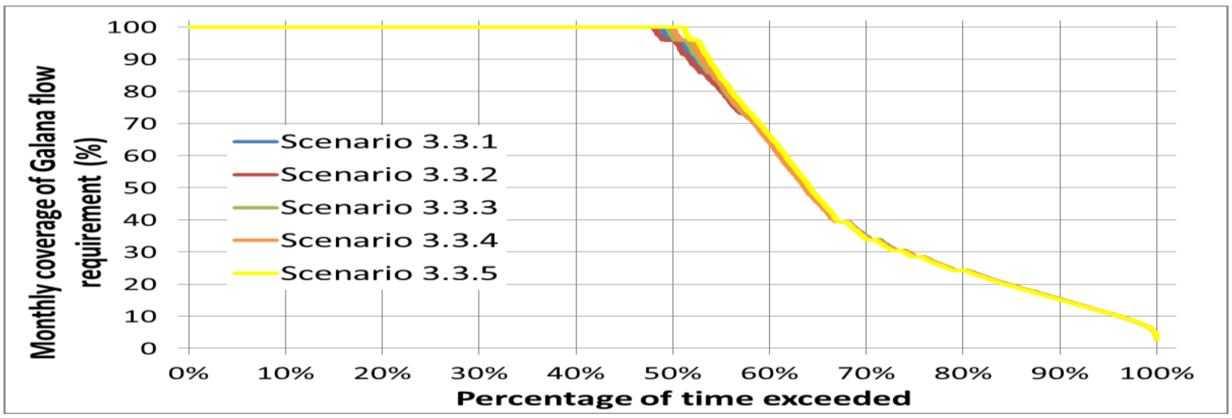




8.3.4 Monthly coverage of Galana downstream flow requirement

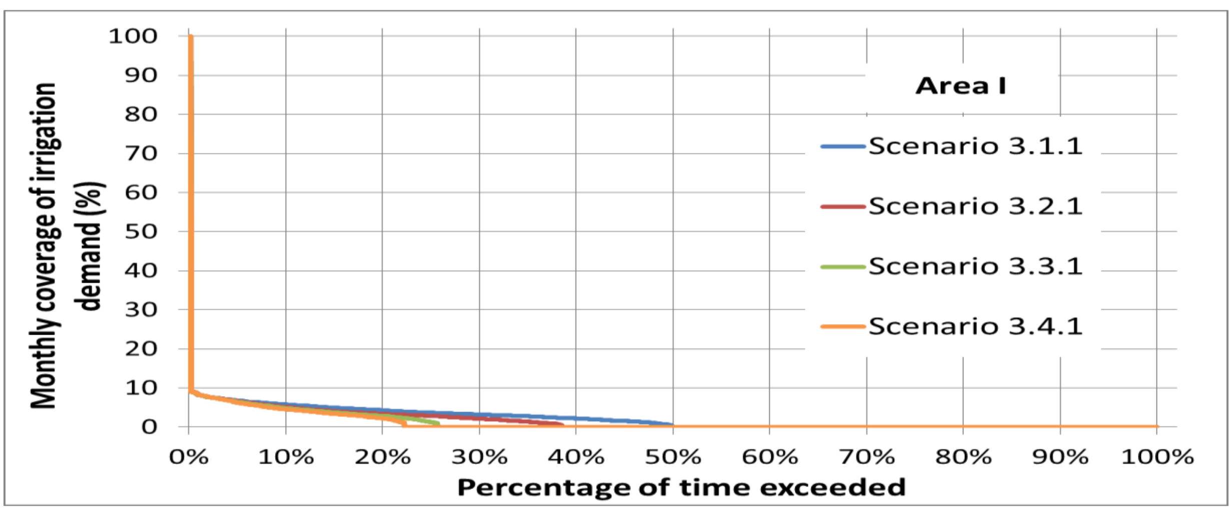
Option 3:

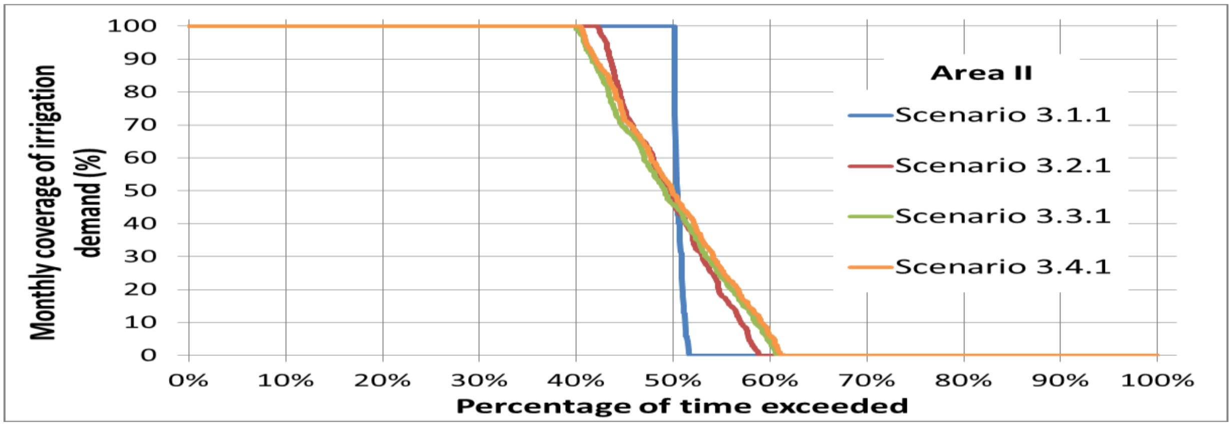




8.3.5 Monthly coverage of the irrigation water demands

Option 3:



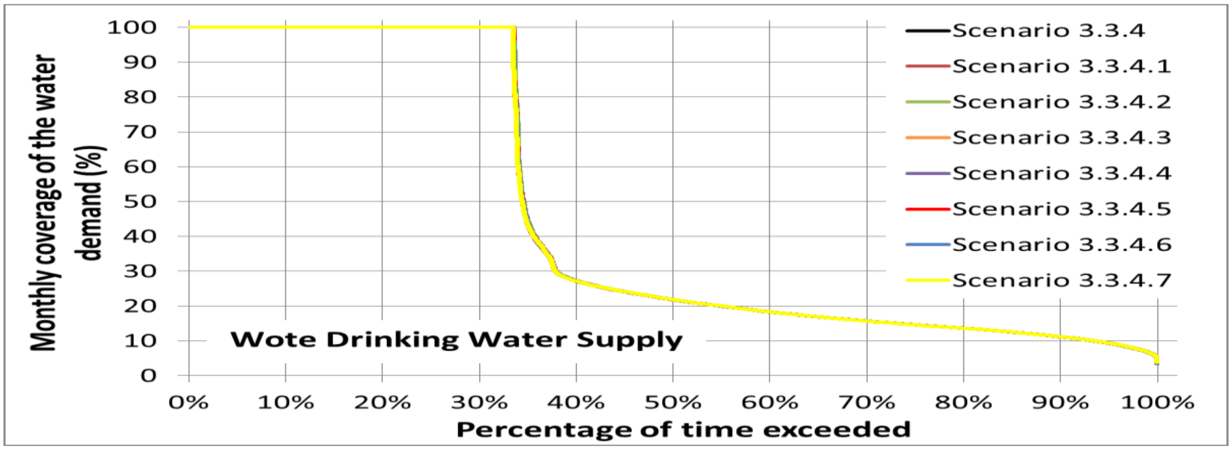


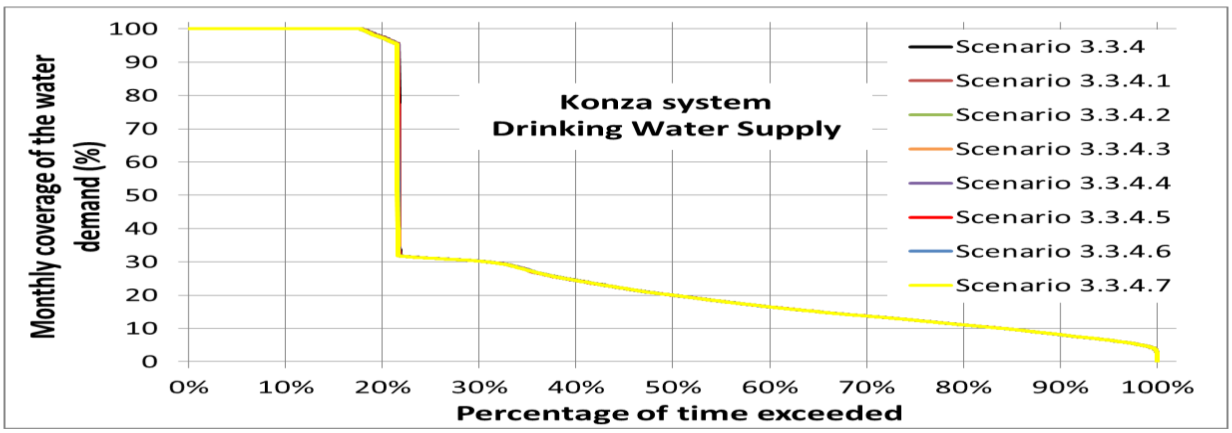
Area II
Scenario 3.1.1
Scenario 3.2.1
Scenario 3.3.1
Scenario 3.4.1
Monthly coverage of irrigation demand (%)
Percentage of time exceeded
100
90
80
70
60
50
40
30
20
10
0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%

8.4 Appendix 4 – Dam development scenario, tuning the operation of the dam for the low priority demands

8.4.1 Monthly coverage of the domestic water demands

<u>Option 3</u>

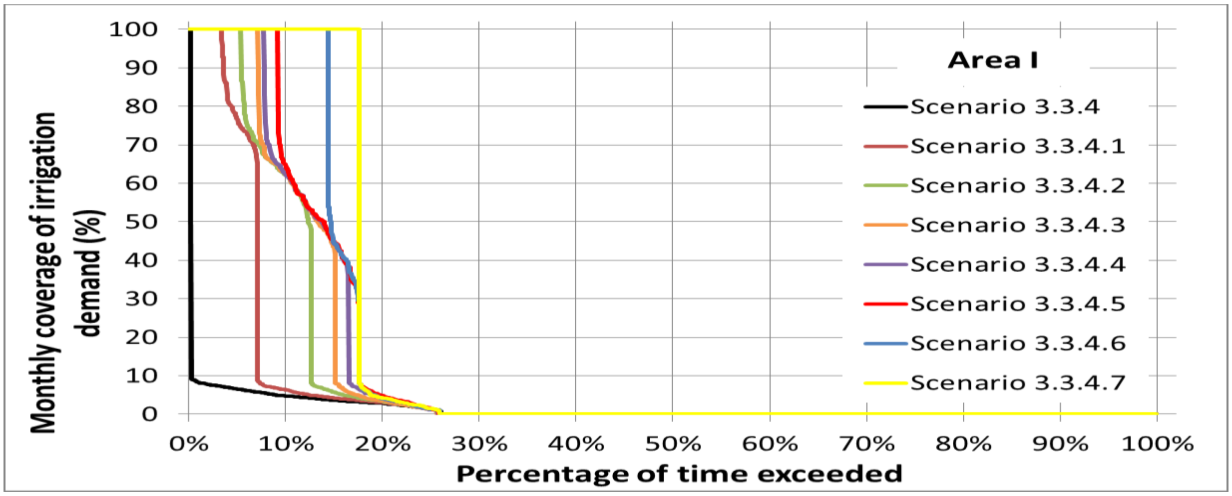


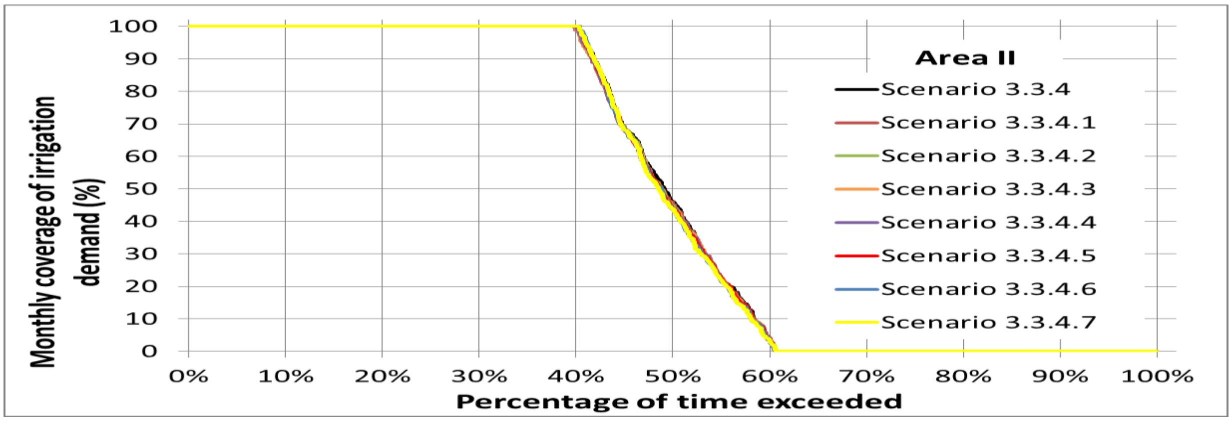


8.4.2 Monthly coverage of the irrigation water demands

The satisfaction of irrigation at Area I and II are examined for the months of September and October.

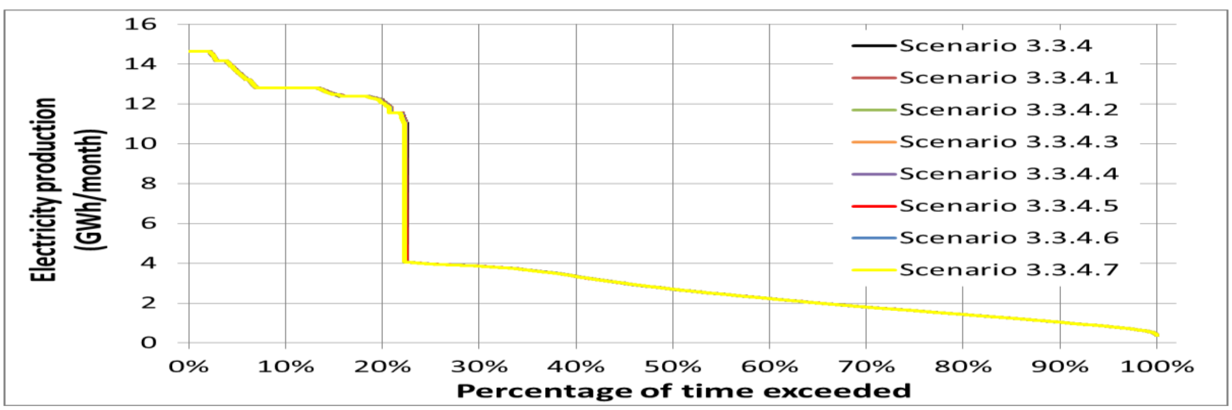
Option 3





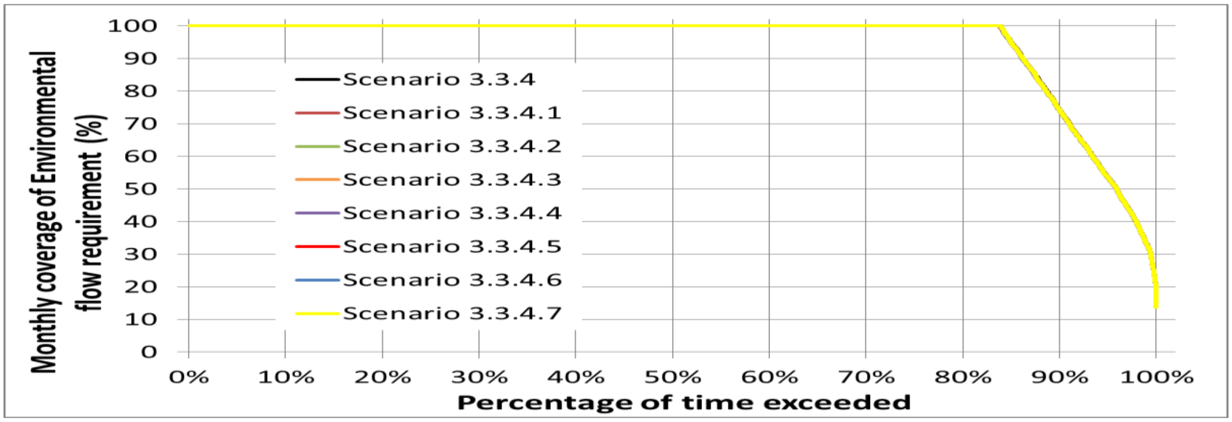
8.4.3 Monthly electricity production

Option 3



8.4.4 Monthly coverage of Environmental Flow requirement

<u>Option 3</u>



8.4.5 Monthly coverage of Galana downstream flow requirement

<u>Option 3</u>