UNIVERSITY OF NAIROBI

SCHOOL OF ENGINEERING

DEPARTMENT OF ENVIRONMENTAL AND BIOSYSTEMS ENGINEERING

DEVELOPING A WATER ALLOCATION PLANNING MODEL FOR A KENYAN SUB-CATCHMENT: A CASE STUDY OF AWACH TENDE SUB-CATCHMENT.

By

Martha Jepkirui Mibey

BSc (Water and Environmental Engineering) Egerton, 2010

F56/67706/2013

A Thesis Submitted in Partial Fulfillment of the Requirements for the Award of the Degree of Master of Science in Environmental and Biosystems Engineering in the Department of Environmental and Biosystems Engineering of the University of Nairobi.

August 2022

DECLARATION

I, **Martha Jepkirui Mibey**, hereby declare that this Thesis is my original work. To the best of my knowledge, the work presented here has not been presented for examination in this or any other Institution of Higher Learning.

Sign: **Date: 25 August 2022**

Martha Jepkirui Mibey, F56/67706/2013

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

Sign…………………… **Date: 25 August 2022**

Dr. C. T. Omuto

Department of Environmental & Biosystems Engineering The University of Nairobi

Sign… ……….Date: 25 Aug 2022

Dr. J. P. O. Obiero

Department of Environmental & Biosystems Engineering The University of Nairobi

DECLARATION OF ORIGINALITY

NAME OF STUDENT: MARTHA JEPKIRUI MIBEY

REGISTRATION NUMBER: F56/67706/2013

COLLEGE: Architecture and Engineering

FACULTY/SCHOOL/INSTITUTE: School of Engineering

DEPARTMENT: Environmental and Biosystems Engineering

COURSE NAME: Master of Science in Environmental and Biosystems Engineering

TITLE OF WORK: *Developing A Water Allocation Planning Model for a Kenyan Sub-Catchment: A Case Study of Awach Tende Sub-Catchment*

1. I understand what plagiarism is and I am aware of the university policy in this regard.
2. I declare that this Master of Science in Environmental and Bio-systems Engineering Thesis is my original work and has not been submitted elsewhere for examination, award of a degree or publication. Where other people's work or my own work has been used, this has properly been acknowledged and referenced in accordance with the University of Nairobi's requirements.
3. I have not sought or used the services of any professional agencies to produce this work.
4. I have not allowed and shall not allow anyone to copy my work with the intention of passing it off as his/her own work.
5. I understand that any false claim in respect of this work shall result in disciplinary action, in accordance with University anti-plagiarism policy.

SIGN: **DATE: 25 August 2022**

DEDICATION

This thesis is dedicated to my husband, the late Eng. Bernard Wanjala Namano.

ACKNOWLEDGEMENT

To my Supervisors, Dr. C. T. Omuto and Dr. J. P. O. Obiero, I am indebted for their guidance, critique and contribution in the completion of my studies. I also acknowledge the Department of Environmental and Biosystems Engineering for enabling my masters' studies.

My thanks go out to officials at WRMA HQ and sub regional offices for the provision of key data that was required to complete the project.

TABLE OF CONTENTS

DECLARATION ii
DECLARATION OF ORIGINALITY iii
DEDICATION iv
ACKNOWLEDGEMENT v
TABLE OF CONTENTS vi
LIST OF TABLES ix
LIST OF FIGURES x
LIST OF ABBREVIATIONS xi
ABSTRACT xiv
CHAPTER 1. INTRODUCTION 1
1.1 Background Information 1
1.2 Problem Statement and Justification 5
1.3 Objectives 6
1.4 Scope of the Study 7
CHAPTER 2. LITERATURE REVIEW 8
2.1 Introduction 8
2.2 Water Resources 8
2.2.1 Water Resources in Kenya and Awach Tende 8
2.2.2 Major water uses in Awach Tende 9
2.3 Water Allocation Planning 9
2.3.1 Water Allocation Planning in Kenya 11
2.4 Decision Support Systems and Tools for Modelling Water Allocation 12
2.4.1 RiverWare 13
2.4.2 Aquarius 14
2.4.3 MODSIM 14
2.4.4 RIBASIM 14
2.4.5 MIKE HYDRO Basin 15

2.4.6 WEAP ... 15
2.4.7 Modelling in WEAP ... 16
2.5 Data Requirements ... 17
CHAPTER 3. MATERIALS AND METHODS ... 19
3.1 Study Area ... 19
3.1.1 Location ... 19
3.1.2 Climate ... 21
3.1.3 Hydrology and water resources ... 21
3.1.4 Economic activities ... 21
3.2 Data Collection ... 22
3.3 Water Allocation ... 23
3.3.1 Stream flow data ... 23
3.3.2 Climate data ... 23
3.3.3 Water use and demand data ... 24
Domestic water demand ... 24
Livestock water demand ... 24
Institutional water demand ... 25
Irrigation water demand ... 25
Commercial water demand ... 25
Environmental flow requirement ... 25
3.3.4 Water allocation scenarios ... 26
3.4 Data Analysis ... 27
3.4.1 Creating the WEAP model ... 27
3.4.2 Rainfall Runoff Simulation in WEAP ... 32
3.4.3 Model calibration and validation ... 33
CHAPTER 4. RESULTS AND DISCUSSION ... 35
4.1 Sub Catchment Hydrology ... 35
4.1.1 Stream flow data ... 35
4.2 Modelling Water Demand ... 36
4.2.1 Domestic water demand ... 37

4.2.2 Livestock water demand 38
4.2.3 Institutional water demand 38
4.2.4 Irrigation water demand 39
4.2.5 Environmental flow requirement 40
4.3 Rainfall-Runoff Modelling 41
4.3.1 Model calibration results 42
4.4 Scenario Analysis 44
4.4.1 Business as usual (2009-2029) 44
4.4.2 Fully operational irrigation scheme 45
4.4.3 Irrigation scheme with gradual expansion to 100% capacity by 2029 46
4.4.4 High population growth rate with operational irrigation scheme 46
4.4.5 Irrigation efficiency improvements 47
4.4.6 Climate change scenarios 47
CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS 49
REFERENCES 51
APPENDICES 56
APPENDIX A: Awach Tende hydrology 56
APPENDIX B: Land use and climatic data 59
APPENDIX C: List of health facilities in Awach Tende sub-catchment 60
APPENDIX D: WEAP model results 61

LIST OF TABLES

Table 2-1 Data Requirements for Water Allocation Planning model 17
Table 3-1 Mean annual climate characteristics of Awach Tende sub-catchment 21
Table 3-2 Data Collection Matrix for modelling water allocation for Awach Tende................. 22
Table 3-3 Summary of scenarios created for analysis 26
Table 4-1 Demand site priorities.. 36
Table 4-2 Human population data in Awach Tende for 1989, 1999 and 2009.......................... 37
Table 4-3 Livestock population data in Awach Tende for 1999 and 2009................................. 38
Table A-1 Description of Environmental Management Classes.. 57
Table A-2 River Awach Tende FDC results for the different EMCs...................................... 58
Table B-1 Monthly variation of crop coefficient and effective precipitation 59
Table B-2 Monthly average precipitation and ET_o values... 59
Table C-1 Health facilities by administrative ward in Awach Tende sub-catchment 60
Table D-1 : Comparison of water demand in the BAU scenario and operational irrigation scheme scenario.. 62

LIST OF FIGURES

Figure 1-1: Definitions of water scarcity (FAO, 2014) 2
Figure 1-2: Water availability for selected African Countries in 1990 and 2025........................... 3
Figure 3-1: Awach Tende sub-catchment boundary.. 28
Figure 3-2: WEAP schematic for Awach Tende sub-catchment 30
Figure 3-3: Setting up of years and time steps in WEAP 31
Figure 4-1: Average monthly flow at River Awach Tende (1974 – 2015)................................... 36
Figure 4-2: Flow duration curve for River Awach Tende 41
Figure 4-3: Awach Tende monthly average observed flow and WEAP model simulated flow.. 43
Figure 4-4: Water demand in the BAU scenario (2009 - 2029) 45

LIST OF ABBREVIATIONS

°C	degrees Celsius
BAU	business as usual
CADSWES	Center for Advanced Decision Support for Water and Environmental Systems
CBO	Community Based Organization
CBS	Central Bureau of Statistics
DSS	Decision Support System
DWO	District Water Office
E	Nash-Sutcliffe efficiency
EMC	Environmental Management Class
ET_o	reference crop evapotranspiration
FAO	Food and Agriculture Organization
FDC	Flow duration Curve
GIS	Geographical Information System
GoK	Government of Kenya
IWMI	International Water Management Institute
K_c	Crop coefficient

km/day	kilometres per day
km^2	square kilometres
KMD	Kenya Meteorological Department
KNBS	Kenya National Bureau of Statistics
LVBA	Lake Victoria Basin Authority
LVEMP	Lake Victoria Environmental Management Programme
m.a.s. l	metres above sea level
m^3	cubic metre
MJ/m^2	Million Joules per square metre
mm	millimetres
Mm^3/yr	million cubic metres per year
MoWI	Ministry of Water and Irrigation
p. a	per annum
PEST	Parameter Estimation tool
PGM	Plant growth model
Q_{95}	Discharge that is exceeded 95 percent of the time
Q_{obs}	Observed runoff

Q_{sim}	Simulated runoff
r^2	coefficient of determination
SEI	Stockholm Environment Institute
SHG	Self Help Group
SIWI	Stockholm International Water Institute
SRTM	Shuttle Radar Topography Mission
UN-Water	United Nations Water
USD	United States Dollars
WEAP	Water Evaluation and Planning System
WRA	Water Resources Authority
WRM	Water Resource Management
WRMA	Water Resources Management Authority
WRUA	Water Resource User Association

ABSTRACT

Water scarcity in Kenya is on the rise due to factors related to population growth and increase in human activities that cause depletion of natural resources, in this case water. The management of water as a resource in a sustainable manner is increasingly becoming a difficult issue for water managers in Kenya

The water allocation process is already complex and is further complicated by the fact that there is little or no strategic planning to cope with increasing demand, water scarcity and climate change at all levels of water resource management. The use of modelling tools is vital in simulating and analysing the consequences of alternative water allocation scenarios and guiding the decision-making process associated with water allocation. This study developed a model for the water allocation in Awach Tende Sub-catchment using the WEAP model. Different water allocation scenarios were analysed considering the different competing water demands in the catchment and the available surface water resource.

The main drivers of water allocation in the sub-catchment are water availability in time and space and the different water use demands. The water demand priorities are governed by existing water resource management rules. This study determined that the key allocation scenarios were a combination of (i) high population rate in the sub-catchment, (ii) the Kimira-Oluch Irrigation Scheme under different operational modalities and (iii) climate change.

Findings from the WEAP model revealed that River Awach Tende is able to meet the domestic, livestock and environmental water demands in the sub-catchment under different scenarios that are a variation of changes in the population. Water resource developments, depending on their extent increase the stress on the surface water resource. In the case of Awach Tende, the Oluch

irrigation scheme can get a water supply provided the water consumption is below 30% irrigation efficiency of the design capacity of the intake weir. The findings from this study can be used to inform decisions to be made by water resource planners in Awach Tende and other similar sub catchments.

CHAPTER 1. INTRODUCTION

1.1 Background Information

Water is vital for meeting basic human needs through its use for food production, drinking, sanitation, and hygiene, reducing poverty, social and economic development and for natural ecosystems (UN-Water, 2008).

The fresh water supply available for consumption has reduced because of population growth; diversification of economic activities; economic growth; climate change; and pollution from human activities. The resulting effect has been water scarcity as a result of a rise in water abstractions, new and increased water uses and a decline in fresh water ecosystems ((UN-Water, 2008; Mogaka, Gichere, Davis, & Hirji, 2006; Speed, Yuanyuan, Le Quesne, Pegram, & Zhiwei, 2013).

Water scarcity is a result of the demand for freshwater from all water using sectors exceeding the available supply in a specified area (FAO, 2012). The indicators used to describe water scarcity are the quantity of renewable freshwater resources available per person and the percentage of freshwater resources that are withdrawn or abstracted. Water stress occurs when the freshwater supplies are below 1 700 m^3 per year /person and water scarce when the freshwater supplies drop below 1 000 m^3 per /year person as illustrated in Figure 1-1 (FAO, 2014).

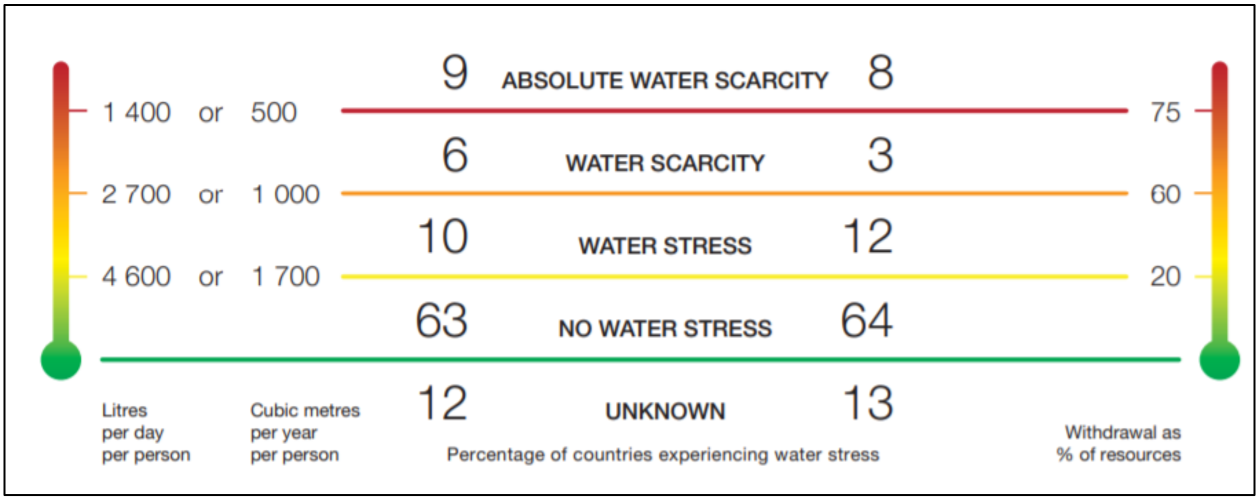

Figure 1-1: Definitions of water scarcity (FAO, 2014)

Since water scarcity is caused by various factors, it has been argued that there are two types of water scarcity. The situation where freshwater resources are not able to meet existing water demand is termed as physical scarcity and where there is no investment in water resource management and or no human capacity to meet the existing demand is known as economic scarcity (IWMI, 2007).

Kenya receives 617m^3 of freshwater per person per annum and is therefore categorized as water scarce by the United Nations. As illustrated in Figure 1-2 (Rekacewiz, 2014) Kenya ranks among the countries in Africa with severe water scarcity (FAO, 2016) (Mogaka, Gichere, Davis, & Hirji, 2006).

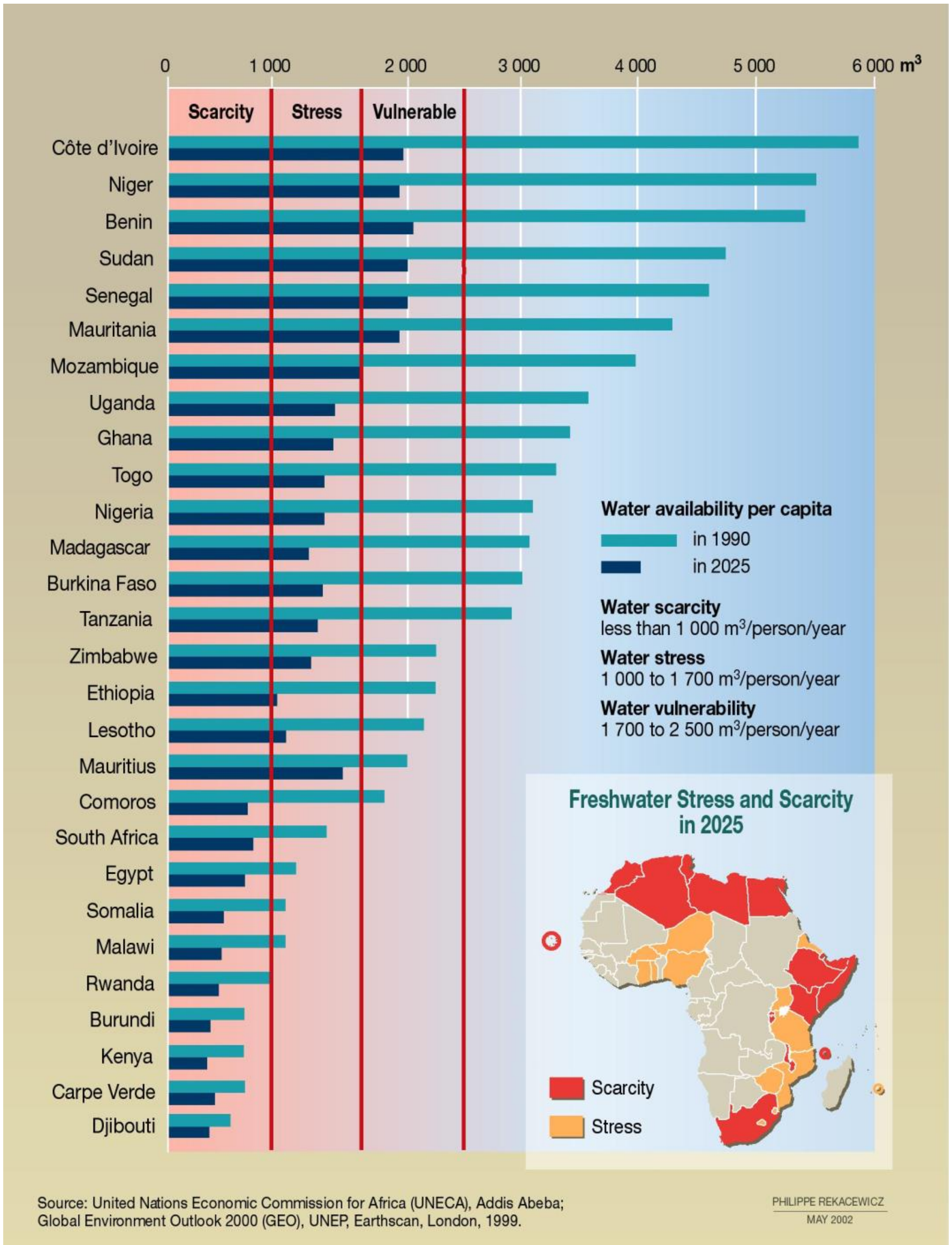

Figure 1-2 : Water availability for selected African Countries in 1990 and 2025

An emerging global water resource management challenge is designing actions and interventions to meet all water demand while also maintaining benefits to the economy and environment. In

Kenya, one of the main challenges has been the management of water resources. The 2003 Joint Donor Statement from the Technical Group on Water Supply and Sanitation and Water Resources Management recognized there has been poor management of water resources through a combination of factors including weak water allocation practices resulting in losses of up to 120 million USD per annum (www.worldbank.org, 2003; SIWI, 2000).

Kenya's Water Act 2002 brought about water sector policy reforms which included setting up water resource management structures through the Water Resources Management Authority. Through this legislation and related policy and regulations, it was mandatory for each catchment to develop a water allocation plan (GoK, 2007). The Water Resources Authority (WRA) was established under Water Act 2016 to take over from WRMA. Under the new regime, water allocation plans are part of water resources management strategy (Government of Kenya, 2018).Currently, there are catchment allocation plans for only less than half of the catchments in Kenya. One of the few published water allocation plans is for the Lake Naivasha Basin (WRMA, 2010). As of June 2017, there were a total of 13 water allocation plans (WAPs) nationally with 4 of these being in the Lake Victoria South basin. (WRA, 2017).

Water resource allocation has been tackled with the aid of modelling tools to analyse the impact of alternative water allocation scenarios while optimizing the use of existing supplies. The main aim of a water allocation model is to aid harmonization of the demand and supply of water resources based on resource availability and environmental flow requirements. This takes into consideration hydrological factors, ecological factors, livelihood, economic costs and benefits of water use options and social factors. A model on its own cannot make a decision; rather it provides support to make a decision by providing scientifically proven results.

The concept of water allocation modelling has been used in different catchments and with different approaches to achieve different goals. In the Malaprabha sub-catchment in India water allocation modelling was used as an analysis tool to determine the effects of different water allocation scenarios using ArcView SWAT and MIKE-BASIN (Reshmi, Christiansen, Badiger, & Barton, 2008). Weragala applied modelling using the SWAT tool to identify the obstacles to water allocation in rural river basins in Sri Lanka using the Walawe River Basin as a case study (Weragala, 2010). Modelling optimal water allocation has also been done for transboundary basins such as the Mekong using an integrated hydrologic-economic model (Ringler, 2001). The different approaches to modelling require using different modelling tools or creating bespoke models to meet the desired goals which creates a layer of complexity. In a bid to reduce the complexity, various modelling tools that seek to create a one stop solution for water allocation modelling purposes have been created. One such tool is the Water Evaluation and Planning System (WEAP) that is used in this study.

1.2 Problem Statement and Justification

Water allocation is the determination of water entitlements to abstractors. It is a multistage process where, ideally, scenario assessments based on the physical processes in the catchment, demand, supply, environmental considerations, equitable allocation and economic development are carried out before allocations for varied uses are determined (Speed, Yuanyuan, Le Quesne, Pegram, & Zhiwei, 2013; Dinar, Rosegrant, & Meinzen-Dick, 1997).

The allocation process by definition is already complex and is further complicated by the fact that there is little or no strategic planning to cope with increasing demand and water scarcity at all levels of water resource management (Mogaka, Gichere, Davis, & Hirji, 2006; Weragala, 2010).The complexity of the water allocation problem is compounded by the variations in availability of water due to climate change. In the Kenyan context, water allocation processes and decision making are guided by policy and legislation and there is little evidence to show that other considerations are made during allocation.

The use of modelling tools is vital in simulating and analysing the impact of alternative water allocation scenarios and guiding the decision-making process in water allocation. There exists several water allocation models but more often than not, they either require specialized training to enable one to use them or they are proprietary software that are costly to purchase. Another limitation that exists with models is that they may need more data than what is already available, particularly for smaller catchments and this limits their applicability in the allocation process.

Different allocation models are available to guide the water allocation planning process. This study aims to investigate a model that can be used to assess water allocation for a Kenyan sub-catchment. The study aimed to use a sub-catchment for which there exists sufficient hydrological data and various competing water demands are present. Awach Tende sub catchment in the Lake Victoria basin met the criteria. Additionally, the existing water scarcity in this sub-catchment is expected to escalate owing to high population growth, urbanization and economic development therefore making it a suitable study site.

1.3 Objectives

The overall objective of this study was to model a water allocation plan for Awach Tende sub-catchment through analysis of water allocation scenarios based on competing water use demands in the catchment.

Specific objectives

- Identify factors affecting water allocation process in the Awach Tende sub-catchment
- To analyse the different allocation scenarios to be used for the sub-catchment
- To model the water allocation scenarios above in the sub-catchment using the WEAP model.

1.4 Scope of the Study

This study was limited to the determination of water allocation based on domestic, institutional and agricultural demand from existing abstraction records. The analyses in the study cover the aspects of physical water scarcity of freshwater from surface runoff. Freshwater from groundwater recharge and snowmelt is not considered. The study made use of existing hydrological data from the Awach-Tende sub-catchment.

CHAPTER 2. LITERATURE REVIEW

2.1 Introduction

Water resource allocation plans are increasingly becoming tools in resolving water conflicts (Karamouz, Szidarovsky, & Zahraie, 2003) resulting from increased demand for limited water resources. The major drivers in the development of allocation planning have been growth of water abstractions from existing resources, a wider variety of water uses as a result of economic growth and change, climate change and loss of ecosystems and river functions (Speed, Yuanyuan, Le Quesne, Pegram, & Zhiwei, 2013)

2.2 Water Resources

2.2.1 Water Resources in Kenya and Awach Tende

Between 1972 and 2017, the amount of freshwater available per capita for Kenya declined steadily from 3,558 cubic metres per year to 617.7 cubic metres per year (FAO, 2016). The country's water resource system is categorised into five major basins namely: Rift Valley, Athi, Ewaso Ng'iro North, Tana Basin, and Lake Victoria. (WRA, 2017).

Awach Tende is one of 51 sub-catchments of the larger Lake Victoria basin and is part of the smaller Lake Victoria South basin. The main water resources in the sub-catchment are surface water and ground water. The river Awach Tende is the main surface water system in the sub-catchment. This sub catchment contributes part of 4% of the river discharge into Lake Victoria (LVEMP, 2005).

Groundwater is present in the sub-catchment in two dominant aquifers namely the Kendu and Oyugis aquifers. The Kendu aquifer is a salty and shallow aquifer with a potential yield of 8 MCM/year whereas the Oyugis aquifer is a freshwater aquifer with pockets of saltiness with a potential yield of 20 MCM/year. Groundwater is accessed in Awach Tende through boreholes, shallow wells, and springs and as base flow to River Awach Tende and its tributaries. The water quality of the groundwater in the sub-catchment is salty with high fluoride and iron content. The fluoride content ranges between 1.5 and 3.0 mg/l which is greater than the WHO standard of 1.5 mg/l for humans but below 6 mg/l for livestock. The iron content ranges between 0.3 and 2.4 mg/l which is considered high against 0.3 mg/l recommended by the WHO (WRMA, 2012).

2.2.2 Major water uses in Awach Tende

In Kenya, water use categories are defined as water demand categories. WRA defines the major water demand categories in order of priority as domestic, public, livestock, irrigation, industry and hydropower (WRA, 2017)

The major water uses in the Awach Tende sub-catchment identified through an abstraction survey were domestic use, institutional use, livestock use, irrigated crop production and commercial purposes such as water supply, car wash activities and fish farming (WRMA, 2012).

2.3 Water Allocation Planning

Water allocation is a process of sharing water in a catchment among competing users in areas where the natural supply and availability does not meet the water demand (Dinar, Rosegrant, & Meinzen-Dick, 1997). The objectives of water allocation planning are promoting efficient use of water; balancing demand and supply; supporting development; and ensuring equitable distribution and environmental protection within the existing policy framework (Speed, Yuanyuan, Le Quesne, Pegram, & Zhiwei, 2013).

The water allocation process involves situational analysis of water resource availability, environmental flows, water use demands that exist and sharing principles that are in place. Scenario development and assessment of implications is based on different supply and allocation options derived from the basin/catchment situation. The entire water allocation planning process is linked to broader social, environmental and development concerns. (Dinar, Rosegrant, & Meinzen-Dick, 1997)

The key elements of a water allocation plan are the objectives, an inventory of the water resources covered and environmental flows, allocation rules and entitlements and the operating rules that govern the plan. Early allocation plans were intended for managing irrigation systems but with increasing scarcity and demand, it is now intended for managing rivers at different catchment levels. Modern allocation plans are ideally undertaken within existing statutory planning frameworks. The common practice in countries like China and South Africa has been to develop National Plans under which Basin Plans are developed and subsequently Sub-Basin Plans. The techniques involved in allocation planning have also evolved from infrastructure development to demand management (Speed, Yuanyuan, Le Quesne, Pegram, & Zhiwei, 2013).

As water allocation is essentially the sharing of water, the main considerations of the catchment that have been used in different allocation plans are: physical characteristics; water demand (existing and future); different water uses (existing and future); population (existing and future); efficiency of water use; required environmental flows and social and economic considerations

(Akivaga, 2010; Weragala, 2010). The different sharing options can be determined using either a single approach or a number of different approaches i.e., hierarchical, criteria based, strategic development or market based (Dinar, Rosegrant, & Meinzen-Dick, 1997).

2.3.1 Water Allocation Planning in Kenya

The development of Water Allocation Plans (WAPs) for different catchments in Kenya is charged to the Water Resources Authority (WRA). Water allocation planning in Kenya is a participatory process which makes use of abstraction survey reports, catchment management plans, information on the available resources and water use thresholds. Abstraction surveys and the subsequent reports provide information on the characteristics and details of abstraction points as well as the existing water uses in the catchment. The criteria used to determine allocation is then guided by the water allocation thresholds and considers the different uses. Thresholds for water allocation are based on catchment area and the status of water resources and are designed to ensure equitable allocation. In Kenya, thresholds are set by the WRM Rules 2007. The general outline of allocation plans so developed by WRA comprises

i. Description of available water resources.
ii. Description and analysis of current and future water demands.
iii. Allocation of resources to meet the demands.
iv. Approval measures to ensure compliance to allocations.
v. Plans to ensure continued compliance and enforcement of allocations and restrictions; and
vi. Provisions for reviewing allocations when the need arises

Water allocation plans developed for different sub catchments using this approach by the WRA include Kuywa and Sosiani in Lake Victoria North catchment, Mara and Mbogo in Lake Victoria South Catchment, Lakes Naivasha and Bogoria in the Rift Valley Catchment, and Timau, Pesi and Suguroi in the Ewaso Nyiro Catchment (WRA, 2017).

2.4 Decision Support Systems and Tools for Modelling Water Allocation

A decision support system is “a computer information system that supports decision making activities”. It is designed to access databases and use analytical decision models to provide information that supports effective decision making. A river management DSS is designed to evaluate hydrological, economic, environmental and policy impacts of different development and management options. More advanced river DSS’s can provide planning frameworks together with real time system operations and controls (Labadie, 2006).

Developing water allocation plans for different classes of basins/catchments follow different approaches (Dinar, Rosegrant, & Meinzen-Dick, 1997) (Speed, Yuanyuan, Le Quesne, Pegram, & Zhiwei, 2013). Hydrological and operational modelling and system yield and optimization models for the water resource systems are key assessment and analyses for developing an allocation plan. These analyses are functions of river management DSS of which there are several modelling tools that can be used to guide decisions made on water allocation. The common approach to water allocation problems has been nodal network approaches where a river catchment is represented in a model as a series of nodes. Each node represents a point where extractions and other activities impacting on stream flow are combined (Letcher, Jakeman, & Croke, 2004). These water allocation models are useful in considering the impacts and possible mitigation actions of different allocation scenarios within the modelled catchment.

Different models have been developed over time to enable development and simulation of water allocation and are classified as either simulation or optimization models based on the modelling techniques that are used. Simulation models depict the behaviour of water resources according to rules dictating the water allocations and operations. Simulation models are useful for where support is required on decisions related to water quantity, water quality and the economic and social implications of alternative allocation scenarios. Optimization models evaluate the best available solutions to allocation targets based on outlined objectives and constraints. These models calculate flows and perform mass balance using a simulation component (Loucks, van Beek, Stedinger, Dijkman, & Villars, 2005).

Various water allocation models that have been developed include RiverWare, Aquarius, MODSIM, MIKE HYDRO Basin, River Basin Simulation Model (RIBASIM) and Water Evaluation and Planning (WEAP) model.

2.4.1 RiverWare

RiverWare modeling tool was designed for rivers and reservoirs developed by CADSWES at the University of Colorado Boulder. It models hydrologic aspects of rivers, reservoirs, groundwater (interactions with surface water and conjunctive use), water quality and water rights. As a result, it can be used to inform aspects such as planning, forecasting, and scheduling operations as well as policy evaluation. RiverWare provides three types of solvers within the program: rule-based simulation, pure simulation, and optimization (RiverWare, 2015).

2.4.2 Aquarius

Aquarius is a software application developed by the U.S Forest Service and Colorado State University. It models allocation of water fluxes both temporally and spatially among competing water uses in a river catchment (Diaz, Brown, & Sveinsson, 2000). The program uses a nonlinear optimization to determine economically efficient water allocation i.e., stream flow is reallocated until there is equilibrium in net marginal return for all water uses (Diaz, Brown, & Sveinsson, 2000). The software considers various water uses i.e.: municipal and industrial, agricultural, habitat protection, storage, flood control area and recreational.

2.4.3 MODSIM

MODSIM was developed at Colorado State University in 1978. This DSS allocates limited water resources by analysing water resource elements and then performing optimization using a minimum cost optimization solver that uses the network costs as constraints. To achieve credible results, users need to understand the DSS's structure (Johnson, 2014). MODSIM can be linked to MODFLOW and QUAL2E for the analysis of conjunctive use of groundwater and surface water and analysing effectiveness of pollution control measures respectively (Sechi & Sulis, 2010).

2.4.4 RIBASIM

This model is a generic package developed by Deltares. The model is designed to analyse the behavior of river catchments under different conditions by linking hydrological inputs with specific water uses at different locations in the catchment system (Deltares, 2019). RIBASIM features include the ability for users to define operating and planning scenarios characterized by either operating rules or water supply projections with a GIS based graphical interface enabling the creation of user-defined objectives to allow for comparison of scenarios. A drawback of the model is the data requirements as it requires extensive and significant data to perform analysis (Sechi & Sulis, 2010).

2.4.5 MIKE HYDRO Basin

MIKE HYDRO Basin is a GIS based DSS tool for analysis, management and planning of river basins developed by DHI (2019). The model provides temporal and spatial simulation and visualization making it suitable for analysis of water sharing issues at different scales.

2.4.6 WEAP

Water Evaluation and Planning System (WEAP) is a generic computer software used for catchment surface water planning developed by the SEI. The software operations are guided by water demand and the environmental flow requirements in a catchment. The model uses the constraints of supply preferences and demand priorities. These constraints are used to determine water allocation and provide analysis through a scenario-based approach (Yates, Purkey, Sieber, Huber-Lee, & Galbraith, 2005).

WEAP's interface is accessible and has a transparent data structure. Users can develop a model schematic comprising a network of nodes connected by links or branches. WEAP then combines water supplies with a water management model by making use of hydrological processes (www.weap21.org, 2021). This feature makes it a suitable tool for allocation modelling between diverse stakeholders and various water demands.

WEAP can simulate water allocation policies using water allocation priorities. Water allocation priorities based on either specific use or first come first served basis can be set up within the DSS. WEAP enables priority allocation of water resources, however, the software is not able to capture all minutiae of a water resource system. As a result, WEAP is best suited for scenario analysis and feasibility studies rather than for detailed allocation tasks such as permitting (Sieber & Purkey, 2015).

WEAP attempts to give equal priority to the demand and supply side of the water balance equation unlike other water DSSs. A notable disadvantage of WEAP is that all scenarios must be quantified, and this places the user at a disadvantage as the development of the scenario during analysis is out of their control. (Loucks, van Beek, Stedinger, Dijkman, & Villars, 2005).

WEAP outputs include a variety of water demand parameters (unmet demand, reliability, coverage, etc.), Tables, Schemes, Charts and Estimates, and others (www.weap21.org, 2021).

2.4.7 Modelling in WEAP

The typical data requirements for a WEAP system are maps, water demand data, supply preference data, other supply data, data linking supply and demand, hydrology data, groundwater data and water quality data (www.weap21.org, 2021).

The steps involved in modelling in WEAP as summarized by Akivaga (2010) are:

1. Definition of the study area using a GIS interface and time frame for analysis
2. Creation of the Current Account which describes the existing conditions of water resources in the study area

3. Creation of future scenarios based on assumptions and allocation priorities
4. Evaluation of scenarios
5. Interpretation of scenario analysis results

The water demand data can be input into the model from files using the ReadFromFile function or entered manually. WEAP performs hydrologic analysis using either of three different methods; Water Year Method, ReadFromFile Method or using user defined mathematical models. Catchment Simulations are performed by either the Rainfall Runoff Method, Irrigation Demand Only Method or the Soil Moisture Method (www.weap21.org, 2021). The method of analysis selected for each analysis is dependent on data availability of the catchment being modelled.

WEAP as a tool is increasingly becoming popular as a water allocation planning and modelling tool as it provides flexibility in modelling approaches, capability to create different scenarios, ease of use as it is fairly straightforward to use. For this reason, the study aimed to use these capabilities to demonstrate that the WEAP tool can be used for sub-catchments in Kenya to achieve the water resource management targets.

2.5 Data Requirements

The main data requirements that are anticipated for the study and methods to be used for their collection are outlined in Table 2-1 below.

Table 2-1 : Data Requirements for Water Allocation Planning model

Data	Comments
Climatic Data	To determine hydrological characteristics of the catchment.

Data	Comments
	Includes rainfall, temperature, and evapotranspiration data.
Digital Elevation Model	For catchment Delineation
Water Use and Demand	To be used for water demand calculation
Land use data	Used to determine hydrological characteristics of the catchment
Stream Flow Data	
Schematic data	Required to create the catchment model

.

CHAPTER 3. MATERIALS AND METHODS

This chapter discusses the study area, data collection and analysis and tools used in the study.

3.1 Study Area

The study area is the Awach Tende sub-catchment in the Lake Victoria South basin. River Awach Tende is one of the eight Kenyan rivers that drain into Lake Victoria.

3.1.1 Location

The Awach Tende sub-catchment borders Kisii and Migori counties in the Lake Victoria Region. The sub-catchment lies between 34° 29' E and 34° 45' E and 0º 22' S and 0° 38' S of the equator. The altitude of the Awach Tende sub-catchment ranges from 1150 to 1650 m.a.s.l. The sub-catchment covers an area of 244 square kilometres.

River Awach Tende has two main tributaries, Mogusi and Isanda which originate from several springs in the Manga Hills. The two river system traverses Kasipul, Karachuonyo and Rangwe sub counties ending at Winam Gulf on the eastern bank of Lake Victoria in Kenya

Figure 3-1 : Awach Tende sub-catchment in Lake Victoria South region

3.1.2 Climate

The sub-catchment's rainfall pattern is bimodal with long rains between February to June and short rains between September to December. The climatic characteristics of the sub-catchment are summarized in Table 3-1 below (Lam, Kyokunda, Fora, & Mosseau, 2006).

Table 3-1 Mean annual climate characteristics of Awach Tende sub-catchment

	Min	Max
Mean Annual Rainfall (mm)	740	1200
Mean Annual Temperature (°C)	10	31
Annual evapotranspiration (mm)	1,800	2,000

3.1.3 Hydrology and water resources

There is a river gauging station on River Awach Tende designated as 1HE01 at GPS co-ordinates E34.5490, S0.4670 identified by LVEMP for continuous monitoring (Mwanuzi, Abuodha, Muyodi, & Hecky, 2005) and listed as operational by the NWMP 2030 (JICA, 2013). A rainfall gauging station in operation also exists at the Homa Bay DWO's Office (Thine, 2013).

The water sources in the sub-catchment are a combination of surface water and groundwater. Surface water sources include River Awach Tende, surface streams, water pans, protected springs and unprotected springs. The groundwater sources in use are shallow wells and boreholes.

3.1.4 Economic activities

Farming (agro-pastoral), fishing, business (trading, water vending), wage/salary employment, CBOs and SHGs, and transport industry with the sub catchment are the main economic activities

(Thine, 2013) (Homa Bay County Government) (Odhiambo, 2011). There are also some income generating activities at the household levels such as sand harvesting in areas with sandy soils, beekeeping, and quarrying. Altogether, these economic activities demand water at different quantities; thus, requiring proper water resources management (Thine, 2013).

Smallholder irrigation is also gaining ground in the sub-catchment. The sub-catchment area is also home to part of the Oluch-Kimira Smallholder Farm Improvement Project. A land area of about 666 hectares designated as the Oluch Scheme is planned for irrigation from River Awach Tende under the project (Raburu, 2005; www.afdb.org, 2016).

3.2 Data Collection

The research study made use of existing secondary data. Data requirements and sources used for the study are given in Table 3-2 below.

Table 3-2 : Data Collection Matrix for modelling water allocation for Awach Tende

Data	Sources
Climatic Data	FAO New LocClim 1.10 (FAO, 2005)
Digital Elevation Model	SRTM 30m DEM (USGS, 2021)
Water Use and Demand	Population Census Data (CBS, 1994), (CBS, 2002), (KNBS, 2010) Water consumption rates (GoK, 2007), (MoWI, 2005) Homabay County Integrated Development Plan (County Government of Homa Bay, 2013)
Land use data	Awach Tende sub-catchment abstraction survey report Google Earth® Imagery

Data	Sources
Stream Flow Data	WRMA /WRA National Water Master Plan
Schematic data	Topographic sheets Google Earth® Imagery

3.3 Water Allocation

The basis of water allocation is the understanding of water availability in time and space and the various water needs that exist within a catchment (Dinar, Rosegrant, & Meinzen-Dick, 1997).

3.3.1 Stream flow data

Daily discharge data for River Awach Tende was obtained from the WRMA records office. Data was available for the river gauging station (RGS) on River Awach Tende designated as 1HE01.

3.3.2 Climate data

Climate data was obtained from FAO's New LocClim 1.10 and Climwat 2.0 for CropWAT. Climatic data from New LocClim 1.10 is available at a temporal resolution of months, days or dekads.

The climatic data available from New LocClim 1.10 and Climwat 2.0 are: Daily Temperature (mean, maximum and minimum); Sunshine hours per day; Wind speed; Relative humidity; Solar radiation; rainfall (monthly and monthly effective); and Reference evapotranspiration (FAO, 2005). LocClim data reflects the mean values for the various parameters. Evapotranspiration is calculated within LocClim using the Penman-Monteith method.

3.3.3 Water use and demand data

Information on the different uses of water in the sub-catchment was collected from different sources and the water demands (current and future) determined. The main uses of water in Awach Tende sub-catchment are institutional, domestic. livestock, environmental needs, and crop production through irrigation. Water is also used for various commercial purposes such as water supply, carwash, and fish farming (WRMA, 2012).

The different sectoral water uses and demands that were identified are discussed below

Domestic water demand

This water demand in the sub-catchment is directly proportional to the human population in the sub-catchment. Human population data was obtained from the KNBS database for three national censuses i.e. 1989, 1999 and 2009 (CBS, 1994) (CBS, 2002) (KNBS, 2010). Using maps of the sub-catchment and sub-locations on a GIS platform, population data was assigned to the sub-locations and uniform population distribution assumed and assigned to the sub-catchment through clipping and various GIS techniques to determine the population in the Awach Tende sub-catchment. The human population growth rate was determined using historical census records

Guidelines from the MoWI Practice Manual and WRMA rules (GoK, 2007) were used to calculate the domestic water demand.

Livestock water demand

The livestock population data, growth rate and water demand were obtained in a similar manner to the human population.

Institutional water demand

The most important institutions in the sub-catchment are schools and health facilities.

Design guidelines recommend using a value of 30% of the human population to determine the school population and a consumption rate of 5 litres per head per day (MoWI, 2005).

It was established from the Kenya Master Health Facility list (MoH, 2020) that there are 23 health facilities in the sub-catchment. A list of the health facilities is provided in Table C-1. The water demand for each facility was determined using guidelines from the MoWI Practice Manual.

Irrigation water demand

The main agricultural water demand in the Awach Tende sub-catchment comes from the irrigation water requirements from the Kimira-Oluch Smallholder Farm Improvement Project (KOSFIP) (KOSFIP, 2016), (County Government of Homa Bay, 2013), (Homa Bay County Government).

Commercial water demand

The main commercial activities in the sub-catchment were identified as water supply, car washing and fish farming. This component refers to water abstracted for the purpose of supplying for domestic and livestock purposed hence this is accounted for in the domestic and livestock demand. On the other hand, the consumption used for other car washing and fish farming is estimated as 10% of Q_{95} (WRMA, 2012).

Environmental flow requirement

The Earth Summit in Rio De Janeiro 1992 started the promotion of conservation of ecosystems as a public good. Subsequently, the concept of granting water rights to the ecosystem gained popularity through environmental flows. Environmental flow was defined as “the flow in a river required to maintain a river’s ecological functions” (Loucks, van Beek, Stedinger, Dijkman, & Villars, 2005).

Over the years, different approaches have been used to determine environmental flow allocations. These approaches are broadly categorized as the use of desktop analysis, look- up tables, functional analysis and hydraulic habitat modelling. The most used methods are the use of look-up tables where simple indices are provided in look up tables (Acreman & Dunbar, 2004).

In Kenya the WRMA Rules 2007 put thus right is at Q_{95}, a hydrological index which represents the river flow exceeded 95% of the time. The value of Q_{95} is determined using a flow duration curve (FDC) derived from values of daily stream flow for the River Awach Tende within the WEAP model.

3.3.4 Water allocation scenarios

Scenarios are logical outlines of how a system might develop over time under different constraints. In WEAP, scenarios can be built starting from a common year and comparisons performed to assess their water requirements, costs and environmental impacts (SEI, 2015).

The allocation scenarios that were considered are outlined in Table 3-3 below

Table 3-3 Summary of scenarios created for analysis

Scenario	**Remarks**

Business as usual (2009-2029)	Simulation of the sub-catchment with no changes to the system except for population growth with 2009 as the base year.
High population growth rate with operational irrigation scheme	A high human population growth rate of 6% p.a.and fully operational scheme is assumed
Fully operational Irrigation scheme	A fully operational irrigation scheme operating at 100% capacity from the year 2013 with normal population growth.
Irrigation scheme with gradual expansion to 100% capacity by 2025	Gradual operationalization of the irrigation scheme is assumed with normal population growth.
Fully operational irrigation scheme with improved irrigation efficiency and use of water conservation measures	A normal population growth is assumed with improvements in irrigation efficiency of up to 20%
Climate change scenario	An increase in surface water supply

3.4 Data Analysis

Data analysis was carried out in WEAP version 2015.0 to simulate the rainfall and runoff in the sub-catchment and to allocate the available surface water among the various water demands (domestic, livestock, institutional, irrigation and environmental flow) under different scenarios for the period between the years 2009 -2029.

Assumptions made in this study is that all water demand in the sub-catchment is met by River Awach Tende and other sources such as water pans and groundwater were not considered.

3.4.1 Creating the WEAP model

The following steps were used to create the WEAP model (Levite, Sally, & Cour, 2003) for the Awach Tende sub-catchment to model the current and future water demands and allocations.

i. Definition of the study area in space and time

The study area was defined using the shapefiles of the boundary of the sub-catchment and the River Awach Tende. The boundary of the sub-catchment (Figure 3-1) was derived from a 30 m DEM using catchment delineation techniques in the QGIS platform (QGIS Development Team, 2016).

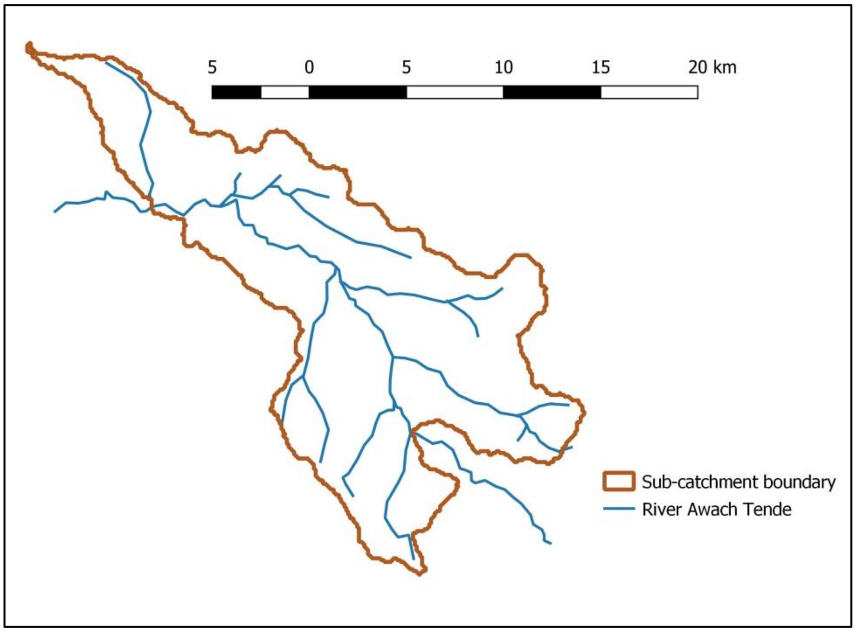

Figure 3-1: Awach Tende sub-catchment boundary

In this step and using the boundary shapefile, the WEAP schematic was created. The schematic shows the spatial layout of the different elements that make up the model being studied. Elements that were included in the schematic are: the main river, demand sites, catchment outlet points, and RGS sites as shown in Figure 3-2 below.

Demand sites represent the different water users within the sub-catchment. As per Section 3.3.3, the main categories of water use in the sub-catchment were lumped together to create aggregate demand sites (Sieber & Purkey, 2015). Each demand site requires

- A transmission link that links the demand site to its source(s).
- A return flow link for any return flows or water not consumed at the demand site.
- A demand allocation priority; and
- Information on annual water use rates and monthly variations which are used to compute the water demand

Demand allocation priorities specify the order of priority to be used for the allocation of limited resources between several demand sites. These sites are assigned priorities with the highest starting from one being supplied first and those with lower priorities (larger numbers) are supplied later in order of priority (Sieber & Purkey, 2015).

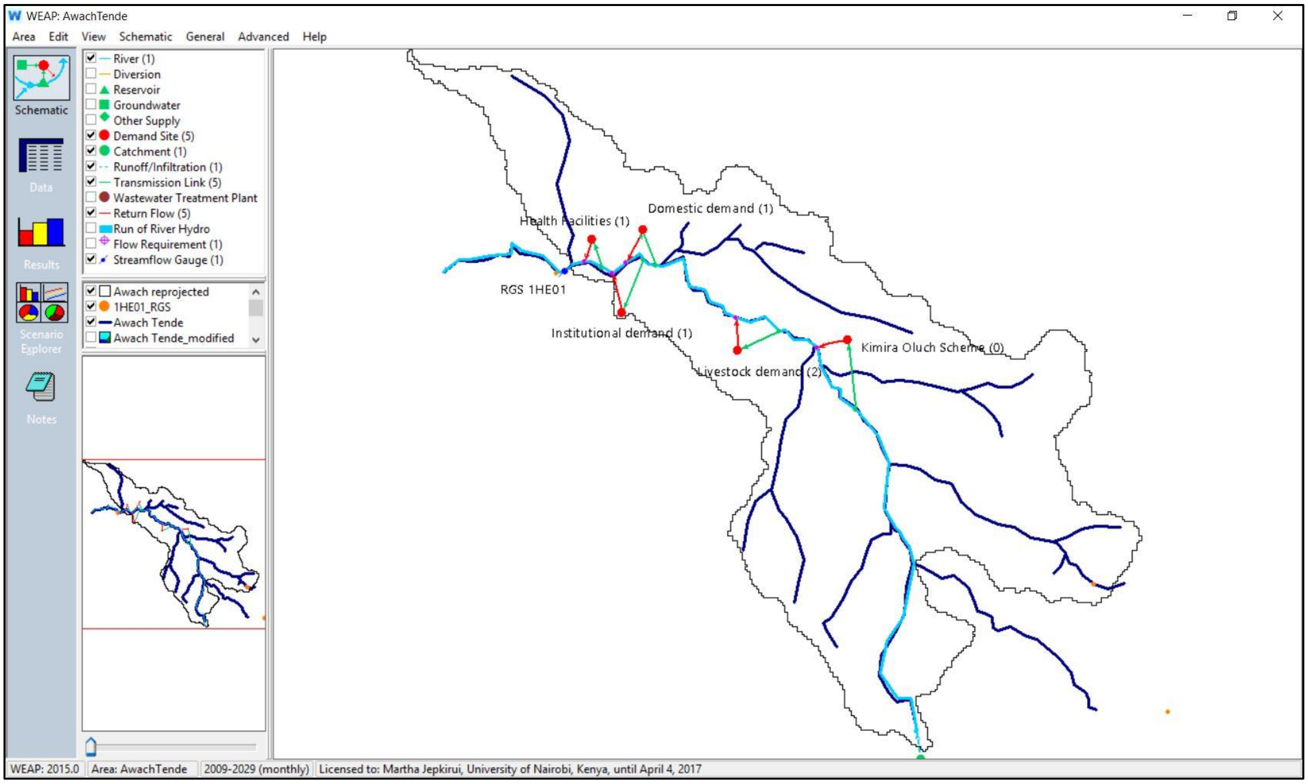

Figure 3-2: WEAP schematic for Awach Tende sub-catchment

The time frame in the WEAP model includes the initial and last year of analysis. For this study, the time frame of the study was for a period of 30 years for the years 2009 – 2029 as shown in Figure 3-3 below

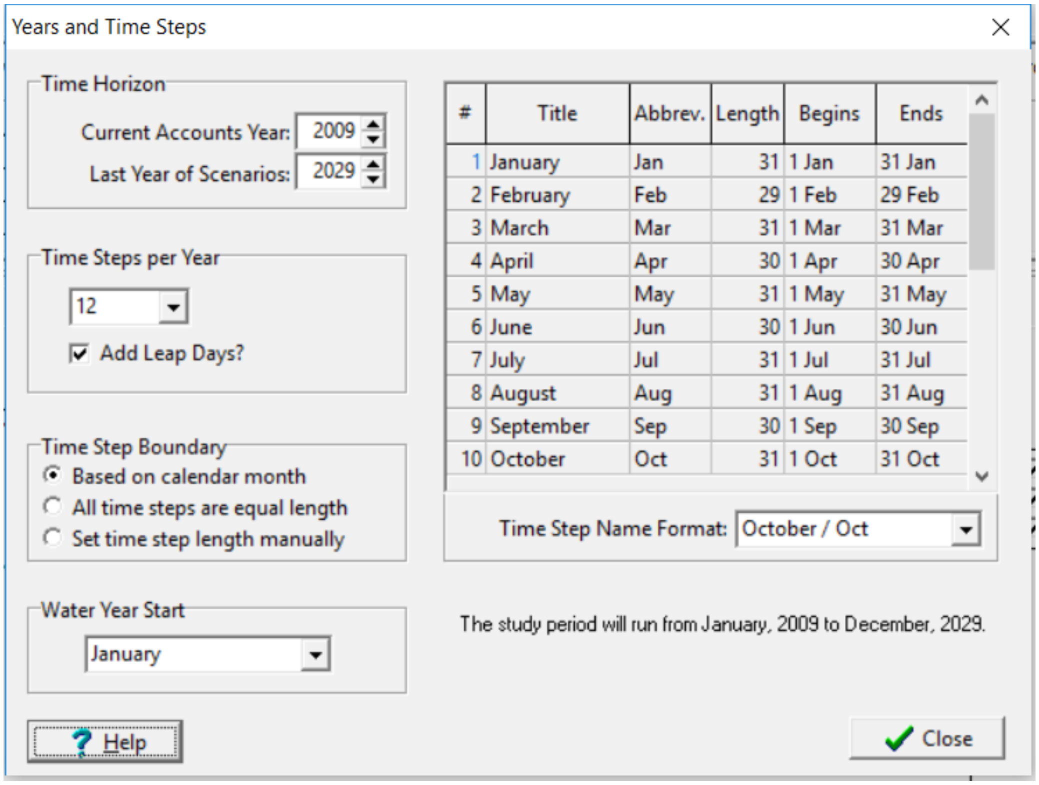

Figure 3-3: Setting up of years and time steps in WEAP

ii. Creation of the current account

The current account refers to the existing water resources situation at the initial year of analysis., The available water resources and the existing water demand points or sites are set out in the current account. In this study, the current account was used for the calibration of the model.

iii. Creation of scenarios

Scenarios are created on the basis of future assumptions and expected changes (increase or decrease) in the various indicators. Scenarios allow for the assessment of ‘what if situations’ that could possibly occur in the area of study. Scenario analysis results from running the model allow for the assessment of water management processes that can or should be adopted. Examples of 'what if situations' include changes in population growth, reduction in available water resources, the addition of new water demand (sites or new uses) in the study area etc. The evaluation scenarios that were created are described in Table 3-3 and the scenario analysis in Section 4.4.

iv. Scenario evaluation with reference to the available water resources in the study area

From the evaluation of scenarios, the results can be used to guide the decision making for water planners/managers.

3.4.2 Rainfall Runoff Simulation in WEAP

The WEAP model provides five methods for simulating catchment processes. These are: The Rainfall Runoff method; Irrigation Demands Only (a versions of the Simplified Coefficient Approach); Soil Moisture Method; MABIA Method; and Plant Growth Model (PGM) (SEI, 2015).

The irrigation demands only method is the simplest method runoff or infiltration processes are not simulated, instead the potential evapotranspiration is calculated using crop coefficients. This is used to determine any irrigation water requirements needed to supplement rainfall in the catchment. (Sieber & Purkey, 2015)

The Rainfall Runoff method uses crop coefficients to calculate the evapotranspiration for irrigated and rainfed crops. Rainfall that is not consumed by evapotranspiration is then simulated as runoff, groundwater or both (Sieber & Purkey, 2015).

The Soil Moisture method depicts the catchment as two soil layers with the potential for snow accumulation. Evapotranspiration, runoff and shallow interflow, and changes in soil moisture are simulated in the top layer. In the second layer, soil moisture changes and baseflow routing are simulated (Sieber & Purkey, 2015).

The MABIA Method uses a daily time step to simulate plant growth using the elements of transpiration, evaporation, irrigation demand, crop growth and yields while making use of the FAO 'dual' K_c method (Sieber & Purkey, 2015).

The Rainfall Runoff method was used to simulate the catchment in this study as a result of the type of data that was available i.e., rainfall, evaporation and crop data.

3.4.3 Model calibration and validation

Model calibration is the process of adjusting model parameters so as to achieve outputs as close to the observed values as possible (Karamouz, Szidarovsky, & Zahraie, 2003).Model calibration can be done manually, automatically or by combining both methods (Refsgaard, 1997). The WEAP model incorporates automatic calibration using a parameter estimation tool (PEST) linkage that compares outputs to historical observations and improves the accuracy by modifying the model parameters. However, this method is useful where the soil moisture method is used to model the catchment (Sieber & Purkey, 2015). For this study, the PEST tool was not used as the soil moisture method was not used to model the catchment and manual methods were used instead. The manual calibration method was therefore used for model calibration in this study

The coefficient of determination r^2 and the Nash-Sutcliffe efficiency E (Krause, Boyle, & Base, 2005) was used to evaluate the model performance as described in the equations below

$$\boldsymbol{r^2} = \left(\frac{\sum_{i=1}^{n} (O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^{n} (O_i - \bar{O})^2} \sqrt{\sum_{i=1}^{n} (P_i - \bar{P})^2}} \right)^2 \qquad \textbf{3.1}$$

$$\boldsymbol{E} = 1 - \left(\frac{\sum_{i=1}^{n} (O_i - P_i)^2}{\sqrt{\sum_{i=1}^{n} (O_i - \bar{O})^2}} \right) \qquad \textbf{3.2}$$

Where

O - *Observed values*

P - *Predicted values*

r^2 - *coefficient of determination*

E - *Nash-Sutcliffe efficiency*

N - *number of observations*

Values of r^2 range from 0 to 1 where a value of zero indicates no correlation and a value of 1 shows that the dispersion of the simulated data is equal to the dispersion of the observed data.

The Nash-Sutcliffe efficiency *E*, a dimensionless and scaled version of the mean squared error provides a distinct evaluation of the model results and performance. Values of *E* range between 0 and 1 where 0 or 1 indicates a perfect model (Tesfaye, 2014).

The WEAP model requires the use of historic data that is not part of the calibration period for validation (Akivaga, 2010) (Hussein, 2015).

CHAPTER 4. RESULTS AND DISCUSSION

The following sections address the objectives of the study as follows Sections 4.1 to 4.3 cover the factors affecting the water allocation process in Awach Tende sub-catchment, the different allocation scenarios and the model outputs are presented in Section 4.4.

4.1 Sub Catchment Hydrology

The hydrological processes of the sub-catchment were used to simulate the sub-catchment hydrology. The processes that were defined are: precipitation, evapotranspiration, stream flow, catchment size and land cover. Groundwater analysis was not included in this study as data required to identify and estimate abstraction rates, aquifer storage capacity, recharge rates for the sub-catchment was not available.

4.1.1 Stream flow data

Daily discharge data for River Awach Tende was obtained from the WRMA records office. Data was available for the river gauging station (RGS) on River Awach Tende designated as 1HE01 for the period of 1 August 1974 to 30 June 2015. The daily flow record is provided in Appendix A. The daily discharge data was computed to monthly average river flow for use in WEAP.

Analysis of the average monthly stream flow for the available period of record shows that April and May are the wettest months.

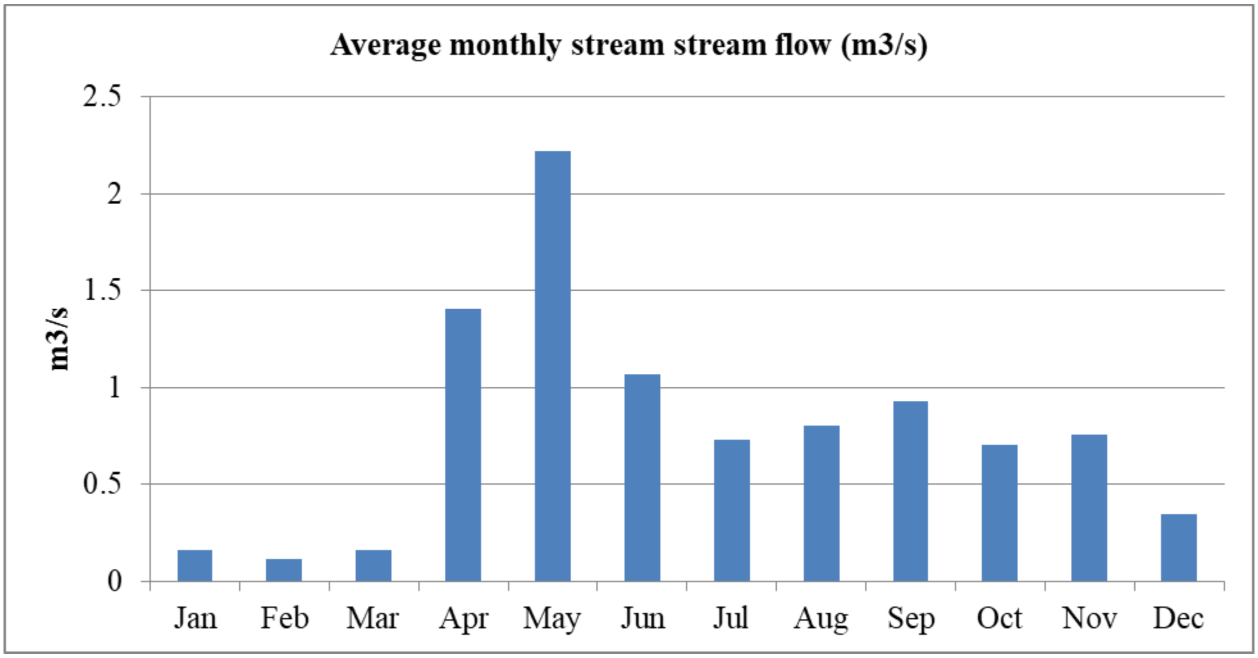

Figure 4-1: Average monthly flow at River Awach Tende (1974 – 2015)

4.2 Modelling Water Demand

The main sectoral water demands were represented as demand sites or nodes in the WEAP schematic. Based on the classification of different water demands from WRMA, the demand sites were assigned allocation priorities as shown in Table 4-1 below. WEAP determines the allocation order based on (i) demand priorities and (ii)supply preferences where there are more than one water sources. Allocation priorities in WEAP range from 1 to 99 where 1 is the highest priority and 99 is the lowest priority (Sieber & Purkey, 2015).

Table 4-1: Demand site priorities

Demand sites	Demand priority
Domestic	1
Livestock	2
Institutional	1
Irrigation	3
Environmental flow requirement	1

4.2.1 Domestic water demand

The domestic water demand in the sub-catchment is directly proportional to the human population in the sub-catchment. Using maps of the sub-catchment and sub-locations on a GIS platform, population data was assigned to the sub-locations and uniform population distribution assumed and assigned to the sub-catchment through clipping and various GIS techniques to determine the population in the Awach Tende sub-catchment as shown in Table 4-2 below

Table 4-2 Human population data in Awach Tende for 1989, 1999 and 2009

Year	1989	1999	2009
Human Population	202,050	282,899	396,310

From the historical census records, the human population growth rate was determined to be 3.4% p.a. The computed growth rate was slightly lower than 4% which was used in the abstraction survey (WRMA, 2012). This can be attributed to the rounding off error in the GIS clipping of population and sub catchment areas. The computed population growth rate was used as a key assumption in the WEAP model for the study period.

The water balance in the abstraction survey used a daily consumption of 40 litres per head per day. This study using guidelines from the MoWI Practice Manual and WRMA 2007 Rules which set domestic water demand at 50 litres per capita per day and water for basic human needs at 25 litres per head per day respectively, the daily domestic water demand was taken as 75 litres per head per day. This was converted into an annual consumption rate of 27.375 m^3/head/yr with no monthly variation in the WEAP model.

4.2.2 Livestock water demand

The livestock population data was available for the years 1999 and 2009. The livestock population in the sub-catchment was obtained in a similar manner to the human population. The livestock population growth rate used for projection of future livestock population was determined to be 5.2% and this was used to project future livestock population for the study period in the WEAP model. Similar to the human population growth rate, the study used a more conservative value for the livestock population growth rate than the abstraction survey which was 6.6% (WRMA, 2012).

Table 4-3Livestock population data in Awach Tende for 1999 and 2009

Year	1999	2009
Livestock Population	116,614	194,046

The overall livestock water demand was determined using a consumption rate of 50 litres per livestock unit per day (MoWI, 2005) resulting in an annual consumption rate of 18.25 m^3/livestock unit/yr

4.2.3 Institutional water demand

The most important institutions in the sub-catchment are schools and health facilities.

Design guidelines recommend using a value of 30% of the human population to determine the school population and a consumption rate of 5 litres per head per day (MoWI, 2005). The annual institutional water demand in the current destination was computed as 1.825 m^3/head/yr.

It was found that there are 23 health facilities in the sub-catchment from the Ministry of Health as compared to the 6 that were accounted for in the abstraction survey (WRMA, 2012). The water demand for each facility was established as 5000 litres per day (MoWI, 2005) resulting in an annual water consumption rate of 1,825 m^3/facility.

4.2.4 Irrigation water demand

The main agricultural water demand in the Awach Tende sub-catchment comes from the irrigation water requirements from the Kimira-Oluch Smallholder Farm Improvement Project (KOSFIP). The KOSFIP scheme is spread out over two sub catchments i.e., Awach Kibuon and Awach Tende. Awach Tende sub-catchment is host to the Oluch Smallholder Irrigation Scheme which covers an area of 666 hectares. The intake weir for the scheme on the River Awach Tende is located at Kodhuch and the scheme comprises of a system of lined surface canals to reduce seepage to ground water and an outlet allowing return flows back into the river. The intake weir has a design capacity of 24.54 Mm^3/yr (http://kosfip.co.ke/pages/project/Components.php, 2014).

An irrigation efficiency of 27% as described by Niejens (2001) and Seckler *et al*. (1998) was assumed for the irrigation scheme and the annual water use set as 6.6 Mm^3/yr. The start year of the project was set as the year 2013 for this study.

4.2.5 Environmental flow requirement

The environmental flow requirement Q_{95} was determined using a flow duration curve. A flow duration curve (FDC) shows the relationship between a discharge value and the percentage of time itis equalled or exceeded (Dinar, Rosegrant, & Meinzen-Dick, 1997). The x-axis represents the flow durations or percentage of time flow is equaled or exceeded and the Y-axis represents the q flow at a given time. A value of zero on the x-axis indicates to the highest stream discharge in the record and 100 to the lowest. Therefore, Q_{95} is the flow exceeded 95% of the time.

WEAP is able to generate a flow duration curve using the FDCShift function which is able to calculate the FDC in a “no change” scenario using the original stream flow time series as well as the FDC for different environmental management classes. A description of the environmental management classes is provided in Table A-1.

Information for the Awach Tende’s FDC generated by WEAP for the different environmental classes is given in Appendix A. The value of Q_{95} for class B was selected because this class reflects the environmental flow requirement for a “largely intact biodiversity and habitats despite water resources development” (Sieber & Purkey, 2015) which closely resembles the conditions in the Awach Tende sub-catchment. The FDC for this situation is as shown in Figure 4-2 where the value of Q_{95} is a flow of 0.03 m^3/s.

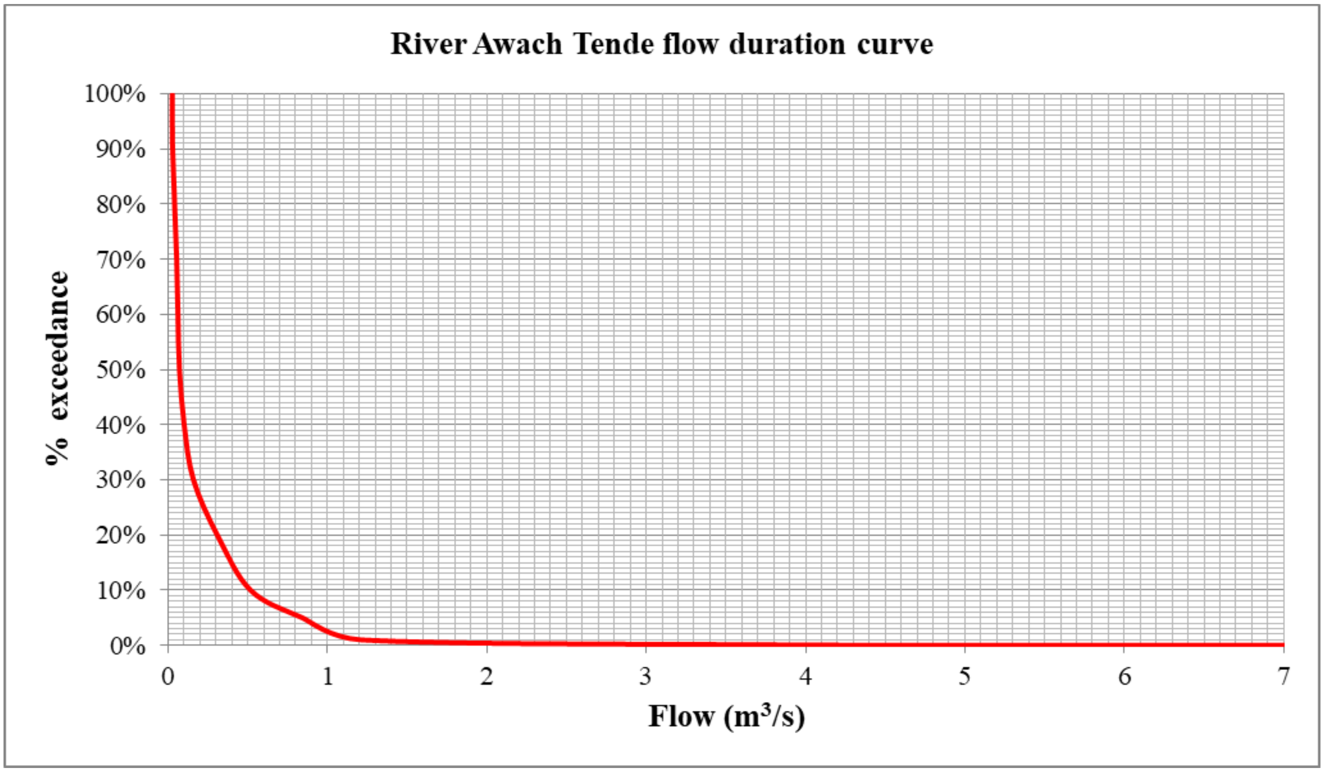

Figure 4-2: Flow duration curve for River Awach Tende

4.3 Rainfall-Runoff Modelling

The rainfall runoff method in WEAP was used to simulate surface runoff. This method was selected based on the data that was available for the Awach Tende sub-catchment. Data required for the rainfall-runoff method are land use area, effective precipitation, reference crop evapotranspiration (ET_o) and crop coefficients (K_c).

The study area comprises of a single catchment in the WEAP model for which land use and climate were defined.

The land use parameters required by the WEAP model are land area, crop coefficient data and effective precipitation.

The main land use types in the sub-catchment are rain fed agricultural land (65%), natural vegetation (15%) and settlements and trading centres (10%) (WRMA, 2012). Other land use types in the sub-catchment are water bodies, forested areas and irrigated agricultural land which accounts for less than 5% of the total land area. For this study, it was taken that 65% of the land was covered with rain fed maize and the remainder with other vegetation.

The crop coefficient is a property that integrates the effects of crop transpiration and soil evaporation and is used to predict evapotranspiration (Allen, Pereira, Raes, & Smith, 2016). For this study rain fed maize was selected as the main crop so that data for dry maize was used. The monthly variation in the crop coefficient taking into account the growing seasons and length of growth stages is shown in Appendix B

The proportion of rainfall available for evapotranspiration and expressed as a percentage is the effective precipitation. From the water balance for the water catchment, the annual effective precipitation was taken as 65% (WRMA, 2012).

The climate parameters required by the WEAP model for the rainfall runoff modelling are the precipitation and reference crop evapotranspiration. Estimation of these data for the sub-catchment was done using the FAO's New LocClim 1.10 database. The precipitation and reference evapotranspiration data derived from New LocClim 1.10 are summarized in Table B-2 in Appendix B.

4.3.1 Model calibration results

In the manual method, the model outputs are physically compared to observations. The observed stream flows for the period 2009 to 2011 were used to calibrate the model whereby the land use parameters were modified. The K_c values of maize were used rather than the average values for maize and other vegetation and the average annual effective precipitation was varied between 60% to 80% by trial and error.

The graph in Figure 4-3 shows that the simulated runoff (Q_{sim}) follows the trend of the observed runoff (Q_{obs}) in the reference scenario. However, it shows that the simulated runoff is higher that the observed runoff. This may be explained by rainfall that contributes to groundwater being attributed to surface runoff as the study does not consider groundwater or groundwater recharge.

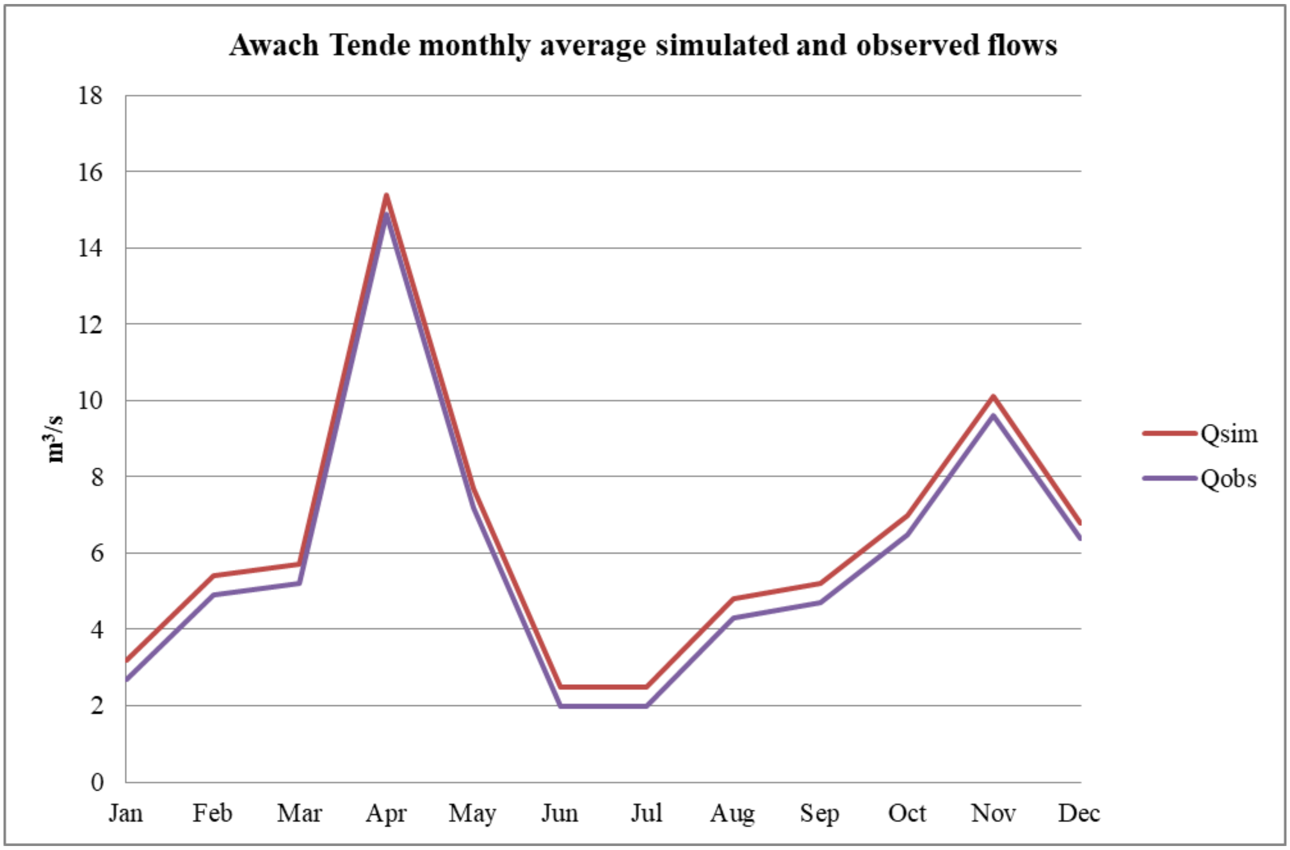

Figure 4-3: Awach Tende monthly average observed flow and WEAP model simulated flow

The value of r^2 for the model from equation 3.1 was 0.99 or 99% showing a strong correlation between the simulated and observed data

The Nash-Sutcliffe efficiency value of E for the model was found as 0.979. The calibration results thus show that the model can predict the hydrology of the sub-catchment.

4.4 Scenario Analysis

4.4.1 Business as usual (2009-2029)

The business-as-usual (BAU) scenario is the reference scenario where the current account year is extended into the future. In this scenario, and exponential population growth at a rate of 3.4% and 5.2% was assumed for people and livestock respectively based on the historical census records. As the scenario is intended to define the current account year, no irrigation water demand was considered in this scenario. This scenario was also used to carry out the model calibration and validation as described in Section 4.3.

In this scenario, the total water demand increases at an annual rate of 4% from 14.6 Mm^3/yr in 2009 to 31.4 Mm^3/yr in the year 2029 as shown in Figure 4-4. The largest water users accounting for 98% of the water demand are the domestic consumers and livestock. In the business-as-usual scenario, there is 100% coverage as all the water demand is met. The water demand computed in the WEAP model is higher than the water demand computed in the abstraction survey by 9.7%, this difference can be attributed to the higher domestic water demand used in this study as well as the increased number of health facilities used to determine the institutional water demand.

In this scenario, all water demands are met from the available 200.19 Mm^3/yr. From a water resources management perspective, water can be allocated to economic activities within the sub catchment.

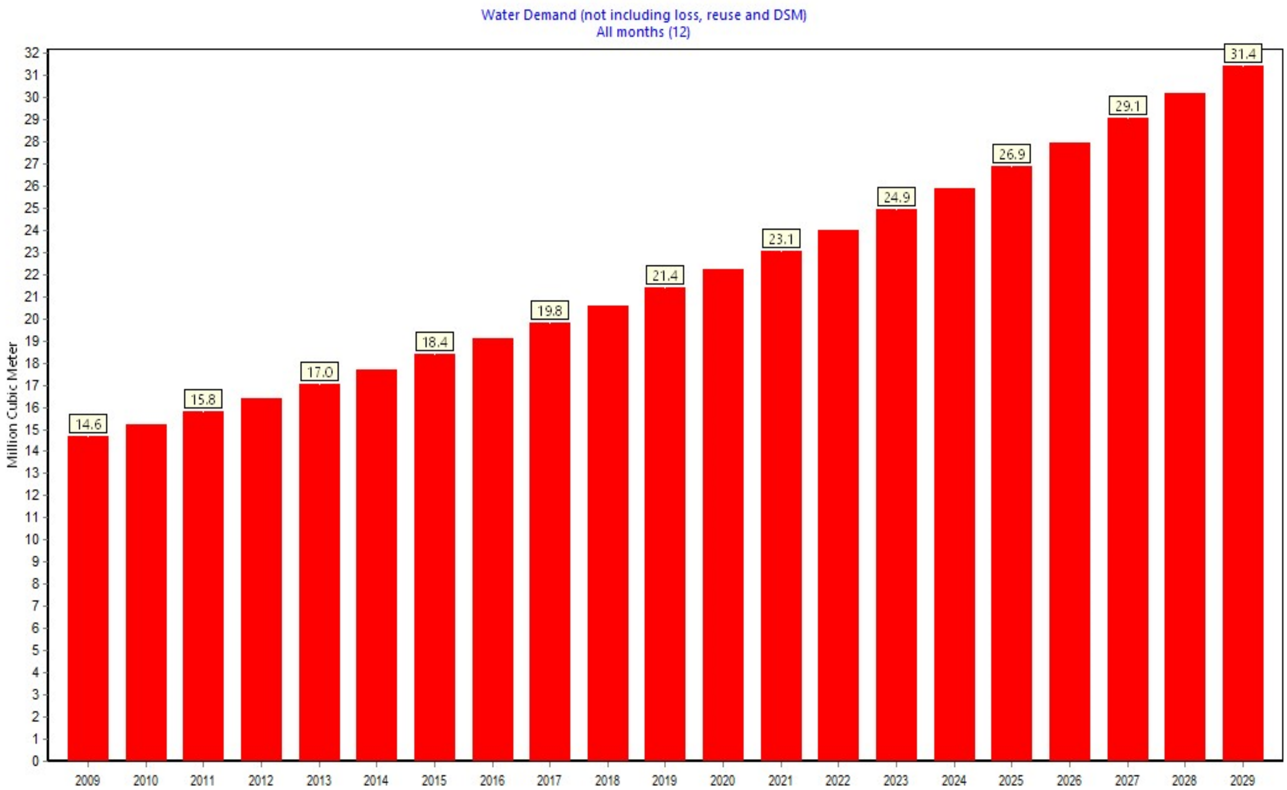

Figure 4-4: Water demand in the BAU scenario (2009 - 2029)

4.4.2 Fully operational irrigation scheme

Various reports indicate that the Oluch irrigation scheme begun operations in the year 2013 which was used as the start year of full operations of the irrigation scheme in the sub-catchment. Based on data from Neijens (2001) it was assumed that the scheme has an irrigation efficiency of 27% of the design flow of the irrigation scheme.

The population growth rates in this scenario were not altered from the BAU scenario and thus remained as 3.4% and 5.2% for human beings and livestock.

Although there is an increase of 6.6 Mm^3/yr in the demand from the start year to the end of the study period in 2029, the River Awach Tende can meet all the water demand in the sub-catchment. The increase in water demand 2013 accounts for an increase of 39% at the inception of the irrigation scheme to 21% in 2029 as shown in Table D-1. This indicates that the introduction of low efficiency irrigation has no effect on the availability of water for human domestic and livestock purposes. With no unmet demand in this scenario, the surplus water can also be allocated to other economic activities suitable to the sub catchment.

4.4.3 Irrigation scheme with gradual expansion to 100% capacity by 2029

This scenario was created to reflect the reality that it may not be possible to achieve 100% capacity at the inception of a smallholder irrigation scheme. A linear growth pattern was assumed for the period of 2013 to 2029. The analysis for this scenario showed that all demand was met. The results of this scenario are similar to those in Section 4.4.2 as the only difference is the implementation plan of the irrigation project.

4.4.4 High population growth rate with operational irrigation scheme

In this scenario, the key assumptions used were a high human population growth rate of 6% with the Oluch irrigation scheme beginning operations in the year 2013 at 100% capacity and with an irrigation efficiency of 27%. The results from the scenario analysis indicate that against an average annual supply of 200.1 Mm^3/yr, a high human population growth rate will not have any effect on the availability of water in Awach Tende if the irrigation scheme continues to operate at low irrigation efficiency.

4.4.5 Irrigation efficiency improvements

Seckler *et al*. (1998) proposed that of irrigation efficiencies could be improved from 27% to 54% by the year 2025 (Seckler, Molden, & Barker R, 1998). In line with this recommendation, this scenario made use of the assumption that the Oluch irrigation scheme would begin operations with a high irrigation efficiency of 54%. The population growth rates used were those used in the BAU scenario.

Due to an improved irrigation efficiency, the annual irrigation water demand increased by approximately 98% from 6.5 Mm^3/yr to 12.5 Mm^3/yr. This increase in demand will result in an unmet demand of 0.42 Mm^3/yr at the irrigation scheme demand site. This implies that any efficiency improvements that will improve the irrigation efficiency above 54% will result in significant supply deficits.

4.4.6 Climate change scenarios

Climate change scenarios developed using Global Circulation Models (GCMs) have projected increased rainfall in the study area which will increase the stream flow by 6%-115% (Odhiambo, 2011). A conservative value of 6% was used to project an increase in the stream flow of River Awach Tende for the study period.

In the first climate change scenario, assumptions used were improved irrigation efficiency and high human population growth rate. In this scenario, the domestic, livestock and institutional demand were all met whereas none of the irrigation demands were supplied with water.

In the second climate change scenario, the normal population growth rates were used as well as the baseline irrigation efficiency of 27%, the results remain the same whereby the surface water resource is not able to meet the irrigation water demand.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

The objective of this study was to develop a water allocation planning model for Awach Tende sub-catchment in the WEAP environment using secondary data. The study identified the main factors affecting water allocation as the available water resources and the existing water demand in the sub-catchment. Different water allocation scenarios were designed to reflect the priorities of water use and demand dictated by the catchment characteristics and relevant policy and legislation.

A model of the sub-catchment was created in WEAP and the r^2 and E values show that the model is able to simulate the sub-catchment and it was possible to project different water allocation scenarios and management issues. The model can therefore be used to conceptualize the sub-catchment. Improvements can be made to the model by including more detailed data from further investigations particularly on groundwater and surface reservoirs.

The sub-catchment has an average annual surface water supply of 200.19 Mm^3/yr for the period of 2009 – 2029. This surface water resource will be able to meet the major water demand sectors of domestic use, livestock water, institutional water and environmental flow requirements. The surface water resource is also able to meet the demand brought about by irrigation developments, however, there will be pressures on the surface water resource as the uptake of irrigation continues to increase. This will require the uptake of water conservation measures in all the major water demand categories e.g., rainwater harvesting at household and institutional levels. It is recommended that further studies are conducted to study the effect of irrigation efficiency on the overall water availability in the sub catchment.

The study found that the surface water resource can meet all the water demands when the irrigation efficiency ranges between 27% - 30%. As the irrigation efficiency increases, more water is utilized in irrigation leading to a shortage of supply. Further studies should be conducted on the optimal irrigation efficiencies that can be achieved in the Oluch irrigation scheme, the output of which can be used to improve the demand and supply projections of the model.

REFERENCES

(2014, July). Retrieved from http://kosfip.co.ke/pages/project/Components.php.

(2017, December). Retrieved from 2030 Water Resource Group: https://www.2030wrg.org/wp-content/uploads/2016/12/Understanding-the-Kenyan-Water-Act-2016.pdf

(2019, November). Retrieved from https://www.mikepoweredbydhi.com/products/mike-hydro-basin

Acreman, M., & Dunbar, M. J. (2004). Defining environmental river flow requirements - a review. *Hydrology and Earth System Sciences, 8*(5), 861-876.

Akivaga, E. (2010). *Simulation and Scenario Analysis of Water Resources Management in Perkerra Catchment using WEAP model.* Moi University, Civil and Structural Engineering. Eldoret: Moi University.

Allen, R. C., Pereira, L. S., Raes, D., & Smith, M. (2016, 10). Retrieved from Crop evapotranspiration - Guidelines for computing water requirements - FAO irrigation and drainage paper 56: http://www.fao.org/docrep/x0490e/

CBS. (1994). *Kenya Population Census 1989.* Office of the Vice President and Ministry of Planning and National Development, Nairobi.

CBS. (2002). *National Census Report 1999.* Ministry of Planning and Development, Nairobi.

Central Bureau of Statistics. (1994). *Kenya Population Census 1989.* Office of the Vice President and Ministry of Planning and National Development, airobi.

Chinnasamy, P., Bharati, L., Bhattarai, U., Khadka, A., Dahal, V., & Wahid, S. (2015, October). Impact of planned water resource development on current and future water demand in the Koshi River basin, Nepal. *Water International, 40*(7), 1004-1020.

County Government of Homa Bay. (2013). *First County Integrated Development Plan 2013 - 2017.*

Deltares. (2019, September). Retrieved from https://www.deltares.nl/en/software/ribasim/

Diaz, G. E., Brown, T. C., & Sveinsson, O. (2000). *Aquarius: A Modeling System for River Basin Water Alloction.* General Technical Report, U.S. Department of Agriculture, Forest Service, Fort Collins, CO.

Dinar, A., Rosegrant, M. W., & Meinzen-Dick, R. (1997). *Water Allocation Mechanisms: Principles and Examples.* The World Bank.

FAO. (2005). New LocClim: Local Climate Estimator, Environment and Natural Resources Working Paper No.20.

FAO. (2012). *Coping with water scarcity: An action framework for agriculture and food security.* FAO Water Reports 38, Food and Agriculture Organization of the United Nations, Rome.

FAO. (2014). Retrieved September 19, 2019, from Water Stress Infographic: http://www.fao.org/nr/water/aquastat/infographics/Stress_eng.pdf

FAO. (2016). *AQUASTAT Main Database. Food and Agriculture Organization of the United Nations*. Retrieved August 2019

Forestry, D. o. (2007). *Vaal River System: Large Bulk Water Supply Reconciliation Strategy: Irrigation Water Use and Return Flows.* DWAF report Number: P RSA C000/00/4406/04, Department of Water Affairs and Forestry, South Africa.

GoK. (2007). *Water Resource Management Rules, LN 171.* Government Press. Nairobi: Government Printer.

Government of Kenya. (2018). *The Water Act 2016.*

Homa Bay County Government. (n.d.). *Second County Integrated Development Plan 2018-2022 (Draft).*

Hussein, A. H. (2015). *Modelling Water Resource System for Effective Water Allocation of Juba Basin in Southern Somalia* . Msc. Thesis, Mekelle University Institute of Water and Environment, Mekelle, Ethiopia.

IWMI. (2007). *Water for Food, Water for Life: A Comprehensive Assessment of Water Management In Agriculture.* Earthscan, London, UK, and International Water Management Institute,Colombo, Sri Lanka. London: Earthscan.

JICA. (2013). *The National Water Master Plan 2030.* Ministry of Environment Water and Natural Resources. Nairobi, Kenya: Nippon Koei Co. Ltd.

Johnson, J. (2014). *MODSIM versus RiverWare: A comparative analysis of two surface water modeling tools.* Research, U.S. Department of the Interior, Bureau of Reclamation.

Karamouz, M., Szidarovsky, F., & Zahraie, B. (2003). *Water Resources System Analysis.* CRC Press LLC.

KNBS. (2010). *Kenya Population and Housing Census 2009.*

KOSFIP. (2016, May). Retrieved from http:www.kosfip.co.ke/.

Krause, P., Boyle, D. P., & Base, F. (2005, December). Comparison of different efficiency criteria for hydrological model assessment. *Advances in Geosciences, 5*, 89-97.

Labadie, J. W. (2006). MODSIM: Decision Support System for Integrated River Basin Management. *International Congress on Environmental Modelling and Software*, (p. 242).

Lam, H. A., Kyokunda, G., Fora, L., & Mosseau, L.-P. (2006). *Kimira-Oluch Smallholder Farm Improvement Project Appraisal Report.* AfDB.

Letcher, R. A., Jakeman, A. J., & Croke, B. F. (2004). *A Generalised Conceptual Framework for Intergrated Assessment Modelling of Water Resource Management Issues.*

Levite, H., Sally, H., & Cour, J. (2003). Testing water demand management scenarios in a waterstressed basin in South Africa: application of the WEAP model. *Science Direct Journals, Physics and Chemistry of the Earth*(28), 779–786.

Loucks, D. P. (1995). Developing and Implementing Decision Support Systems: A critique and a challenge. *Water Bulletin, 31*(4), 571-582.

Loucks, D. P., van Beek, E., Stedinger, J. R., Dijkman, J. P., & Villars, M. T. (2005). *Water Resources Systems Planning and Management: An Introduction to Methods, Models and Applications.* UNESCO.

LVEMP. (2005). *Kenya National Water Quality Synthesis Report.* Synthesis Report, Lake Victoria Environment Management Project.

Mogaka, H., Gichere, S., Davis, R., & Hirji, R. (2006). *Climate Variability and Water Resources Degradation in Kenya: Improving Water Resources Development and Management.* Washington, D.C.: The World Bank.

MoH. (2020). Retrieved from Kenya Master Health Facility List: kmhfl.health.go.ke/#/home

MoWI. (2005). *Practice Manual for Water Supply Services in Kenya.* Kenya-Belgium Study and Consultancy Fund, Nairobi.

Mwanuzi, F. L., Abuodha, J. O., Muyodi, F. J., & Hecky, R. E. (2005). *Lake Victoria Environmental Management Report: Water Quality and Ecosystems Statu.* LVEMP.

Neijens, T. (2001). *Analysis of Irrigation Efficiency and Design of Irrigation Strategies for the Perkerra Irrigation Scheme, Kenya.* Msc. Thesis, KU Leuven, Leuven.

Odhiambo, O. (2011). *Status of IWRM implementation and climate change adaptation measures Tende and Kibuon River Basins.* Draft, Nairobi.

QGIS Development Team. (2016). QGIS Geographic Information System. Open Source Geospatial Foundation Project. http://qgis.osgeo.org.

Raburu, P. (2005). *National Lessons Learnt Consultancy on Wetlands Components Activities.* LVEMP.

Refsgaard, C. J. (1997). Parameterization, Calibration and Validation of Distributed Hydrological. *Journal of Hydrology*(198), 69-97.

Rekacewiz, P. (2014, November). Retrieved from www.unep.org: http://www.unep.org/dewa/vitalwater/article83.html

Reshmi, T. V., Christiansen, A. B., Badiger, S., & Barton, D. N. (2008). *Hydrology and Water Allocation in Malaprabha: Comprehensive database and integrated hydro economic model for selected water services in the Malaprabha river basin* . Norwegian Institute for Water Research.

Ringler, C. (2001, May). Optimal water allocation in the Mekong river. *ZEF Discussion Papers on Development Policy, No. 38, University of Bonn, Center for Development Research (ZEF)*, p. 50.

RiverWare. (2015). Retrieved from RiverWare: https://www.riverware.org/riverware/overview.html

Sechi, G. M., & Sulis, A. (2010). Intercomparison of Generic Simulation Models for Water Resource Systems. *International Congress on Environmental Modelling and Software*, (p. 168).

Seckler, D., Molden, D., & Barker R. (1998). *Water Scarcity in the twent-first century.* IWMI Water Brief, International Water Management Institute, Colombo, Sri Lamka.

SEI. (2015). *Water Evaluation And Planning System Tutorial: A collection of stand-alone modules to aid in learning the WEAP software.* SEI.

Sieber, J., & Purkey, D. (2015). *Water Evaluation and Planning System User Guide for WEAP 2015.* Stockholm Environment Institute.

SIWI. (2000). *Water and Development in the Developing Countries.* Stockholm: SIWI.

Speed, R., Yuanyuan, L., Le Quesne, T., Pegram, G., & Zhiwei, Z. (2013). *Basin Water Allocation Planning: Principles, Procedures and Approaches for Basin Allocation Planning.* Paris: UNESCO.

Tesfaye, E. (2014). *Proceedings of the 4th National Conference on Environment and Development.* Dilla.

Thine, C. (2013, November 22). *General Description of Sub-Catchment.* University of Nairobi.

UN-Water. (2008). *Status Report on IWRM and Water Efficiency Plans for CSD16.*

USGS. (2021). Retrieved from https://earthexplorer.usgs.gov

Water Resources Authority. (2017). *Performance Report A report to the public from the Water Resources Management Authority for the period 2015/2016.*

Water Resources Authority. (2021). Retrieved from https://wra.go.ke/

Weragala, D. N. (2010). *Water Allocation Challenges in Rural River Basins: A Case Study from the Walawe River Basin, Sri Lanka.* Utah State University, Civil and Environmental Engineering. Utah State University.

WRA. (2017). *Water Resources Impact Report. A Report to the Public from the Water Resources Authority, Kenya 2016/2017.* WRA.

WRMA. (2010). *Water Allocation Plan-Naivasha Basin 2010-2012.* WRMA.

WRMA. (2012). *Awach Tende Water Abstraction Survey.* WRMA, Nairobi.

www.afdb.org. (2016). Retrieved March 5, 2014, from www.afdb.org: www.afdb.org/projects-and-operations/project-portfolio/p-ke-aaz-001/

www.weap21.org. (2021). Retrieved from WEAP21: http://www.weap21.org

www.worldbank.org. (2003, November 4). Retrieved December 14, 2013, from www.worldbank.org: siteresources.worldbank.org/KENYAEXTN/Resources/water.pdf

Yates, D., Purkey, D., Sieber, J., Huber-Lee, A., & Galbraith, H. (2005). WEAP21, A Demand, Priority and Preference Driven Water Planning Model. *Water International, 30*(4), 501-512.

APPENDICES

APPENDIX A: Awach Tende hydrology

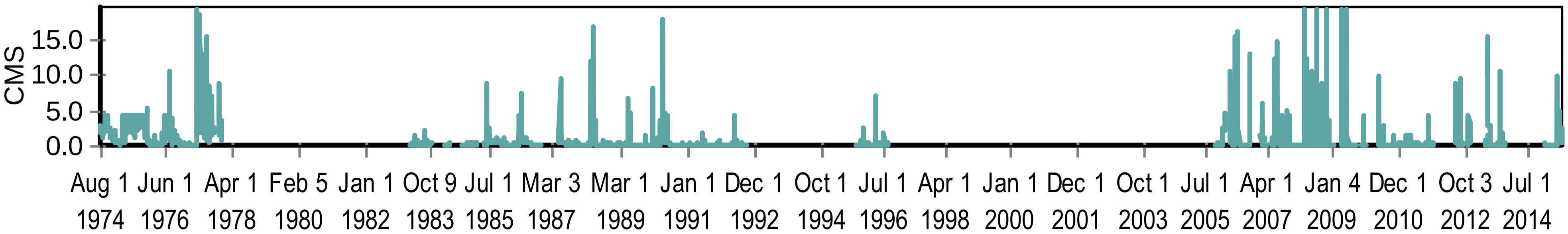

Figure A-1: Daily stream flow record at 1HE01 (Source: WRMA)

Table A-1 Description of Environmental Management Classes (Yates, Purkey, Sieber, Huber-Lee, & Galbraith, 2005)

Environmental Management Class	Percentile Places to Shift	Description
No Change	0	Pristine condition.
A: Natural Flow	1	Minor modification of instream and riparian habitat.
B: Slightly Modified	2	Largely intact biodiversity and habitats despite water resources development and/or basin modifications.
C: Moderately Modified	3	The habitats and dynamics of the biota have been disturbed, but basic ecosystem functions are still intact. Some sensitive species are lost or reduced in extent. Alien species present.
D: Largely Modified	4	Large changes in natural habitat, biota and basic ecosystem functions have occurred. A clearly lower than expected species richness. Much lowered presence of intolerant species. Alien species prevail.
E: Seriously Modified	5	Habitat diversity and availability have declined. A strikingly lower than expected species richness. Only tolerant species remain. Indigenous species can no longer breed. Alien species have invaded the ecosystem.
F: Critically Modified	6	Modifications have reached a critical level and ecosystem has been completely modified with almost total loss of natural habitat and biota. In the worst case, the basic ecosystem functions have been destroyed and the changes are irreversible.

Table A-2 River Awach Tende FDC results for the different EMCs

%	No change	Environmental Management Class					
		A	B	C	D	E	F
0.01%	8.22	8.13	7.23	3.82	1.21	0.84	0.52
0.1%	8.13	7.23	3.82	1.21	0.84	0.52	0.31
1%	7.23	3.82	1.21	0.84	0.52	0.31	0.16
5%	3.82	1.21	0.84	0.52	0.31	0.16	0.10
10%	1.21	0.84	0.52	0.31	0.16	0.10	0.07
20%	0.84	0.52	0.31	0.16	0.10	0.07	0.06
30%	0.52	0.31	0.16	0.10	0.07	0.06	0.05
40%	0.31	0.16	0.10	0.07	0.06	0.05	0.04
50%	0.16	0.10	0.07	0.06	0.05	0.04	0.03
60%	0.10	0.07	0.06	0.05	0.04	0.03	0.03
70%	0.07	0.06	0.05	0.04	0.03	0.03	0.03
80%	0.06	0.05	0.041	0.029	0.027	0.027	0.027
90%	0.05	0.041	0.029	0.027	0.027	0.027	0.026
95%	0.04	0.029	0.027	0.027	0.027	0.026	0.026
99%	0.03	0.027	0.027	0.027	0.026	0.026	0.026
100%	0.03	0.027	0.027	0.026	0.026	0.026	0.026

APPENDIX B: Land use and climatic data

Table B-1 Monthly variation of crop coefficient and effective precipitation

Month	**Kc (Maize)**	**Effective precipitation (%)**
January	0.20	90
February	0.35	90
March	0.68	90
April	0.68	80
May	1.20	75
June	1.20	79
July	1.02	70
August	0.88	80
September	0.75	85
October	0.60	90
November	0.40	95
December	0.35	95

Table B-2 Monthly average precipitation and ET_o values

Month	**Precipitation (mm)**	**ETo (mm)**
January	58	114.90
February	93	111.90
March	144	119.50
April	232	100.50
May	205	100.80
June	126	96.60
July	92	100.90
August	145	105.50
September	136	108.20
October	146	115.10
November	147	99.70
December	111	102.80

APPENDIX C: List of health facilities in Awach Tende sub-catchment

Table C-1 Health facilities by administrative ward in Awach Tende sub-catchment

Sub county	Ward	Health facility	Beds
Karachuonyo	Kanyaluo	Bernard Vision Medical Centre	4
		Wikondiek Dispensary	0
		Olando dispensary	0
		Adiedo Dispensary	4
		Omboga Dispensary	0
	Kibiri	Oneno Nam	0
		Homa Lime Health Centre	8
		Raruowa Health Centre	28
		Kandiege Sub-District Hospital	36
Kasipul	South Kasipul	Yala Dispensary	0
		Kokech Mirondo Health Centre	0
	West Kasipul	Ong'amo Dispensary	0
		Ragwe Dispensary	0
		Nyabola Dispensary	0
		Nyagowa Elck Dispensary	0
		Ombek Dispensary	0
		Nyangiela Sub District	0
		Mangima SDA Health Centre	10
Rangwe	Kagan	Shelter of Hope Medical Clinic	1
		Obunga Dispensary	0
		Manyatta (SDA) Dispensary	0
		Obwanda Dispensary	1
		Gongo Dispensary	0

APPENDIX D: WEAP model results

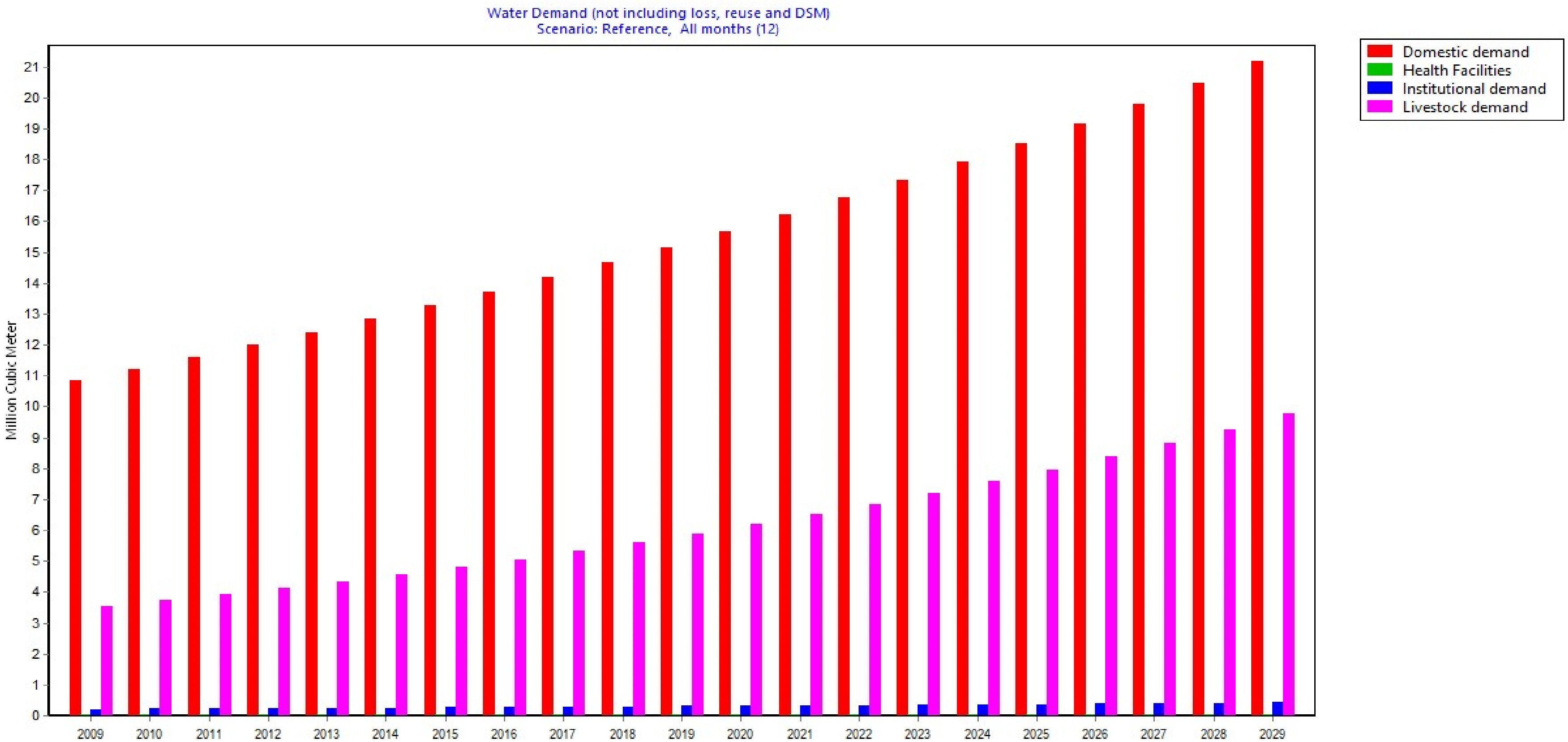

Figure D-1: Water demand in the business-as-usual scenario

Table D-1 : Comparison of water demand in the BAU scenario and operational irrigation scheme scenario

Year	Business as usual (BAU) (Mm^3/yr)	Operational irrigation scheme (100% capacity) (Mm^3/yr)	% Increase in demand from BAU	Unmet demand
2009	14.6	14.6	0%	0
2010	15.2	15.2	0%	0
2011	15.8	15.8	0%	0
2012	16.4	16.4	0%	0
2013	17	23.7	39%	0
2014	17.7	24.3	37%	0
2015	18.4	25.0	36%	0
2016	19.1	25.7	35%	0
2017	19.8	26.4	34%	0
2018	20.6	27.2	32%	0
2019	21.4	28.0	31%	0
2020	22.2	28.8	30%	0
2021	23.1	29.7	29%	0
2022	24	30.6	28%	0
2023	24.9	31.5	27%	0
2024	25.9	32.5	26%	0
2025	26.9	33.5	25%	0
2026	28	34.6	24%	0
2027	29.1	35.7	23%	0
2028	30.2	36.8	22%	0
2029	31.4	38.0	21%	0