MAKERERE UNIVERSITY

COLLEGE OF ENGINEERING, DESIGN, ART AND TECHNOLOGY

SCHOOL OF ENGINEERING

ASSESSING THE IMPACT OF LAND USE/LAND COVER AND CLIMATE CHANGE ON ENVIRONMENTAL FLOW REQUIREMENT IN RIVER SYSTEMS WITH MULTIPLE USES

BY

WAKIIBI CEASER KISA

BSc. Civil Eng. (MaK)

REG. No.: 2021/HD08/0201U

Signature: ....

Date: 10/December/2025

Supervisors

Dr. Philip M. Nyenje	Dr. Ronald S. Musenze	Prof. Alfred Owuor Opere
Signature:	Signature:	Signature: ....
Date: 12/12/2025	Date: 12/12/25	Date: 03/11/2025

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DECLARATION

This dissertation is original and has not been submitted for any other degree award to any other University before.

……………………………………………..

WAKIIBI CEASER KISA

REG. No.: 2021/HD08/0201U

APPROVAL

This research has been submitted for examination with the approval of the following supervisors.

Dr. Philip M. Nyenje **Date: 10 December 2025**

College of Engineering, Design, Art, and Technology

Makerere University

Kampala – UGANDA

Dr. Ronald S. Musenze **Date: 10 December 2025**

College of Engineering, Design, Art, and Technology

Makerere University

Kampala – UGANDA

Prof. Alfred Owuor Opere **Date: 10 December 2025**

Host Supervisor (Student exchange Programme)

University of Nairobi

DEDICATION

I dedicate this research to my dear wife Gloria Agnes Wakiibi and my children Harriet Ruby and Patience Wakiibi for their extensive support and encouragement throughout this journey.

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ABSTRACT

Water resources systems like the R. Namatala, shaped by the hydrological cycle, involve complex processes impacted by both human activities and climate change. The pressures of commercialization, industrialization, and increasing water demands exert immense stress on water resources with 65% of the world's rivers now at risk. Diminished river flows, driven by more water withdrawals, land use changes, and climate change, are compromising environmental flow requirements and threatening ecosystem health. Challenges such as inadequate water management practices and limited data on river systems hinder the maintenance of ecological flows, leading to unsustainable water resources exploitation. Consequently, reliance on flow estimates that overlook essential ecological factors worsens the threat to freshwater ecosystems.

The purpose of this study was to assess the impact of land use change and climate change on environmental flow (e-flow) requirements. Specifically, the study; i) determined the current environmental flow requirements, ii) examined land use change trends and, iii) determined the impact of land use / land cover and climate change trends on the environmental flow requirements of R. Namatala.

Three approaches were that included; (1) Hydrological method, (2) Hydraulic method and (3) Holistic approach were selected to estimate the current E-flow requirements. Land use trends between 1995 to 2023 were determined using image classification tools in google earth engine and trends for 2023 to 2040 were projected using Terrset Land Change Modeler. Hydrologiska Byråns Vattenbalansavdelning (HBV) model was used to determine impact of Land use/land cover and climate change on environmental flow under RCP 2.6 and RCP 8.5.

River Namatala had a mean annual flow of 2.65 ± 0.08 m^3/s obtained over a period of 73 years. The river normally experiences low flows in the months of December to March and high flows in the months of April to June. Average annual Low flows of 0.65 ± 0.45 m^3/hr and max average annual flows of 18.41 ± 8.79 m^3/hr. The current E-flow requirement for R. Namatala was determined based on the flows over a period of 73 years, consideration of the different water demands. The estimated current e-flow requirement at the outlet of R. Namatala catchment was 1.072 , 1.036 and 1.103 m^3/s as determined from the hydrological, hydraulic and holistic methods, respectively. The results from the historical land use/ land cover trends estimated over a period of 26 years (1995 – 2020) indicated an incremental dominance by cropland (0.471% yr^{-1}),

followed by grassland (0.158% yr^{-1}) at the expense of forestland (-0.466% yr^{-1}) and wetlands (-0.176% yr^{-1}). The projected LULC trends estimated over a period of 17 years (2023 – 2040) indicated that forestland would have the predominant increment (0.263% yr^{-1}) followed by cropland (0.071% yr^{-1}) while grasslands would decrease (-0.343% yr^{-1}). Utilizing projected land use data and climate change most likely scenario - RCP 2.6, the projected e-flow requirement was estimated to be 0.880, 1.082 and 1.1591 m^3/s for the hydrological, hydraulic and holistic methods, respectively. On the other hand, for the most unlikely scenario - RCP 8.5, e-flows were estimated as 0.910, 1.076 and 1.153 m^3/s for the hydrological, hydraulic and holistic methods, respectively.

The study concluded that land use together with climate change will have an incremental impact to the future e-flow requirement for R. Namatala of between 4.53% and 5.08% as predicted by the most unlikely and most likely scenarios, respectively. Further to this, the ecosystem is foreseen to have water quantity challenges due to abstractions with months of December to February cited as critical months with reduced flows. Government interventions, including wetland gazettement and forest protection, contributed to increased forest cover but there was a reduction in cropland, a factor that could in itself contribute to food scarcity in the area. Climate projections under RCP 2.6 and RCP 8.5 indicated increased precipitation and seasonal flow shifts, with minimal variation in environmental flow requirements.

The study assumed socio-economic dependence of the communities on the river based on the communities' proximity and accessibility to the river. The e-flow determination also depended on measured flows and no groundwater component. It is thus recommended that further socio-economic and groundwater assessments, improved water management, enhanced policy enforcement, and continued climate-focused research are done to ensure sustainable catchment management.

With there being no universally accepted e-flow determination method, this study notes a minimum e-flow requirement of 0.880 m^3/hr as determined using the hydrologic method but recommends a value of 1.153 m^3/hr as determined using the holistic approach for sustainable exploitation of the water resource since the holistic approach considers a number of ecosystem functions that are not considered by the other methods.

Key Words: *Environmental Flow, Land use, Land Cover, LULC, Terrset, Climate Change, Building Block Method.*

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LIST OF ACROYNMS

AWS	Automatic Weather Station
CMIP	Coupled Model Intercomparison Project
CFR	Central Forest Reserves
E-flows	Environmental Flows
FAO	Food and Agriculture Organization
GCM	General Circulation Models
GEE	Google Earth Engine
GHG	Greenhouse Gases
HBV	Hydrologiska Byråns Vattenbalansavdelning model
IPCC	Intergovernmental Panel on Climate Change
KWMZ	Kyoga water management zone
LCM	Land Change Modeler
LULC	land use/land cover
MAF	Mean annual flow
Mt	Mountain
MMF	Mean Monthly flow
MWE	Ministry of Water and Environment
N/A	Not Applicable
NDP	National Development Plan
NWSC	National Water and Sewerage Corporation
OSM	OpenStreetMap
RCP	Representative Concentration Pathways
REDD	Reducing Emissions from Deforestation and Forest Degradation
RMSE	Root Mean Square Error
SPI	Standardized Precipitation Index
SSP	Shared Socioeconomic Pathways
UBOS	Uganda Bureau of Statistics
UTM	Universal Transverse Mercator
WSSP	Water Supply and Sanitation Project

CHAPTER ONE: INTRODUCTION

1.1 Background of the study

Water holds a special place among all renewable resources (Nsubuga et al., 2014). Water resource systems, which are regulated by the hydrological cycle, are made up of complex processes that are envisaged to be influenced by human activity and climatic change (Bahati et al., 2021). Maintaining health, growing food, producing energy, managing the environment, and creating jobs are all critical to the sustainable development of the global economy (World Bank, 2021). One of the most pressing issues of the twenty-first century is how to manage water and other natural resources in the climate change era so that human needs can be met while minimizing environmental damage (Pastor et al., 2014). As the world tends towards commercialization and industrial development, the water resources are facing an immense threat with 65% of the world's rivers now considered to be under moderate-to-high threat due to high withdrawals.

Due to increased water withdrawals, major rivers such as the Yellow River basin have seen their flow reduced by nearly 75% over the last 30 years. The most visible causes of biodiversity risk are stressors associated with high demand, reduced flow and water quality, which directly degrade aquatic ecosystems. As water withdrawals intensify to meet growing demand, maintaining a dependable flow within the water resource system becomes critical for supporting ecosystem functioning. Understanding the dynamics between volume, timing and quality with aim of meeting livelihoods whilst preserving ecosystem functioning defines environmental flow Kaushal et al., (2012). Such dynamics have been over looked by a number of water resource managers who maximize withdraw of water to meet ever-changing industrialization (Arthington et al., 2006). On top of that, the ecosystem which is the first dependent of the water resource is greatly impacted by climate change and land use scenarios.

Among these discussions, climate change, land use/land cover alteration, which are among the contenders of environmental alteration due to their connection. Studies like Aich et al., (2014), Bahati et al., (2021), Kusangaya Samueland Mazvimavi, (2021), Onyutha, Turyahabwe, et al., (2021), Onyutha, Nyesigire, et al., (2021), and Turyasingura et al., (2022) analysed flow variability due to climate change. The studies further noted that various parts of the world revealed having different degrees greatly impacted river flows. A futuristic change in temperature and precipitation in the future is envisaged to cause long-term changes in flows over a temporal and variable scale (Onyutha, Nyesigire, et al., 2021b). Such alterations in climate have the potential to worsen Africa's already fragile ecological and human systems. Comprehending the potential effects of global climate change on the continent, especially those with limited ability to adapt, is crucial for creating well-informed plans and decisions to address environmental issues in the upcoming years.

In Uganda, the situation is more or less dramatic as compared to the global scale. Rivers are experiencing low to dry flows due to high demand requirements, LULC and Climate change (Kayamba & Kwesiga, 2019; Nseka et al., 2022). Rivers like R. Namatala, R. Mpanga, Rwizi, Enyau and L.Wamala etc. have been cited as water resources facing immerse threat due to uncontrolled abstractions, rapid LULC change and climate change(Nseka et al., 2022). Given the sensitivity of these water systems, the ecosystem functioning especially downstream of the catchment has greatly deteriorated due to the fact that there is little water management strategies in line with the threat at hand (Onyutha, Nyesigire, et al., 2021b). To top it all, river systems like R. Namatala are blessed with growing developments like Mbale City, Budaka, Butaleja which are constantly changing in Land use and water needs. These needs comes with high water needs yet little or no strategy to ensure that these water resources can meet the future requirements without impacting the ecosystem that are the primary users. With lack of strategy and little knowledge in line with ecosystem needs, the impact of this everchanging land use in this climate change era on flows specifically ecosystem needs is yet to be quantified O'Brien et al., (2021). This has prompted practioners to adopt values ranging between 10-30% of the Q_{90-95} flow of the river citing dependability due to data scarcity. A combination of some of these factors is cited to be responsible for the lack of flows in the rivers which in turn affect the ecosystem downstream.

1.2 Statement of the Problem

Globally, countries grapple with significant water supply and quality challenges, with one of the major contributors being Climate and Land Use/Land Cover change (Dwarakish & Ganasri, 2015). Rapid urbanization together with growing population in many cities have led to significant shifts in land use, especially areas surrounding water system (Wu et al., 2016). This is driven by the need to utilize water for domestic use or satisfy the rapid commercialization creating an overwhelming demand on these systems. This reliance to meet the growing demand has created a high demand for water resources, leading to creation of conflicting use priorities between upstream and downstream water users. The alteration of land use patterns as well as rivaling water use priorities have had profound effect on the natural flow of rivers jeopardizing the ecosystems' functioning, health and sustainability.

Besides the conflicting priorities, there is little or no sustainable integrated water management approaches and practices incorporated to ensure preservation of environmental flow requirement (Overton et al., 2014, O'Brien et al., 2021). In Uganda, current water resources management approaches and practices that prioritize satisfaction of water demand requirements lack sufficient integration of sustainable measures, leading to a concerning neglect of environmental flow requirements. On top of poorly implemented water management approaches and practices, poorly captured data on river systems, lack of transparency and accessibility of crucial information and dependence on quality Information needed for effective e-flows management have been cited as major challenges in implementing E-flow (Katusiime & Schütt, 2020; UN, 2024). This has encouraged practioners and water resource planners to utilize an estimate of the dependable flow to act as environmental flow. Such estimates don't account for a number of variables that depend on the river system such as ecosystem functioning among others. The consequences of utilizing undocumented estimates are noticeable in degrading habitats, loss of biodiversity, diminished ecosystem services such as nutrient retention, flood moderation and base-flow maintenance and increased vulnerability to droughts and floods.

Focusing on the River Namatala catchment in Eastern Uganda, the situation exemplifies these dynamics(MWE, 2018b). Land use/cover change and pollution loading have been documented in the catchment with cropland expansion increasing runoff, sediment and nutrient loads in the river and associated wetland. The conversion of wetlands and riparian vegetation into agriculture and built-up areas has reduced the natural buffering capacity. At the same time, water abstraction and urban expansion around Mbale town place increasing demands on the river and wetland system. This is further justified by a study by MWE, (2018a) that reported that the mean in the dry season, river Namatala barely has any flow left after abstraction. Further to this, an estimated figure of 0.19 m^3/s was estimated as environmental flow. This leaves little margin for ecological resilience, particularly during dry seasons when aquatic life and wetland processes are dependent on sustained flows while captivating on meeting demand.

The ecosystem functioning in the Namatala catchment has been largely compromised due to this high-water demand/low-flow scenario. Key ecological processes such as base flow provision during dry periods, sediment and nutrient retention by wetlands, habitat connectivity, spawning and migration of aquatic species are impaired. For example, the Namatala Wetland has lost much of its original papyrus vegetation, reducing its capacity to retain nutrients and sediment and sustain downstream water quality and habitats. The prioritization of water supply over aquatic ecosystem needs means that during critical low-flow periods, habitat drying, increased temperatures, reduced dissolved oxygen and loss of refuge for aquatic organisms can occur. Moreover, altered flow regimes (higher peak flows, lower base flows) affect the connectivity and stability of aquatic systems, reducing biodiversity and resilience

1.3 Study Objective

The overall objective of this study was to assess the impact of Land Use / Land Cover and climate change on environmental flow requirement in river systems with multiple uses. The case study is River Namatala catchment in Mbale - Sironko District.

1.3.1 Specific Objective

Specifically, the study was aimed at

i. Determining the current environmental flow requirements for R. Namatala.

ii. Examining land use change trends in the R. Namatala Catchment.

iii. Determining the impact of land use / land cover and climate change trends on the Environmental Flow requirements of R. Namatala

1.4 Research Questions

1. What is the current E-flow requirements for R. Namatala based on three methods of Hydrological, hydraulic and holistic approach?
2. How does climate change interact with land use changes to affect river flow requirements?
3. What is the relative contribution of climate change and land use change on the future environmental flow in Namatala river catchment?
4. What are the potential future scenarios for environmental flow requirements under different climate change scenarios?

1.5 Justification of the Study

The study was essential for understanding how land use and climate change affect environmental flow requirements in river systems that serve multiple purposes. River systems like R. Namatala which are vital for ecological health, providing habitat for diverse species, and supporting human activities like agriculture and industry were analyzed. This helped on creating a limit to which water can be abstracted from R. Namatala. The study also assessed land use changes, such as urbanization and deforestation, and climate change, with their respective alterations in precipitation and temperature, to determine disruptions in river flow patterns and impact on ecosystems.

This research ascertained the combined effects of Land use/land cover and climate change on Environmental flow requirements, enabling more effective management strategies that balance ecological needs with human demands. By addressing current gaps in knowledge and policy, the study is able to inform adaptive management practices and support sustainable water resource management, ultimately contributing to the preservation of both ecological and socio-economic values of river systems.

The study helped add to the knowledge bank and assisting other scholars.

1.6 Scope of the study

The purpose of this research was to determine the impact of land use change upstream and climate change on the environmental flow requirements downstream on R, Namatala. The study specifically assessed land use change over a 20-year period, determined the impact of land use change on R. Namatala Environmental flow requirement, and then predicted land use and its effect on Environmental flow requirement downstream from 2022 to 2040.

R. Namatala catchment was classified into three; Upstream, Mid-stream and Downstream. Upstream of the catchment comprised of Sironko, Mbale and Bududa areas originating from slopes of Mt Elgon, Mid-stream comprised of Mbale city and district while downstream comprised of Budaka and Butaleja (Figure 1.1).

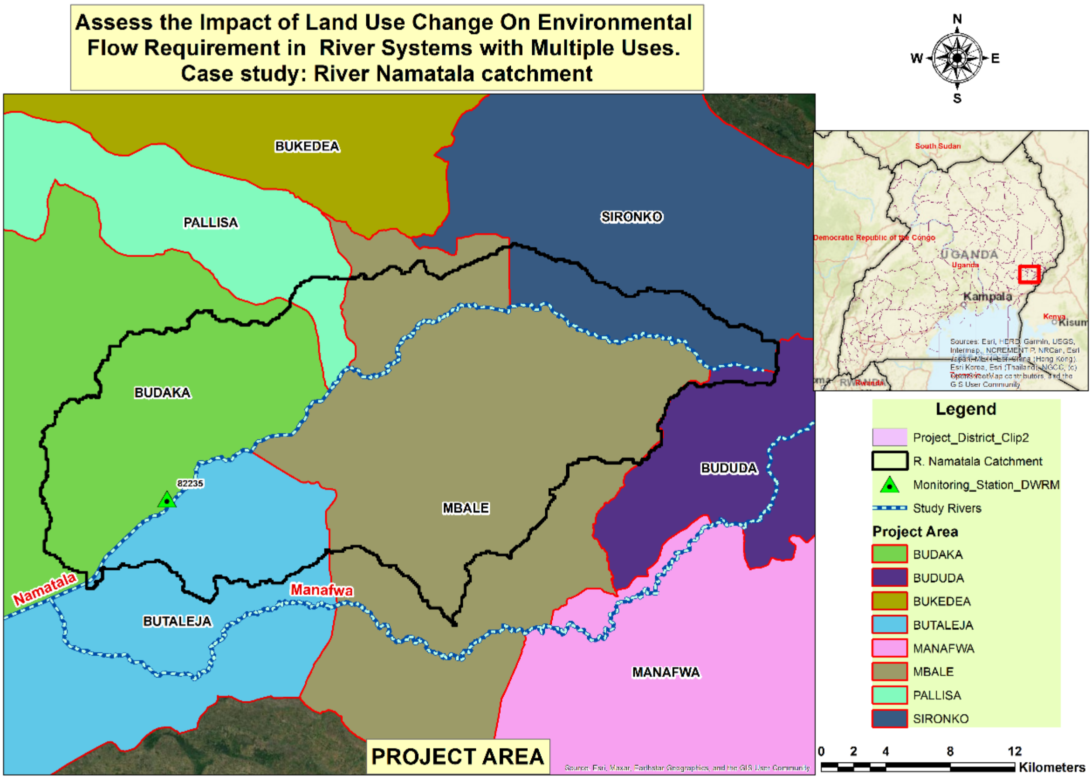


Figure 1.1: Administrative boundaries of R. Namatala Catchment

1.7 Conceptual framework

The study adopted a conceptual framework that illustrated the relationship between land use dynamics, climate change variability, hydrological processes and environmental flow requirements (Figure 1.2). The conceptual framework focuses on four main components; Independent variables, process, intervening variables and dependent variables which reflect the output. The independent variables comprised of land use and land cover change scenarios over a period of 1984 – 2020 (36 years) with projections extending to 2040. The projections covered the climate change scenarios. Independent variables represented primary drivers influencing hydrological responses within the catchment.

The core process within the framework was the rainfall-runoff simulations using the Hydrologiska Byrans Vattenbalansavdelning (HBV) model. The Model integrated the effects of LULC change and climate variability through intervening variables like soil moisture and routing routine, to simulate catchment behavior.

The output of the process was simulated flow river flows, which was categorized as the dependent variable. The Environmental flow requirements would then be determined from the simulated rover flows.

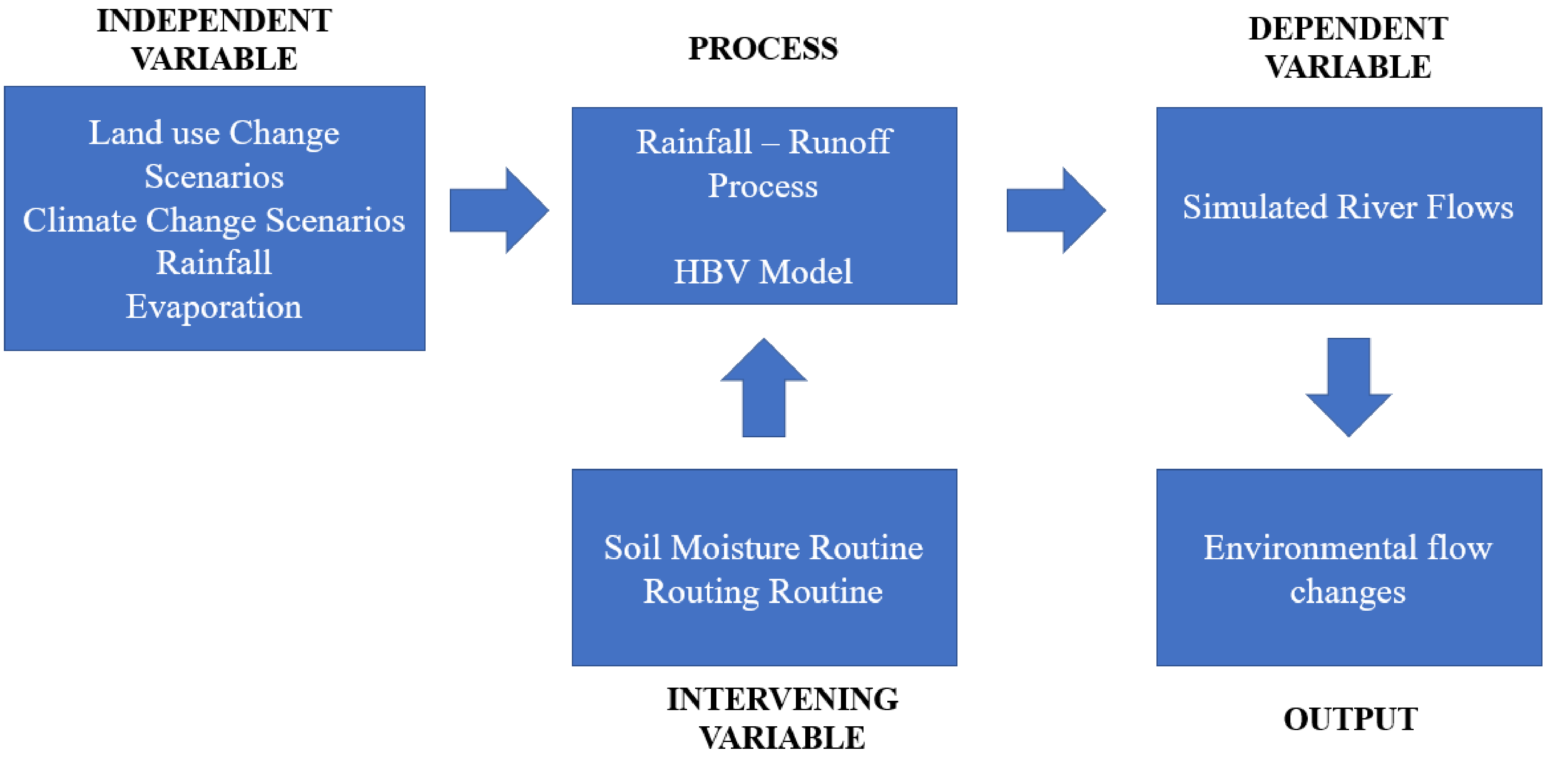


Figure 1.2: Conceptual Framework

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

The interaction between land use change, climate change, and environmental flow requirements is a critical area of study for managing river systems with multiple uses. This literature review explores existing research on how land use modifications—such as urban expansion, deforestation, and agricultural intensification—alter hydrological patterns and water quality, impacting river ecosystems. It also examines the effects of climate change, including shifting precipitation patterns, rising temperatures, and extreme weather events, on river flow regimes. The review will integrate findings on the ecological and socio-economic consequences of these changes, highlighting the challenges and trade-offs involved in balancing environmental needs with human demands. By synthesizing current knowledge and identifying research gaps, this review aims to provide a comprehensive foundation for understanding the complex dynamics influencing environmental flow requirements and informing effective management strategies for sustainable river system stewardship.

2.2 Land use and Land Cover

According to the FAO, land is an area of the Earth's surface (Briassoulis, 2020). (Paul & Rashid, 2017) on the other hand defined land use as how people use land. It is a representation of the social, economic, and cultural activities that happen in a certain locality. Public and private properties are frequently put to quite different uses. Urban growth is unusual on publicly held grounds, whereas privately owned lands are rarely protected for wilderness purposes (Bunyangha et al., 2021). Around 13% of Earth's surface was classified as arable land in the early 1990s, compared to 26% for pasture, 32 % for forests and woodlands, and 1.5% for urban areas (Bunyangha et al., 2021).

Briassoulis, (2020) defines Land cover as the biophysical state of the earth’s surface and immediate subsurface (Paul & Rashid, 2017). There exists a number of land use classifications categorized into 6 classes and these includes; forest land, cropland, built up, grassland, water and wetland systems.

Forestland is an ecosystem dominated by trees (defined as perennial woody plants taller than 5 m at maturity), with a tree crown cover (or equivalent stocking level) greater than 10% and an area greater than 0.5 hectares (Lwasa et al., 2015). Tree plantations are regions where exotic tree species have been methodically planted and managed (including hybrids). This category comprises both young and mature plantations created for commercial timber production, seedling experiments, and large enough woodlots/windbreaks to be visible on satellite photography. Non-timber plantations such as tea, sisal, and orchards are not permitted. Forest areas with partial or permanent livestock activity were classed as forest with livestock activities, while those with farming activities were classified as forest with subsistence activities. Protected Forests included those located in national parks, forest reserves, bird sanctuaries, botanical gardens, and other conservation zones that could be identified on a map (Lwasa et al., 2015).

Cropland is defined as land suited for growing crops. Cropland has a number of classifications of agricultural land, commercial cropland and subsistence farmland. Agricultural lands are arable and regularly tilled for the production of crops, with or without irrigation. Commercial agricultural lands are characterized by large, uniform, well-managed field units, often mechanized, and more than 10 ha in size, with the aim of supplying both regional and national and export markets. Some use supplementary irrigation and others are rain-fed. Subsistence farmlands are generally smaller in size, i.e., less than 10 ha in size (about 2 ha on average). Subsistence farmlands are generally rain-fed (Nakalembe et al., 2017).

Built-up land classification essentially includes all formal built-up areas where people live on a permanent or near-permanent basis, which are distinguished by a high density of residential and associated infrastructure. Cities, towns, municipalities, and rural clusters are all included (Osaliya et al., 2020).

Grasslands are defined as areas where herbaceous plants predominate and woody plants and shrubs cover less than 10% of the area. There are five grassland land use systems, three of which involve livestock (grassland with high livestock density, grassland with medium livestock density, and grassland with low livestock density). Other land use systems include protected grassland and unprotected grassland (Muwanga et al., 2020).

Water resource systems are made up of man-made or natural open water that is either static or flowing, salty, brackish, or fresh. This land use system includes lakes, lagoons, ponds, and large reservoirs (big dams) (Tsai et al., 2018).

Wetlands are large areas of land with a permanent mosaic of water and herbaceous or woody vegetation. The vegetation can be found in salt, brackish, or fresh water with a depth of no more than six meters. Wetlands have three land use systems: wetlands with livestock activities, wetlands with crop farmland activities, and protected wetlands (Kayendeke, 2018).

2.2.1 Land Use Change Analysis

While land-use change refers to a change in how a particular area of land is utilized or managed by humans, land-cover change refers to a change in some continuous characteristics of the land, such as vegetation type, soil conditions, and so forth (KilamaLuwa et al., 2021). The biggest drivers for Land use change is population growth and pressure (Toma et al., 2022).

Uganda's population is projected to reach 80 million people by 2040, up from 6.8 million in 1960 and 34.6 million in 2014 (UBOS, 2014). More people meant a greater need for food, housing, employment opportunities, and other environmental resources. Increased agriculture and built-up regions have reportedly been observed at the expense of forest, wetland, woodland, etc., according to Frank Mugagga et al. (2015).

Increased unemployment was concurrent with population growth. The rate of unemployment climbed from 1% in 1991 to 3.6 % in 2003, then declined to 1.9 % in 2005 before rising to 3.6 % in 2009 even though the current statistic is 1.7 % (KilamaLuwa et al., 2021). When the resources get over constrained, especially in urban areas, people are forced to settle in or cultivate wetlands. Wetland decline has been reported in western, central, and eastern Uganda.

2.2.2 Land Use Datasets

Land use data sets provide valuable information about how land is used for various purposes, such as agriculture, urban development, forestry, conservation, and more. These data sets are essential for land planning, environmental monitoring, and policy decision-making. Here are some common types of land use data sets and sources where you can find them (Kayendeke, 2018):

1. **MODIS Land Cover Dataset:** Global land cover information was provided by NASA's MODIS satellite, which has a modest resolution of 500m (MODIS, 2023). The MCD12Q1 V6.1 dataset offers global land cover types based on six different classification techniques at yearly intervals (2001-2016). supervised classifications of MODIS Terra and Aqua reflectance data are used to derive it.
2. **FAO Land Use Dataset**: The United Nations Food and Agriculture Organization (FAO) offers land use and land cover data, primarily for agriculture and forestry. FAO Land use dataset has a spatial resolution of 30 arc-seconds (FAO, 2023).
3. **USGS / NASA Landsat Dataset (Landsat):** This is a cooperative USGS and NASA initiative that has been continuously observing the Earth since 1972 and continues to do so now. Landsat satellites now photograph the entire Earth's surface at 30-meter resolution every two weeks, collecting multispectral and thermal data (NASA, 2023). There are 10 satellites that have been deployed by NASA to provide Landsat images and these vary from Landsat 1-9 to Landsat Next. All of the images are in the public domain and may be used with attribution.
4. **OpenStreetMap (OSM):** OSM is a crowd-sourced mapping application with valuable land use data for numerous places across the world. OSM data is frequently utilized in academic research, urban planning, and geographic analysis.

2.2.3 Land use Models

Land use models are tools and strategies used in urban and regional planning to simulate and anticipate how land will be used in the future in a certain area. These models are critical for making sound judgments on zoning, infrastructure development, transit planning, and environmental protection. Policymakers, urban planners, and developers can utilize land use modeling to evaluate the possible implications of various land use scenarios and make informed decisions to support sustainable development (Wegener, 1995).

Land use models come in a variety of flavors, each with its own purpose and level of complexity. Some examples of common land use models are:

1. **Cellular Automata Models**: These models divide a study region into grid cells and simulate land use changes through time using rules that govern the transition from one land use type to another. Cellular automata models are frequently used to anticipate urban expansion and land use change.

2. **Agent-Based Models**: Agent-based models imitate individual agent activity (for example, households and companies) and how they interact to generate land use patterns. These models are capable of capturing complicated social and economic interactions (Matthews et al., 2007).

3. **Markov Chain Models**: The chance of a location shifting from one land use category to another is the basis for Markov models. They are excellent for simulating progressive changes in land usage over time (Briassoulis, 2020).

4. **Spatial Econometric Models**: These models use economic and spatial data to examine the connections between land use, transportation, and other variables. They can aid in identifying the causes of land use change.

5. **GIS-Based Models**: Geographic Information Systems (GIS) are frequently used to build spatial datasets and conduct spatial analysis. Land use modeling can be accomplished using a variety of GIS tools and software (Briassoulis, 2020).

6. **Urban Simulation Models**: These elaborate models seek to represent urban dynamics such as land use change, transportation, population increase, and economic development. They can offer a comprehensive view of urban development.

2.2.4 Land Use Modelling software

Google Earth Engine (GEE) is a cloud-based computing platform that makes use of Google's infrastructure to facilitate access to and processing of geospatial data (Velastegui-Montoya et al., 2023a). Access to this platform requires an account, but it is free for educational and research purposes via https://code.earthengine.

Different sensors provide us with images of varying resolutions that are aimed at detecting specific land types. There are differences in their spatial and temporal characteristics, in addition to differences in their collection methods. This not only generates a wide range of data but also necessitates the efficient handling of large volumes of data, particularly for global scale analysis (Zhao et al., 2021).

One of the primary benefits of GEE is its ease of use and consolidated library of global remotely sensed data. Currently, users from a wide range of disciplines are involved in GEE-implemented projects. Another significant advantage of working with GEE is its cloud computing power. Data processing works well because the user's personal computer memory is never a limiting factor, especially when working with global-scale data and imagery. The availability of an API, on the other hand, represents a trade-off between a user's ease of use and the flexibility to implement complex functions within said API (Sidhu et al., 2018).

The study utilized Terrset Land change modeler to assess land use change. Land Change Modeler is a cutting-edge land planning and decision-making system that is fully integrated into the Terrset program (ClarkLabs, 2023). Land Change Modeler reduces the intricacies of change analysis with an automated, user-friendly approach. You can use Land Change Modeler to quickly assess land cover change, empirically model correlations to explanatory variables, and simulate future land change scenarios. Special tools for assessing REDD climate change mitigation measures are also included in Land Change Modeler. Land Change Modeler is a one-stop shop for all of your land change analysis needs.

2.2.5 Land-Use Contributions to Climate Change

Changes in land use and land cover are important drivers of global environmental change. However, in terrestrial biosphere models, the processes and drivers of anthropogenic land-use activity are still unduly simplified (Prestele et al., 2017). The published results of these models are utilized in significant assessments of global environmental change processes and implications, such as the IPCC.

There are currently no fully coupled models of climate, land use, and biogeochemical cycles available to investigate land use-climate interactions across spatial scales.

Instead, land-use information is delivered to TBMs as exogenous data from the land-use change modules of integrated assessment models (IAMs) (Gabiri et al., 2020).

2.3 Hydrological Modelling

A model is a simplified version of a real-world system. The best model is one that produces results that are close to reality while utilizing the fewest parameters and model complexity. Models are primarily used to predict system behavior and to comprehend various hydrological processes. Hydrological models are now regarded as an important and necessary tool for managing water and environmental resources (Lin et al., 2014).

Sten Bergström created the Hydrologiska Byråns Vattenbalansavdelning (HBV) model as a conceptual runoff simulation model with a simple framework (Fredrik Wetterhall, 2024). The model is semi-distributed and it allows the division of catchment into sub basins, elevations and vegetation zones (Johansson, 2000; Crooks & Naden, 2007; Pervin et al., 2021). Because the HBV model has been used in Sweden and other Nordic nations, it is simple to comprehend, learn, and implement. In its use, it has produced positive outcomes (Bergström, 1992; Seibert, 1998). It may be partially utilized in other models and has become a typical tool for runoff studies in Nordic countries with minimal input and data needs.

A small watershed to river basin-scale model called the Soil & Water Assessment Tool (SWAT) is used to estimate the environmental effects of land use, land management techniques, and climate change as well as to simulate the quantity and quality of surface and ground water(J. Zhao et al., 2024). SWAT is frequently used to evaluate regional management in watersheds, non-point source pollution control, and soil erosion prevention and control.

In 1990, SOGREAH (France), DHI, and the Institute of Hydrology (the United Kingdom) created the physically based model known as MIKE SHE (Denmark). As a result, the model needs large amounts of physical parameters as inputs. The model takes into consideration a number of hydrological cycle phenomena, including river flow, evapotranspiration, precipitation, and the movement of saturated and unsaturated ground water. It may replicate the flow of surface and groundwater, their interactions, sedimentation, nutrient and pesticide transport in the model area and various water quality problems and can be applied for large watersheds (Twesige et al., 2019).

2.4 Climate Change

Long-term alterations in the Earth's climate system, such as variations in temperature, precipitation, and weather patterns, are referred to as climate change (Turyasingura et al., 2022). These changes are mostly the result of human activity, mainly the burning of fossil fuels and deforestation, which releases greenhouse gases into the atmosphere (World Bank, 2021a).

Climate change scenarios are potential projected developments in the Earth's climate system based on various assumptions regarding elements such as greenhouse gas emissions, land use changes, and technology breakthroughs (World Bank, 2021a).

Two pathways exist at the moment in projecting climate change i.e. Representative Concentration Pathways (RCP) and Shared Socioeconomic Pathways (SSP) (Lee et al., 2017). RCPs are based on CMIP5 while SSPs are based on CMIP6 (Verma et al., 2023; Van Vuuren et al., 2011).

The RCPs climate change scenarios are designed to depict future concentrations of greenhouse gases, not emissions, and have been officially approved by the (IPCC, 2008). The paths outline many possibilities of climate change, all of which were thought to be plausible given the quantity of greenhouse gases (GHG) released in the years to come. According to Lee et al., 2017; Van Vuuren et al., 2021), four RCPs were developed;

1. **RCP 2.6 (Peaking scenario):** Assumes that global annual greenhouse gas emissions peak around 2020 and then decline, leading to a low level of radiative forcing by 2100.
2. **RCP4.5 (Stabilization scenario):** Assumes that emissions peak around 2040 and then decline, resulting in a moderate level of radiative forcing by 2100.
3. **RCP6.0 (Intermediate scenario):** Assumes that emissions peak around 2080 and then decline, leading to a higher level of radiative forcing by 2100 compared to RCP4.5.
4. **RCP 8.5 (High-emission scenario):** Assumes that emissions continue to rise throughout the 21st century, resulting in a very high level of radiative forcing by 2100,

are labelled after a possible range of radiative forcing values in the year 2100 (Knutti et al., 2013).

SSPs on the other hand are based on projected changes in global society, economy, and demography during the next century with 5 narratives (Meinshausen et al., 2020; Zeke Hausfather, 2018). Based on five narratives that outline major socioeconomic developments that have the potential to influence future civilization, SSPs (Zeke Hausfather, 2018). These narratives include;

1. SSP1 - Sustainability – Taking the Green Road (Low challenges to mitigation and adaptation)
2. SSP2 - Middle of the Road (Medium challenges to mitigation and adaptation)
3. SSP3 - Regional Rivalry – A Rocky Road (High challenges to mitigation and adaptation)
4. SSP4 - Inequality – A Road Divided (Low challenges to mitigation, high challenges to adaptation)
5. SSP5 - Fossil-fueled Development – Taking the Highway (High challenges to mitigation, low challenges to adaptation) (Meinshausen et al., 2020).

2.5 Environmental flow

2.5.1 Environmental Flow Definition

Kaushal et al., (2012) defines environmental flow as volume, timing, and quality of water flows necessary to preserve freshwater and estuarine ecosystems, as well as the human livelihoods and well-being that depend on these ecosystems. Acreman, (2016) further defines environmental flows as the river-flow characteristics necessary to maintain the integrity of riverine ecosystems. According to Alberta, (2023), When studying Environmental flow, the following elements of a river need to be addressed as shown in Figure 2.1 where;

1. The river, a flowing body of freshwater.
2. The riverbank, which is the transitional zone between the water and the surrounding land.
3. The benthic zone, which is the ecological region at the lowest level of a body of water, including the sediment surface and subsurface layers.

4. The riparian zone, which is the area of land adjacent to a river or other body of water.
5. The watershed, which is the area of land where all of the water drains into a common outlet, such as a river, lake, or bay.

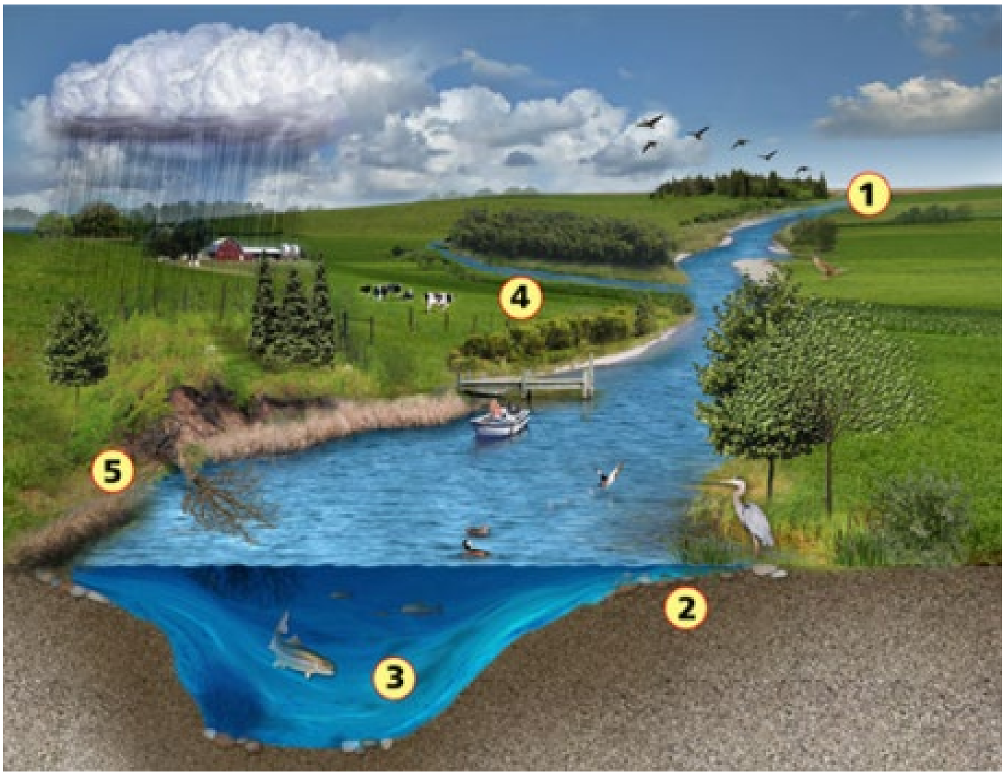


Figure 2.1: Five elements of a river or stream's ecology

2.5.2 Classification Environmental Flow Methods

Information on the relationships between river flows and river health is available from E-flows Assessments. They provide the anticipated basin-wide ecological and socioeconomic impacts connected to various water management alternatives in their most detailed form (King & Brown, 2018). A number of studies classified the methods used in Environmental flow assessment and these included:

Dyson et al., (2013) distinguished between Methods, Approaches, and Frameworks by stating that Methods are usually concerned with specific assessments of the ecological requirement, Approaches are methods of obtaining the assessments, such as through expert teams, and Frameworks for flow management provide a broader strategy for environmental flow assessment by utilizing one or more specific Methods and applying a Specific Method and a Specific Approach.

Brown & King., (2003) differentiated methodologies focused on interactive versus prescriptive approaches. The prescriptive approach-based techniques often focus on a particular goal and prescribe a single flow value or single element of the flow regime. The relationship between changes in flow and a particular river feature that is used to set the flow depending on the desired river condition is the subject of interactive approach methods.

Tharme., (2003) preferred to divide the techniques into four categories: hydrological, hydraulic, habitat-simulation (or habitat assessment), and holistic techniques. This classification system has been extensively used, and it is used here to describe the more crucial techniques within each category.

2.5.3 Methods for Environmental Flow Assessment

2.5.3.1 Hydrological Methods

Hydrological techniques relied on historical stream flow records to estimate e-flows. e-flows are usually estimated by taking a fixed percentage of the Annual Average Flow (AAF) of a river (Dyson et al., 2013). This percentage is set through expert opinion and at a level to support good ecological status.

According to Tennant's method, the following percentages are proposed to estimate e-flow and these included;

- 10% - in streams that are degraded with few sensitive aquatic organisms
- 30% - in streams/rivers with fish and recreation
- 60% - in stream that have very sensitive and rare aquatic organisms (Brij Gopal, 2013)

The Tennant (or Montana) method with modifications from Tessman are used to assess hydrological e-flows (Shaeri Karimi et al., 2012). These modifications are;

- Mean Monthly Flow (MMF), if MMF<40% Mean Annual Flow (MAF)
- 40% MAF, if 40%MAF<MAF<100%MAF
- 40% MAF, if MMF>MAF

2.5.3.2 Hydraulic rating Methods (Wetted Perimeter Method)

The hydraulic technique was adopted for environmental flow evaluation because of the link between the hydraulic characteristics of watercourses and the quality of the aquatic environment, which varies based on the needs of the many species living in ecosystems or the direct or indirect relationship between the river's ecological function (Efstratiadis et al., 2014).

This method relates a relationship between discharge in the river and hydraulic measure of the river. Wetted Perimeter method relates various parameters of stream geometry such as width, depth and wetted perimeter, based on surveyed cross-sections, to discharge rates. Minimum or optimal flows, usually for fish spawning, or maximum production by benthic invertebrates, were identified from a discharge near the breakpoint of the wetted perimeter-discharge curve (Yan et al., 2018).

2.5.3.3 Holistic approach

In holistic approaches the central rationale is that different parts of the flow regime elicit different responses from the river ecosystem. Thus, removal of one part of the flow regime was affect the ecosystem differently than removal of another part.
Furthermore, it is assumed that:

- it is possible to identify and isolate these different parts of the flow regime within a long-term hydrological data set of daily flows.
- it is possible to describe in isolation the probable biophysical consequences of partial or whole removal of any one of these parts.
- the parts of the flow regime and their linked consequences can be re-combined in various ways, to describe the river condition of any flow regime of interest (the biophysical part of the scenario).
- the social impacts of each river condition can be described (the socio-economic part of the scenario).

The flow is analyzed and differentiated according to four classification; Low flows, Small, floods, Large floods and Flow variability.

2.5.4 Impact of Environmental flow

A change in the quantity of water in a river can lead to water scarcity downstream, erosion of riverbanks, and alteration of the physical characteristics of ecosystems (Croker N et al., 2022; Hirpa et al., 2019). The timing of released water is also important, as every river has a natural variance in release frequency, that it is used by several migratory aquatic species to synchronize their spawning period and ensure that eggs or larvae have the best chances to survive.

Environmental Flow assessments can help balance the trade-offs between infrastructure projects and the benefits of ecosystem services from natural flows throughout river basins. A good, holistic Environmental Flow assessments allows policy makers and project designers to consider all factors of river flows (including the quantity, timing, and quality of water plus the sediments, fish, and other life flowing through river basins) as well as the impacts of these factors on the livelihood, cultural practices, and the overall well-being of local people. This information can help shape the project plan and make management adaptive to avoid or mitigate any changes in natural river flows that would negatively impact downstream communities.

2.6 Response of Stream flow due to Land use change

The application of one land use scenario or more and more physical land descriptions is one requirement for evaluating the impacts of predicted changes in land use/cover on streamflow (Andualem et al., 2023). Several factors, such as increased urbanization, agricultural practices, forests, and other land use activities, can have a significant impact on the streamflow levels of a given river in a basin. Furthermore, using meteorological data from a specific basin and time period, the natural streamflow of a river can be simulated under the influence of both climate and land use change.

2.7 Review of Comparative Studies

A number of studies that are similar in nature to the study objective formed a basis of the literature review. Comparing and contrasting methods used, results obtained, conclusions and limitations adopted to steer the study into achieving its intended objectives.

2.7.1 Land Use and Land Cover Change

Sidhu et al., (2018): utilized Google Earth Engine to detect land cover change: Singapore as a case study. The study evaluated the utility of Google Earth Engine (GEE) for performing raster and vector manipulations on various satellite imagery datasets, such as Landsat, Moderate Resolution Imaging Spectroradiometer, and GlobCover (2009) imagery. Assessing the capacity of GEE to conduct space-time analysis for urban and wetlands land classes in two subregions of Singapore, Tuas and the Central Catchment Reserve (CCR). Highlighting the challenges faced by GEE, which are common to most parallel processing and big-data architectures. Analyzing

Singapore's land use and cover as a use case for exploring GEE, including observing land reclamation and the impact of monsoon cycles on forest cover in the CCR. Evaluating GEE's capability to carry out simultaneous spatial and temporal aggregations over satellite imagery, specifically in the Tuas industrial zone and the CCR. The study the lacked a comprehensive evaluation of the accuracy of land cover change detection using GEE, which could be a limitation in terms of the reliability of the results.

Bunyangha et al., (2021) assessed Remote sensing and supervised classification were used to analyze 33-year multitemporal LULC changes in Mpologoma catchment while future patterns for the next two decades were predicted using the Cellular Automata-Markov modelling technique in TerrSet's Land Change Modeler. Initially, in 1986, the catchment was dominated by grassland (32.08%). However, most grassland (92.77%) was gradually converted to subsistence farming (75%) and built-up (15.7%). Grassland, woodland and wetland annually declined at a rate of 5.52%, 2.47% and 0.63% respectively while farmland and built-up expanded at 9.32% and 6.22% respectively and by 2019 subsistence farming was the dominant class (53.16%). Prediction results showed that by 2039, woodland, grassland, wetland and open water will decrease while there will be major increases in built-up and commercial farming from 11.61% to 27.91% and 0.18% to 0.34% respectively. Subsistence farming will continue to be the dominant land use by 2039 attributed to gains from woodland (4.7%), grassland (3.7%) and wetland (4.9%). These LULC changes indicate an intensifying land use pressure in Mpologoma catchment and provide useful information for land use planners, environmentalists and policymakers in this catchment to consider when planning for sustainable management of the watershed.

Li et al., (2016) examined historical and future land use changes in Uganda using change detection methods and agent-based modelling from 1996 to 2013. Farmers' decision-making processes were included into biophysical and socioeconomic elements, which are then used to analyze the impact of farmers' decisions on agricultural land use changes. To create spatial relationships between farmers and land cover systems, geographic information system techniques were used. Satellite images are utilized to depict the initial land cover conditions and to calibrate the simulated findings using observed land cover datasets. Images and land use datasets were collected for the years 1996, 2001, and 2013. Land use values for 1996 and 2001 were derived from the Uganda-Africover land cover database, whereas land use datasets for 2013 were derived from Landsat 8 OLI satellite photos for Uganda. In 2013, the study picked six spectral bands for Landsat 8 OLI images (band 2, band 3, band 4, band 5, band 6, and band 7). Significant agricultural and grassland cover, as well as urban land uses, are observed in 72% and 36% of the areas, respectively, while wetland land uses have expanded significantly in 82% of the regions. In contrast, 91% of the regions have decreased in forest cover, with the exception of the Teso region, which has increased by 62%. Acholi is the only region (extreme outlier) that has had remarkable increases in wetlands of more than 88 %. The simulation model's results are encouraging, and it proved successful in modeling past and future possibilities of agricultural land use patterns on a national scale.

Osaliya et al., (2020) investigated cropland expansion in Karamoja, Uganda, and its impact on livelihoods. It examines the connections between biophysical and political historical events that have led to the region's current state of agricultural land use. According to the study, government programs encouraging sedentary agriculture are the primary drivers of cropland expansion in Karamoja, resulting in a significant increase in cropland area between 2000 and 2011. However, this expansion has not resulted in increased crop production or food security, and food aid was still required due to crop failures. The cultivation of small-sized fields, as well as the abandonment of previously cultivated land, raises concerns about the region's rain-fed agriculture's sustainability. Cropland expansion was also having a negative impact on pasture areas, which are critical for livestock-based livelihoods. The paper emphasizes the importance of strong agricultural extension programs as well as climate-smart options for mitigating the negative effects of cropland expansion in Karamoja.

Tayyebi et al., (2014) compared three global parametric and local non-parametric models to simulate land use change in diverse areas of the world. Three models were fed with identical data from different parts of the world: one with large agricultural expansion (East Africa), another with re-growing woods (Muskegon River Watershed in the United States), and a third with significant urbanization (South-Eastern Wisconsin in the United States). Each model was trained and calibrated using independent training and testing data. The traditional goodness-of-fit measures in land use change science were used to compare simulated maps from the three types of land use change patterns. The results of the data mining models' temporal and spatial comparison show that the artificial neural network outperformed all other models in a short time interval (East Africa; 5 years) and for coarse resolution data (East Africa; 1 km); however, the three data mining models obtained similar accuracies in a long-time interval (Muskegon River Watershed; 20 years) and for fine resolution data with a large number of cells (Muskegon River Watershed; 30 m). Furthermore, the results showed that the probability of agriculture gain was higher in areas closer to towns and large cities in East Africa, urbanization was higher in areas closer to roads and urban areas in South-Eastern Wisconsin, and forest gain was higher in areas closer to forest and shrub land cover and farther away from roads in the Muskegon River Watershed. The study also identified the factors that influence land use change in each region, such as proximity to towns and large cities for agricultural gain in East Africa, proximity to roads and urban areas for urbanization in South-Eastern Wisconsin, and proximity to forest and shrub land cover and distance from roads for forest gain in the Muskegon River Watershed. However, the study had calibration flaws as well as a lack of social and economic data for developing countries.

Nakalembe et al., (2017) examined dramatic cropland expansion in Karamoja, Uganda by investigating the links between bio-physical and political historical events leading to the current state of agricultural land use. The study objective was to quantify agricultural expansion, uncover the dominant drivers leading to the current state of Agri-cultural land use and its impacts on livelihoods. Region wide analysis of remotely sensed data, land use policy and history as well as farmer interviews were undertaken. The study showed a 299% increase in cropland area between 2000 and 2011 with most expansion occurring in Moroto District (from 706 ha to 23,328 ha). There was no evidence of an increase in overall crop production or food security and food aid continues to be essential due to recurrent crop failures. Due to lack of resources for inputs (e.g., seeds and labor) cultivated fields remain very small in size and over 55% of once cultivated land is left fallow. Findings bring into question whether continued promotion of rain-fed agriculture in Karamoja serves the best interests of the people. Current cropland expansion is directly competing and compromising pasture areas critical for livestock-based livelihoods. Without strong agricultural extension programs and major investments in climate-smart options, cropland expansion will continue to have net negative impact, especially in the context of current climate projections which indicate a future decrease in rainfall, increase in temperature and an increase in the frequency and magnitude of extreme events.

2.7.2 Environmental Flow

Lv et al., (2023) quantified e-flow in the form of pulse flow for fish protection in China's Songhua river using fish spawning behavior and habitat simulation. the study included examining fish species' spawning patterns, determining habitat preferences and egg hatching periods, and creating a hydrodynamic and hydrological model. The study found that high-pulse flows, with peak flows of roughly 900-1200 m^3/s, occur around five times each year, primarily between April and august. from May to July, two pulses were advised each month to meet e-flow needs for systems with multiple fish species and reservoirs upstream.

Mikołaj et al., (2011) estimated e-flows in Semi-Natural Lowland Rivers in Narew Basin Poland. The study focused on a building block method to estimating environmental flows in semi-natural lowland rivers, with a particular emphasis on fish and floodplain wetland plants. According to the data, changes in environmental flow indicators were detected between 1976 and 2008 in 16 chosen river sections of the Narew basin. The findings revealed that hydrological conditions for fish and floodplain wetland vegetation were much better in the past compared to the present. The study noted that the interpretation of environmental flow indicators was relatively straightforward, but it is critical to develop site-specific linkages between flow regime and dependent ecosystem components.

Shaeri Karimi et al., (2012) utilized hydrological methods to assess e-flow in a river reach. The study used FDC shifting along with Global e-flow Calculator with four alternative hydrological methods were also used for comparison: the desktop reserve model (DRM), Tennant, low-flow index, and flow duration curve analysis (FDCA). The FDC shifting technique and DRM were found to provide more reliable predictions for maintaining the basic function of the river ecosystem compared to the Tennant method, low-flow index, and FDCA. The study determined that a minimum flow rate of 1.2 m^3/s (equivalent to 23% of the natural mean annual runoff or flow with 80% occurrence depicted from the FDC) is required for the Shahr Chai River to run toward the internationally recognized Urmia Lake in Iran

Abdi et al., (2014) assessed ecologic-hydraulic-hydrologic methods used in evaluating e-flow for R. Zab a transboundary river in Iran with three different reaches. The study examined the FDC shifting, hydraulic-wetted perimeter method, synthetic habitat simulation method, and water quality control method. The FDC Shifting method was found to be suitable for the upper reaches of the river, while the synthetic Eco-hydraulic method is recommended for the middle and downstream reaches, specifically for meeting the ecological requirements of the Barbus Capito fish. The mean annual flows in the three river reaches were determined as 2.3, 7.6, and 7.9 m^3/s, respectively. Proposed monthly flow rates are also provided for preserving the riverine life. The paper mentioned the use of the Global Environmental Flow Calculator and other methods such as Low-Flow Index, Flow Duration Curve Analysis, Range of Variation Approach, and Desktop Reserve Model for evaluating environmental flows.

Geleta et al., (2023) looked at how an ungauged catchment in Africa was affected by small-scale irrigation (Ethiopia). This was significant because sustainable management of water resources depends on a knowledge of how irrigation impacts river water flow. Using resources such as the Water Evaluation and Planning System (WEAP), it examined the catchment's water balance to calculate the environmental flow needs under various conditions. This is useful in figuring out the minimal amount of water flow required to maintain ecosystems and human activity without exhausting the river system. 9% of the water resources in the watershed are used for agriculture, according to the research; the other 91% flows downstream to Lake Ziway. This result emphasizes how important irrigation techniques are in influencing the availability of water downstream. The results of the study showed seasonal variations in meeting environmental flow requirements, with deficits in water supply during certain months, particularly in January and February. Overall, the research advances our understanding of the relationship between environmental flow in ungauged rivers and small-scale irrigation, highlighting the significance of striking a balance between agricultural water usage and the preservation of aquatic ecosystems and downstream water consumers.

Ramulifho et al., (2019) focused on the difficulties encountered in the Luvuvhu River Catchment, South Africa, when establishing an environmental flow regime. River management has grown increasingly important as a result of rising water demands brought on by an expanding world population. Natural ecosystems depend on environmental flow requirements, yet there are several challenges in putting them into practice. According to the study, there is a possibility that stream flow in the Luvuvhu River Catchment would cease soon due to a worrying decline in stream flow volume in some locations. In order to assist alleviate diminishing stream flow levels, the study stressed the necessity for scientific environmental flow norms and abstraction thresholds. Sustainable water resource management has been hampered by institutional issues such as the lack of a watershed management agency, ignorance of the advantages of environmental flow, budgetary limitations, capacity issues, and conflicts of interest. Variations in stream flow have a detrimental effect on aquatic life and cause the extinction of delicate species.

2.7.3 Impact of LULC, Climate Change on Hydrology.

Arfasa et al., (2024): reviewed the impacts of climate and land use/cover changes on irrigation water sustainability in West Africa, highlighting the challenges posed by rising temperatures, reduced precipitation, and increased irrigation demand due to population growth. Effective adaptation measures are essential to address these adverse effects on water availability. The Visualizing similarities viewer software was utilized for bibliometric mapping, allowing for the identification of similarities and significant themes among selected publications. The analysis includes performance metrics such as the number of publications, citations, and impact factors, derived from specific equations. A screening process is implemented to remove duplicates and ensure the selection of relevant articles for further analysis. The study revealed that climate and land use/land cover (LULC) changes significantly impacted hydrological processes, including evapotranspiration and groundwater flow, affecting irrigation sustainability in West Africa. The study further highlighted that the demand for freshwater for irrigation in West Africa is projected to triple by 2050, driven by factors such as population growth and climate change. The research indicated a notable decrease in forest area by 24.6% from 1997 to 2018, while residential and agricultural land areas increased by 140% and 11.7%, respectively. Effective mitigation and adaptation measures were identified as critical policy issues to address the adverse impacts of future climate and LULC changes on water availability.

Sempewo et al., (2024) assessed the distinct and combined impacts of future climate and land use change on river Rwizi flows using a combination of statistical downscaling techniques, machine learning and physically based hydrological modelling techniques.

The study employed statistical downscaling techniques, machine learning, and physically based hydrological modeling to assess the impacts of climate and land use change on river flows in the Rwizi catchment area. For modeling land use and land cover (LULC) transition probabilities, an Artificial Neural Network (ANN) multi-layer perceptron was utilized due to its high accuracy and suitability for data-scarce situations. Calibration and validation of the models were conducted using the semi-automated SUFI-2 algorithm within the SWAT Calibration and Uncertainty Procedures (SWAT-CUP) version 5.2.1, which is noted for its computational efficiency. The study analyzed the isolated and combined impacts of land use and climate change on river flows, indicating a comprehensive approach to understanding hydrological changes. The research utilized an ensemble of six CORDEX Regional Climate Models under different emission scenarios (RCP4.5 and RCP 8.5) for future projections

The study concluded that land use change has a more dominant influence on total annual runoff compared to climate change, with isolated impacts of land use change showing an increase in future total annual river flows. It is found that while climate change is the primary factor affecting future high-flow quantiles, future annual flow and extreme low-flow variations are mainly attributed to land use changes. The limitations identified were as follows; (i). the approach used is only suitable for regions where precipitation matches evaporative demand, which limits its applicability to all hydroclimatic conditions (ii). isolated impacts of climate change showed a reduction in future total annual flow, indicating a limitation in understanding the full effects of climate change (iii). the influence of land use changes on total annual runoff is more dominant than that of climate change, which may not be applicable in all contexts

Chawanda et al., (2024) examined the impacts of land-use and climate change on water resources across Africa, highlighting the need for adaptive land-use policies to mitigate these effects. The study emphasized the potential for land-use changes to influence river flows and water availability, particularly in regions like the Congo basin and Senegal. The HMBC methodology was used to calibrate a continental-scale hydrological model, which is essential for accurate simulations of hydrological processes. Bias-adjusted global climate models was utilized to drive the hydrological model, ensuring that future runoff, evapotranspiration (ET), and river flow projections are based on reliable climate scenarios. The research focused on simulating future conditions under climate change and land use/land cover change scenarios, specifically for Representative Concentration

Pathways (RCPs) 2.6, 6.0, and 8.5. The study demonstrated that climate change and land-use change significantly impact water resources across Africa, with varying effects on different river basins. The Niger River basin was projected to experience the largest reduction in river flows under higher RCP scenarios, while the Congo River basin is expected to see reduced flows across all scenarios. The Limpopo River is likely to experience increased river flows in the future, particularly under certain climate scenarios, while the Nile River shows mixed signals. The study emphasized the need for agricultural policies that enhance resilience against climate change, as projected changes threaten the livelihoods of small-scale farmers dependent on rainfall. The limitations faced were; (i). nonoverlapping observation data, which affected the accuracy of the results, (ii). lack of reservoir management data, which hindered the understanding of water resource management, (iii). Poor-resolution input data that impacted the model's reliability and (iv). Limited information on agricultural management practices restricted the comprehensiveness of the study

Gül et al., (2010) assessed the impact of climate change on river flows and catchment area environmental flow needs. The paper showed that modeling the effects of climate change on lowland river systems is difficult and that these effects are more apparent locally. The study examined the effects of climate change on a lowland watershed in Denmark using the coupled MIKE SHE/MIKE 11 model. The linked model works well for dynamically modeling groundwater levels and stream flows. Variations in the reactions of different global circulation models to climate change result in river flows and environmental flow potentials that deviate from averages for the base period. In order to fully comprehend the effects of climate change on aquatic ecosystems, the research highlights the significance of resolving the scale mismatch between large-scale climate models and catchment-scale studies. In light of shifting climatic circumstances, balancing water uses requires an assessment of environmental flow needs. The work highlights the need for precise modeling to assist sustainable water resource management methods and offers insights into how river flows may vary as a result of climate change.

Arnell, (1999) investigated the effects of climate change on water resources worldwide, with particular attention to the consequences for hydrological regimes and water availability. It forecasts changes in river flows and water resources globally by utilizing climate change scenarios from Hadley Center climate models. The findings indicated that while runoff would generally decrease in mid-latitudes and most subtropical regions, it will increase in high latitudes, equatorial Africa, Asia, and southeast Asia. The timing of stream flow in some areas is impacted by the change from snowfall to greater winter runoff as temperatures rise. Millions more people are expected to live in water-stressed nations by 2025 as a result of climate change. However, under other situations, there may be a net decrease in stressed populations by 2050. The study emphasizes how diverse future water consumption forecasts and challenges in establishing impact indices at a wide scale affect the diversity in assessing the impact of climate change on water resources. The study emphasizes how diverse future water consumption forecasts and challenges in establishing impact indices at a wide scale affect the diversity in assessing the impact of climate change on water resources. Overall, the study highlights the intricate connection between water stress and climate change, highlighting the necessity of improved comprehension and management of water resources in the face of climate change.

Pervin et al., (2021) utilized the Hydrologiska Byråns Vattenbalansavdelning (HBV) model to project future water levels in the Mackenzie River Basin using dynamically downscaled climate data from the Weather Research and Forecasting model. HBV model was calibrated and validated using historical flow data from the Fort Simpson and Arctic Red River stations, showing a strong correlation (R^2 value around 0.85) between simulated and observed streamflow. River flow projections indicated a decrease in mean flow by approximately 5% under both RCP 4.5 and RCP 8.5 scenarios, with peak flow reductions of about 12% and 9%, respectively, in the 2050s. The study highlighted that these projected lower water levels could significantly impact navigability and northern ferry operations on the Mackenzie River. The study was however limited to one Global Climate Models hence limiting variability across other models.

2.8 Summary of the Literature Review

Studies consistently show that LULC changes, such as urbanization and agricultural expansion, significantly alter hydrological patterns and water quality (Andualem et al., 2023, Mbungu & Kashaigili, 2017). Similarly, climate change affects river systems through altered precipitation, increased temperatures, and more frequent extreme weather events (Onyutha, Turyahabwe, et al., 2021, Onyutha, Nyesigire, et al., 2021, Gül et al., 2010 & Turyasingura et al., 2022).. However, there is a notable lack of integrated research that combines these factors to assess their cumulative impact on e-flows.

A notable gap is the insufficient integration of LULC and climate change impacts into e-flow assessments. Many studies like Andualem et al., 2023, Driessen et al., 2010, Gabiri et al., 2020 among others focus separately on land use or climate effects but fail to combine these factors in a unified model. This separation limits the ability to predict and manage future flow requirements accurately. Additionally, the existing literature frequently highlights poor management strategies that do not fully utilize scientific findings. For instance, the application of e-flow guidelines is often inconsistent or based on outdated models that do not incorporate recent LULC and climate data (Arthington et al., 2006).

CHAPTER THREE: MATERIALS AND METHODS

3.1 Introduction

This chapter presents the location of the study area, sources of data, different techniques, methods and materials used towards achieving the set objectives of the study.

3.2 Description of the Study Area

3.2.1 Catchment Delineation

The R. Namatala Catchment was defined by the confluence of the Namatala and Manafwa rivers. The catchment delineation using ARC GIS SWAT tool was done and corresponding sub basins was obtained (Luo et al., 2011). This delineation process utilized topo data to define natural hydrological boundaries, enabling a clearer understanding of runoff distribution and water flow within the basin. The delineated catchment of area 626.30 km^2 had 5 sub catchments varying in size ranging from 25.29 km^2 to 311.69 km^2 and elevations between 1068 m and 2345 m above sea level (Table 3.1).

In line with the spatial scale, the catchment spanned through six districts of Sironko, Bududa, Mbale, Butaleja, Budaka, and Pallisa (Figure 3.1). The delineated watershed is part of the larger Mpologoma catchment, which is part of Kyoga water management zone (KWMZ) (Bunyangha et al., 2021).

Table 3.1: Sub Basin characteristics

Sub basin	Area (Km^2)	Elevation (m.a.s.l)	Minimum Elevation	Maximum Elevation
1	311.69	1360.883	1081	2345
2	107.88	1210.718	1081	2334
3	75.63	1114.014	1077	1161
4	25.29	1107.255	1077	1187
5	105.81	1100.755	1068	1183
Total	**626.3**			

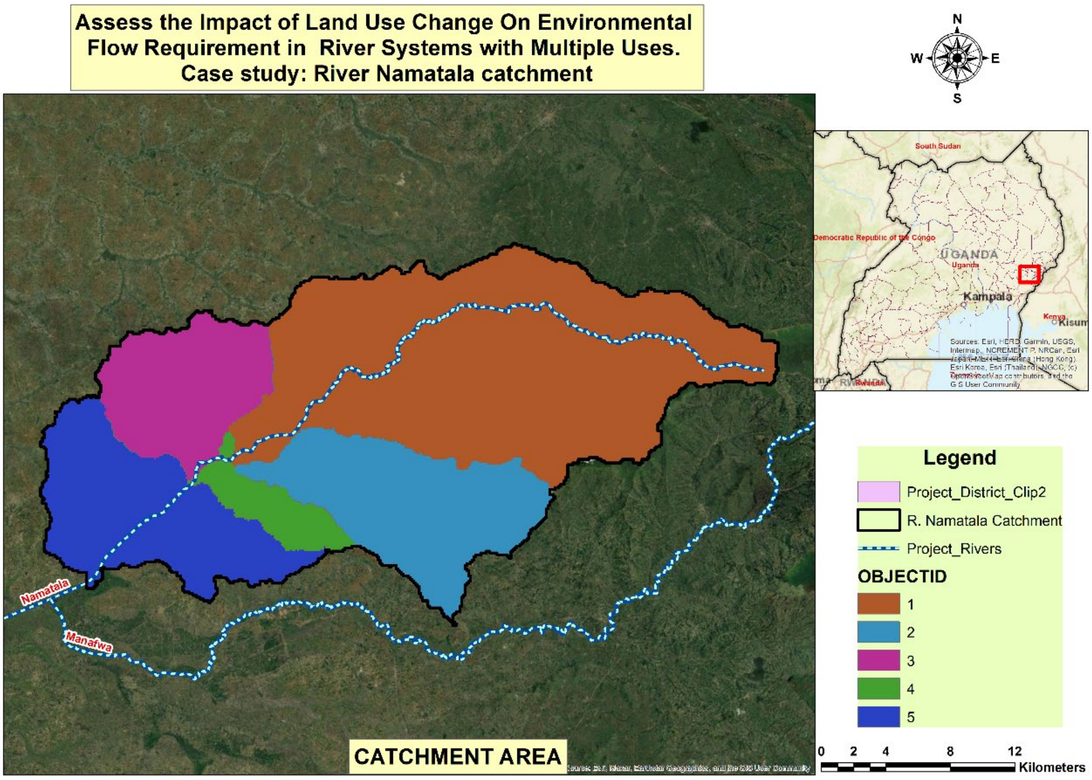


Figure 3.1: Delineated R. Namatala Catchment

3.2.2 Location of study area

The Namatala River flows along the borders of Sironko, Bududa, Mbale, Butaleja, Budaka, and Pallisa Districts before emptying into the River Mpologoma near Tirinyi Town Council in the west of the study area (Figure 1.1). Other smaller rivers and streams also contribute to the study area's hydrology (Bunyangha et al., 2021).

The delineated catchment has an area of 626.3 km^2 dominated in terms of district coverage by Mbale (51%) followed by Budaka (26%), Butaleja (12%), Sironko (8%), Butebo (2%), and Bududa (1%) (Figure 1.1).

3.2.3 Climate

The project area receives plenty of rain and sunshine due to its equatorial climate, which is moderated by the relatively high altitude of Elgon Mountain (NWSC et al., 2021). Mbale has a tropical wet and dry climate, but the city's higher altitudes influence average temperatures, making it noticeably cooler than other cities with this climate.

Climatic data was obtained from obtained from Uganda National Meteorological Agency (UNMA) for Bugusege Automatic weather station spanning for 49 years.

Based on the results, majority of the rain falls between March and October. The wettest month is January, with only 25 mm of rain (Figure 3.2).

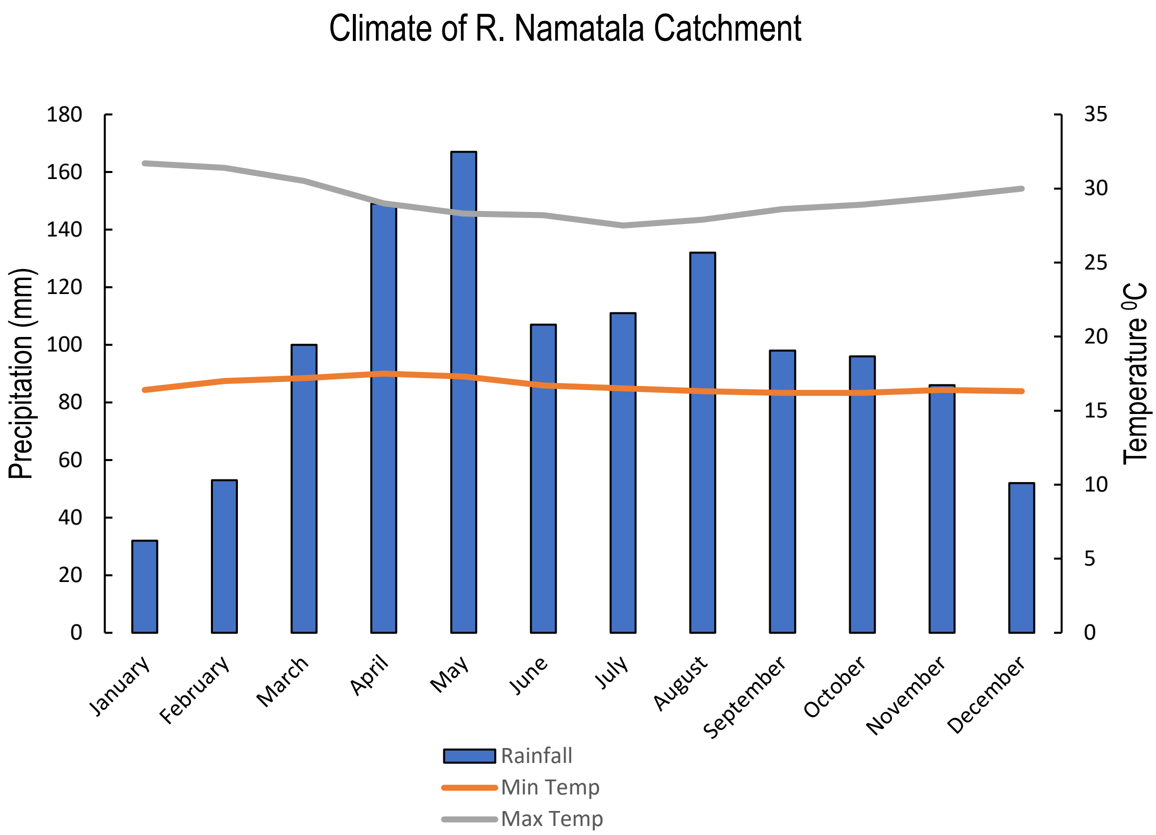


Figure 3.2: Climate of R. Namatala Catchment
Source: Climate data from Bugusege AWS

3.2.4 Topography

Mt Elgon has an impact on the study area's elevation and slopes. The elevation is highest in the eastern region, with altitudes of over 3000 m on the slopes of Mt Elgon and 1200 - 1700 m in the river valleys. The watershed to the east of Mbale has an average elevation of 1650 m and is characterized by steep slopes ranging from 20 to 50 % in the mountains and 2 to 20 % near the main rivers. As one moves west of Mbale, the mountainous terrain gives way to swamps and wetland. The elevation of the wetlands along the Namatala River ranges between 1110 m near Mbale and 1068 m in the west of the study area near Butaleja (Figure 3.3).

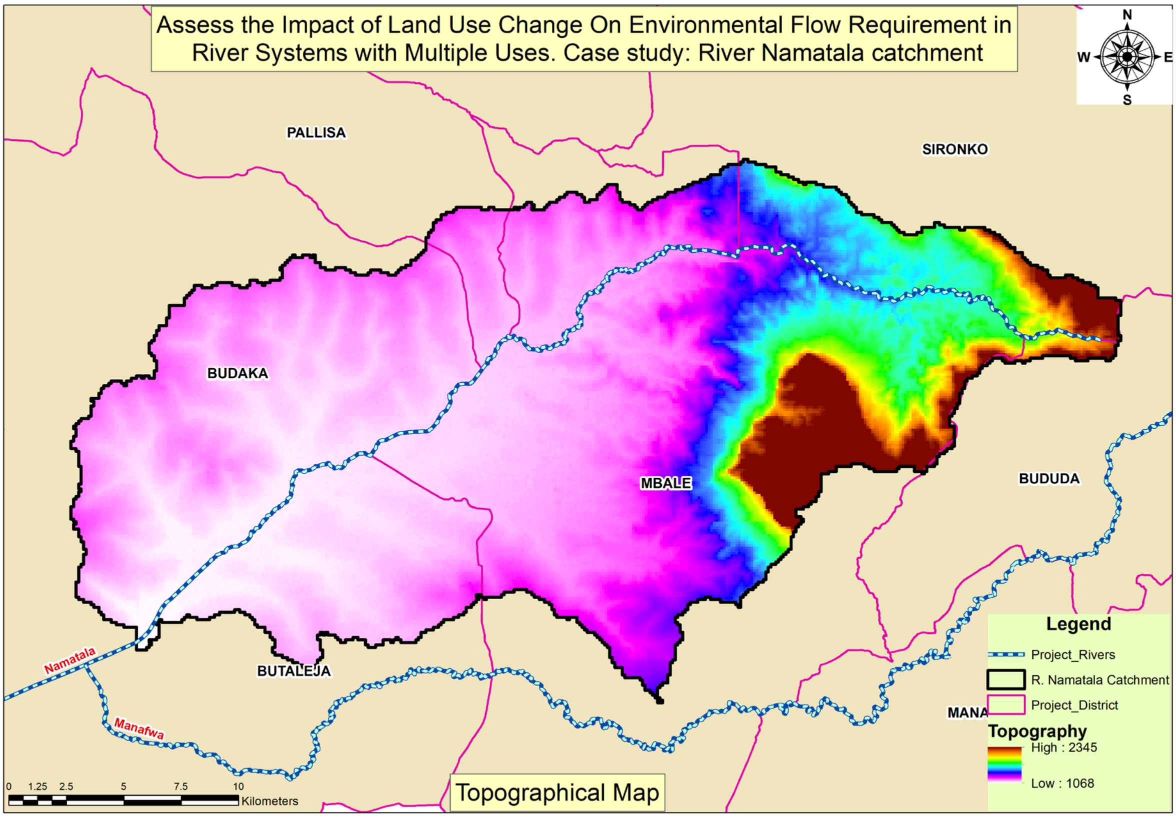


Figure 3.3: Topography of R. Namatala Catchment

3.2.5 Geology

The study area is in the Mpologoma catchment, which was dominated by Petric Plintholos, Gleysols, and Histosols. Gleysols grow in depressions and low landscape positions with shallow groundwater. Histosols are soils formed from organic material, most often under papyrus vegetation. (Figure 3.4).

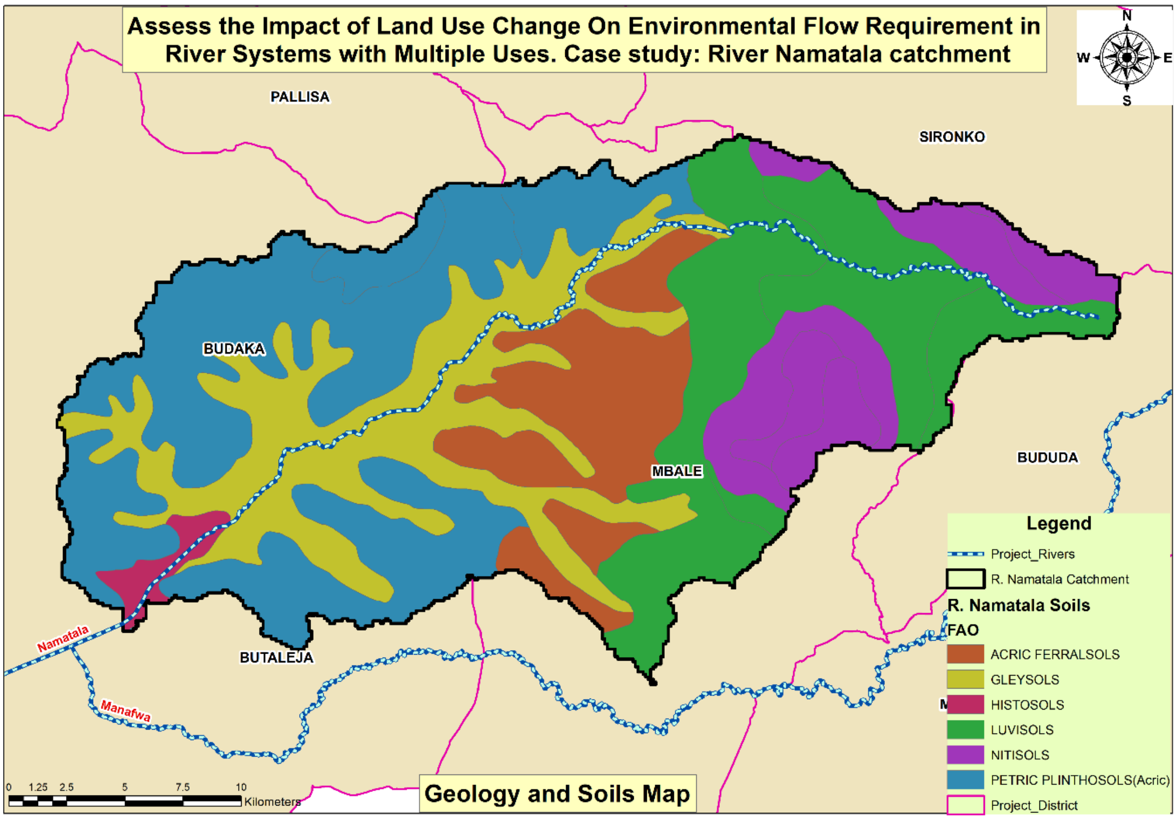


Figure 3.4: Geology of R. Namatala Catchment

3.2.6 Hydrology

Rivers and streams are the primary water resources found in the study area due to the region's mountainous terrain. The main rivers flow from the higher altitude slopes of Mt Elgon to the lowland wetlands in the project area's west. Rivers Namatala and Manafwa flow westward from the slopes of Mt. Elgon, respectively, passing Mbale to the north and south (NWSC et al., 2021). Rivers Nabuyonga and Nabijo flow from the Wanale Mountains east of Mbale to the Namatala River west of Mbale (Figure 3.5).

Two rivers were gauged i.e. Namatala (2No.) and Nabuyonga (1No.). However, the gauging station for Nabuyonga was destroyed by floods thus the catchment now has two stations.

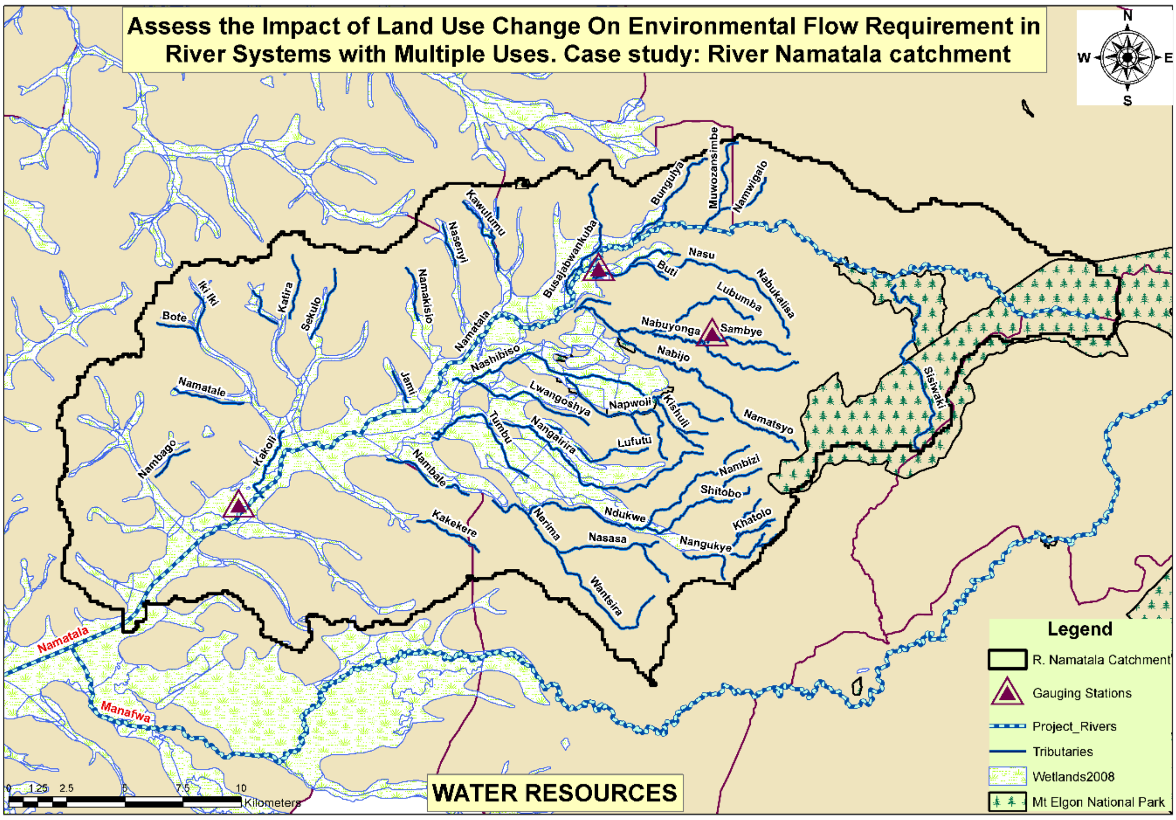


Figure 3.5: Water Resources of R. Namatala Catchment

3.3 Sources of data

Different data was used to assess the impact of land use change on environmental flow requirements as described below.

3.3.1 Collection of data

Data for the study was obtained from a variety of sources, including the Uganda National Meteorological Agency, the Directorate of Water Development, and the Directorate of Water Resources Management. Among the data obtained was Temperature, Rainfall, Humidity shape files, flow data for R. Namatala as well as R. Nabuyonga and articles related to the project area.

The precipitation, temperature and humidity data for R. Namatala was obtained from Uganda National Meteorological Agency (UNMA) specifically an Automatic Weather Station (AWS) in Bugusege (34°16'E, 01°09'N) which is 18 km upstream of Mbale City. This weather station was a good representation of the study area with data ranging between 1970 to 2018 (49 years). CHIRPS climate data (2000 – 2023) was obtained using Google Earth Engine (GEE) to allow for gap filling for the Bugusege rainfall data.

Table 3.2: Climate station

Station ID	Easting	Northing	Start data	End date	Duration (years)	Missing Data
AWS Bugusege	34°16'E	01°09'N	1970	2018	49	19%

Projected Climatic data obtained from Marksim DSSAT weather file generator, were obtained from 2024 to 2040 under RCP 2.6 and 8.5.

River flow data was obtained from Directorate of Water Resources Management for R. Namatala and Nabijo. R. Namatala is gauged and monitored at Nangeye II (82264) and Northern IUIU (82235). The data obtained for R. Namatala was spanning for a duration of 73 years. R, Nabuyonga, a major tributary of R. Namatala was gauged and monitored at Namazaba (82248). The data record goes from April 1972 to September 1996, owned and operated by Directorate of Water Resource Management (DWRM).

Permitted Users data was obtained from Directorate of Water Resources Management for R. Namatala and Nabuyonga.

GIS data was a critical input in delineating the catchment. A 30m Digital Elevation Model utilized in catchment delineation was obtained from Surveying team from Air Water Earth (AWE) Limited as well as NASA . Shape files for R. Namatala, Nabuyonga and Nabijo were obtained from Ministry of Water and Environment (MWE). Land use maps were obtained from Google earth engine.

Table 3.3: Summary of data sources

Sn	Data requirement	Source
1.	Current Climatic Data	Uganda National Meteorological Agency
2.	Current Satellite Data	CHIRPS climate data
3.	Projected Climatic data for RCP 2.6 & 8.5	Marksim DSSAT weather file generator
4.	Flow Data	Directorate of Water Resources Management
5.	Permitted Users	Directorate of Water Resources Management
6.	Shapefiles for Mbale WSSP	Survey Team from Mbale WSSP Consultant
7.	Shapefiles for Rivers	Ministry of Water and Environment
8.	Land use maps	Google Earth Engine

9.	Digital Elevation Model (DEM)ss	National Aeronautics and Space Administration (NASA[1])
10.	Land use	National Forestry Authority (NFA)
11.	Soil and Geology	

Slides, books, textbooks, articles, and journals were used to obtain relevant and important information such as Detailed Design review report for Mbale WSSP. Similar research on other case studies was used and analyzed. The internet, which contains a wealth of information, was used at this stage to better understand the dynamics of river flow as a result of land use change with google scholar at the centre of the research.[2]

3.3.2 Consultations and discussions

This involved approaching specialized institutions like DWRM, MWE, Sironko District water officer and communities found in R. Namatala basin to get the understanding of the river dynamics.

3.4 Objective 1: To determine the current e-flow requirement

3.4.1 Surface flow assessment

The R. Namatala gauging station (Stn No. 82264) has a catchment area (540 km^2) which is lower than the delineated R. Namatala catchment (626.30 km^2). Stn No. 82264 presented good and reliable periods of flow data that were used in both statistical analysis and hydrological modelling. The 18% missing data was excluded from the analysis.

The R. Nabuyonga gauging station (Stn No. 82248) is part of the delineated R. Namatala catchment (626.30 km^2). Stn No. 82248 presented unreliable periods of flow data that were only used in water balance modelling. The 28% missing data was excluded from the analysis.

1 https://www.earthdata.nasa.gov/topics/land-surface/digital-elevation-terrain-model-dem/data-access-tools

2 https://scholar.google.com/

Table 3.4: Summary of flow records for R. Namatala and Nabuyonga Gauging stations

Element	**Description**	
Station	82264 (R. Namatala)	82248 (R. Nabuyonga)
Overall quality of the gauging station	Good Quality	Poor
Available chronic length / Selected data for analysis	Data available: 1948 - 2021 Selected data: 1948 – 2021 Missing Data: 18.1%	Data available: 1972 - 1996 Selected data: 1972 - 1996 Missing Data: 28%
Remark	Suitable for modelling with a R. Catchment area of 626.3 km^2	Suitable for water balance modelling

3.4.2 Frequency Analysis

Frequency analysis was vital in e-flow assessment as it revealed flow variability, defined and ecological flow requirements. Frequency analysis assisted in understanding the impact of water management on flow conditions, ensuring that aquatic ecosystems receive necessary flow levels to sustain health and biodiversity.

From Data obtained, the Mean Annual Daily (MAD) flow was obtained for the dataset as well as mean monthly flow using equation 1 (Maity, 2018).

$$\bar{x} = \frac{x_1 + x_1 \pm \cdots x_1}{n} = \sum_{i=1}^{n} \frac{x_i}{n} \qquad \text{(Equation 1)}$$

From Data obtained, the Median flow was obtained using equation 2 (Maity, 2018).

$$\sum_{i=1}^{n} P_x(x_i) = 0.5 \qquad \text{(Equation 2)}$$

A flow hydrograph was plotted for the flow data obtained using Excel 2019. The Flow duration Curve (FDC) was constructed using average daily discharges sorted from the highest value to the smallest value, and the exceedance ranging from 0 to 100% in 10 increments. This was done to determine the lowest daily flows at a 90% exceedance.

3.4.3 Flow frequency analysis using HEC SSP

Low, Average and Peak flow analyses were done to estimate high discharges that were used in Hydraulic e-flow estimation method. Annual Maximum, Average and Low daily flows in each year were used, inserted into HEC-SSP software utilizing log-Pearson Type III was used to provide the goodness of fit. The return periods considered were; 2, 5, 10, 20, 50, 100, 200, and 500 years

The selected peaks were fitted onto a theoretical frequency distribution using selected fitting method. Events for returns periods of interest even beyond the observed period of record were extracted with the assumption that future probabilities of exceedance will be the same as past probabilities to facilitate assessment of R. Namatala.

3.4.4 Water Quality Assessment

Baseline water quality assessments were carried out along the R. Namatala and tributaries in order to understand the physicochemical properties of the environment and its effects on terrestrial and aquatic ecosystems. In-situ measurements were carried out in 10No. sections as indicated in Figure 7.2 a to f (Appendix F: Water Quality).

3.4.5 Water Demand Assessment

3.4.5.1 Population Coverage

From the data collected, it was determined that on average community buffering the river walk a distance of at least 500 m to access water from the river. From this, Villages were mapped in a radius of 0.5 km from the river banks. From this, a total of 109 villages were selected in 6 districts of Mbale, Bududa, Sironko, Pallisa, Butaleja and Budaka (Figure 3.6). The list of the buffer villages is appended under annex.

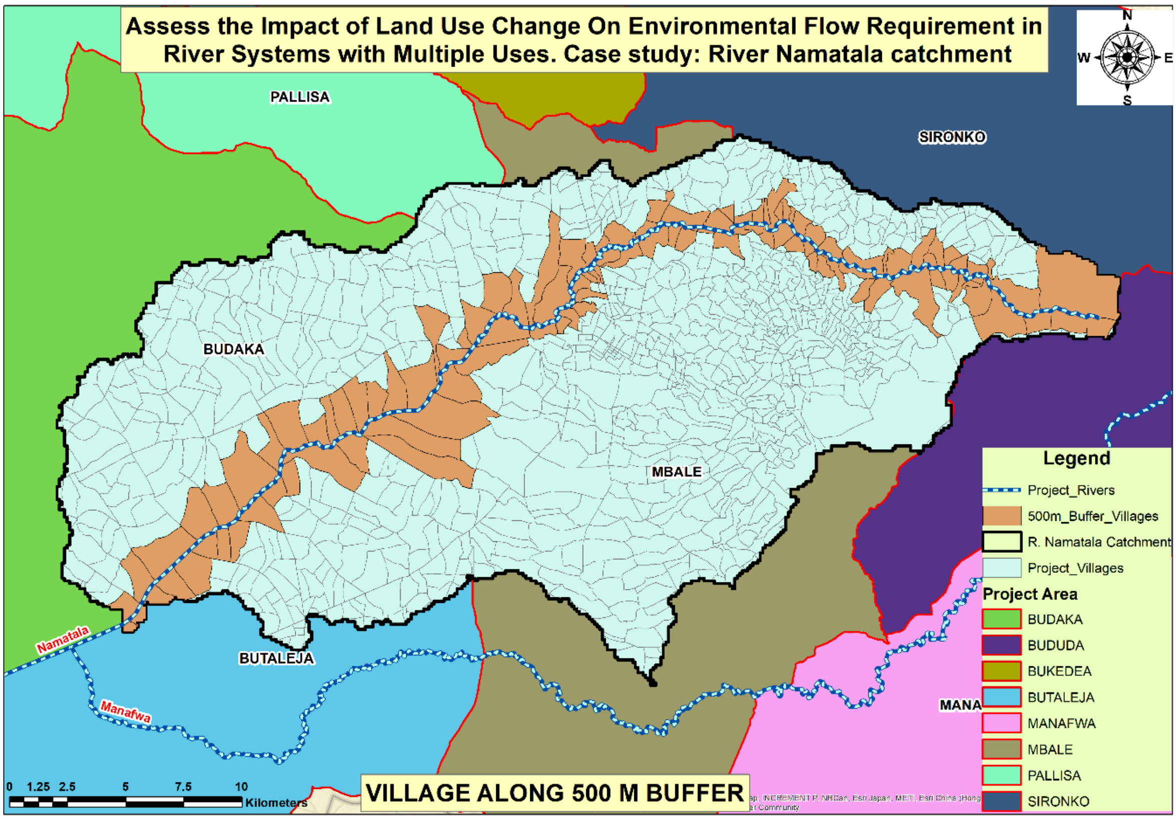


Figure 3.6: Villages Buffering R. Namatala

3.4.5.2 Population Projections

Populations were projected from UBOS Population data of 2014 hence the base year was considered as 2014. The initial year was taken to be 2023 because it coincided with the year when the research was initiated and ultimate year was considered to be 2040. This is in line with Uganda's Vision 2040. Population projections were done using the geometric population growth formula (Equation 3).

$$P_n = P(1 + r)^n \qquad \text{(Equation 3)}$$

Where, P_n is the population after n years;

P is the present population

r is the annual growth rate (%).

n is the study horizon

Table 3.5 showed the growth rates for the study area villages considered with Budaka, Bududa and Butaleja having 3.2% while Mbale having 2.5% and Butebo with 1.4%.

Table 3.5: Growth rates in R. Namatala Catchment

District	Adapted Population growth rates (%)		
	2014-2023	2023-2033	2033-2040
Mbale	2.5%	2.5%	2.5%
Pallisa	1.4%	1.4%	1.4%
Sironko	2.5%	2.5%	2.5%
Budaka	3.2%	3.2%	3.2%
Bududa	3.2%	3.2%	3.2%
Butaleja	3.2%	3.2%	3.2%

From the buffer villages (Figure 3.6) and growth rates (Table 3.5), domestic population was projected up to 2040. It should be noted that district-level population projections from UBOS do not distinguish between urban and rural areas. The global district growth rates have been applied in this sense. Nonetheless, as a greater proportion of the population currently resides in urban regions, it is anticipated that the equitable allocation of parishes between rural and urban areas will have no impact on population growth.

3.4.5.3 Domestic Water Demand

According to the MWE, (1999), the basic service level for rural areas, built-up areas and peri-urban zones is 20-25 litres per capita per day. The findings in the socio-economic revealed that on average, each person uses at least 24 l/ca/day and 48 l/ca/day to cater for domestic and livestock needs. A value of 25 l/ca/d was chosen to be the minimum seasonal water requirement for domestic use translating to 9125 l/ca in a 365-calendar year. These findings were in line with the assumptions done under the Augmentation Study report - demand projections for Mbale Water supply and sanitation Project (NWSC et al., 2021).

3.4.5.4 Livestock water needs (Lw)

According to a study conducted by FAO (2010) in the sub-Saharan region, growth rates for cattle, goats, sheep, and pigs should be 0.002, -0.041, -0.048, and 0.061, respectively. All of the project area's districts were considered to have the same rates of cattle growth.

According to MAAIF, (2017), one TLU needs 50 litres/day; one head of cattle, one goat, one sheep, one pig was deemed to be 0.7, 0.15, 0.15 and 0.4 of a TLU respectively. The conversion factor for poultry as proposed by Winchell (2001) is 0.005. Table 3.6 provides more information about the growth rates.

Table 3.6: Adopted livestock Growth Rates

	Assumptions				
	Cattle	**Goats**	**Sheep**	**Pigs**	**Poultry**
Livestock Growth Rates	0.002%	-0.041%	-0.048%	0.061%	3.10%

The current (2023) livestock counts were projected from UBOS's 2008 livestock census using the following formula:

$$L_n = L\,(1 + r)^n \qquad \text{(Equation 4)}$$

where, L_n is the livestock count after n years;

L the baseline (2008) livestock count

r is the annual growth rate (%).

Livestock water demand needs was calculated using on tropical livestock unit (TLU) water demand of 50 l/d. Livestock census undertaken by the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) in collaboration with the Uganda Bureau of Statistics (UBOS) was used. Estimation of the water demand for livestock was based on the duration of the dry season and animal unit water consumption.

By adding up the water requirements for each variety of livestock, including cattle, goats, sheep, pigs, and poultry, the present livestock water demand for the R. Namatala Catchment was calculated. Equation 5 was used to assess each variety of livestock's current water demand:

$$WD_{LT} = L_n \times WD_{TLU} \times L_c \qquad \text{(Equation 5)}$$

Where: WD_L is the water demand for each livestock type,

L_n is the current livestock count for each livestock type

WD_{TLU} is unit water demand for one (1) Tropical Livestock Unit (TLU)

L_c is the livestock coefficient.

3.4.5.5 Industrial Demand

In Uganda's rural areas, the demand for industrial water is quite moderate when compared to other users' use, such as home water users and prospective irrigation water demand. Water is used by industries in a variety of ways, both for processing and non-processing purposes. Examples of these uses include cleaning, heating, cooking, conveying raw materials or solvents, and even as a component of the final product (MWE, 2013).

The same methodology used to create the Awoja catchment management plan was applied to the assessment of industrial water demand (MWE, 2014). The water demand for rural industries was approximated as a percentage of the water demands of the agriculture, residential, and livestock sectors, according the Awoja watershed management plan. It was projected that metropolitan areas with city status would require thirty percent of the demand needed for the domestic, livestock, and agricultural sectors, while rural industries would need 1-6% percent.

3.4.5.6 Irrigation water needs (Iw)

It is now recognized that the gradual effects of population pressure and climate change on land use are starting to have a notable detrimental effect on agricultural productivity. For this reason, irrigation should be taken into consideration as an intervention to lessen the effects of climate change on agricultural production. Due to the large initial capital expenditure needs for the building of irrigation infrastructure and farmers' restricted access to agricultural finance, Uganda has seen modest investment in the planning and development of irrigation projects despite its importance and potential (MAAIF, 2017).

Land use maps from 1990 to 2040, both historical and projected, were created using ArcGIS and land change modeler and Google Earth Engine. Land Use Cover for 2022 shows that 61.3% of R. Namatala's total area (626.3 km^2) is made up of grassland, while 22.4% is made up of cropland, with 51% of the cropland area located in Mbale.

In estimating the potential irrigated farmland, Irrigated acreage of cropland was then investigated at 35% of the current and projected cropland as shown Table 3.7.

Table 3.7: Estimated Irrigable Area Assuming 35% of Irrigated Farmland

Catchment	District	Area (Hectares @35%)	
		_2022	_2023
R. Namatala	Mbale	287.32	287.46
	Butebo	0.44	0.44
	Sironko	7.07	7.07
	Budaka	74.67	74.71
	Bududa	0.11	0.11
	Butaleja	15.91	15.91
	Total	**385.52**	**385.7**

The irrigation water demand for the catchment was estimated by multiplying the projected (2023) farmland acreage with the approximated average annual gross irrigation water use (6,000m^3/ha/year) for Eastern Uganda as derived from the 2010-2035 National Irrigation Master Plan for Uganda (MAAIF & MWE, 2017). The figure was derived from cropping calendar baseline (2005) data compiled at district level in Uganda as published by (FAO, 2011)

Due to the limitation on proprietary information regarding projected acreage for irrigation, an expansion rate of 0.05% was applied on the current irrigated acreage to determine the projected irrigated acreage as follows:

$$A_n = A*(1+r)^n \qquad \text{(Equation 6)}$$

Where, A_n is the projected acreage after n years

A is the current irrigated acreage

r is the estimated irrigation expansion rate.

3.4.5.7 Permitted water abstractions (Pw)

Data on permitted water abstractions was obtained from the Directorate of Water Resources Management (DWRM). Figure 3.7 (a and b) shows the location of permitted users along the R. Namatala.

(a) Mota - Engil Abstraction Point (b) Mbale WSSP Intake Location

Figure 3.7: Permitted users on R. Namatala

Table 3.8 gives an overview of the permitted water abstractions on River Namatala. The location of the permitted users and abstraction points amounting to 13,999 m^3/day.

Table 3.8: Permitted water abstractions on River Namatala

NAMATALA RIVER			
User	**Reference**	**Abstraction (m^{3}/day)**	**Remarks**
a) NWSC Sironko (Namatala intake)	SIR201763/1SWMDW	13,939	n/a
b) Moto Engli Engenharia Construcao Africa	MBL203675/1SWJDW 2019	60	n/a
	Total	**13,999**	

3.4.5.8 Fish/Aquatic life water needs (Fw)

In determining ecosystem requirements, two methods were considered;

1. Estimation using Tennant's methods
2. Biodiversity Assessment

Tennant's (1976) method was used to estimate the environmental flow requirements for meeting aquatic water needs as well as recreational water needs (Lv et al., 2023). A biodiversity assessment was carried out along the river banks to ascertain the fauna utilizing R. Namatala. However, given the insufficiency of fish population, estimation using tenant's method was taken with a 5% of flow taken as the aquatic water needs.

3.4.6 Water Budgeting for R. Namatala Catchment

3.4.6.1 Water Balance Assumption

WEAP was used to determine water balance for R. Namatala catchment. A basic assumption of the WEAP model is that when a rainfall event occurs in a defined hydrological area, part of the water is stored in that area, some of it is lost through evapotranspiration, and part is lost from the catchment as surface runoff of the catchment Q. Simply situate, Precipitation is either transferred to surface run off, evaporates or is stored in the ground or in existing reservoir. That being said, the water balance is governed by Equation 7:

$$\text{Water inflows} = \text{water outflows} \pm \text{changes in storage} \quad (\text{Equation 7})$$

The basic water balance equation in such a situation then becomes:

$$P - Q - ET + Gin - Gout = Ds \qquad (\text{Equation 8})$$

Where:

- P is precipitation,
- Q is surface run off from the catchment,
- ET is evapotranspiration,
- Gin is Groundwater inflow,
- Gout is groundwater out flow,
- Ds is change in storage

Over a long period of time for a given catchment, Ds = 0. Therefore P – Q – ET + Gin - Gout = 0. Then, assuming that Gin and Gout are either equal or negligible:

$$P - Q - ET = 0 \qquad \text{(Equation 9)}$$

$$P = Q + ET \qquad \text{(Equation 10)}$$

3.4.6.2 Water Balance Studies

Water balance estimation can be thought of as a tool to assess the current status and trends in water resources availability in an area over a specific period of time and to strengthen water management decision-making by assessing and improving the validity of visions, scenarios and strategies. More specifically, the provision of appropriate and sustainable water use infrastructure in R. Namatala catchment and the subsequent equitable water use and allocation need to be based on a reliable estimate of the water balance within the basin. The annual stream discharge is mainly composed of interflow that contributes a major part of flow during the wet season and is followed by the baseflow that is critical to sustaining the streamflow during the dry season.

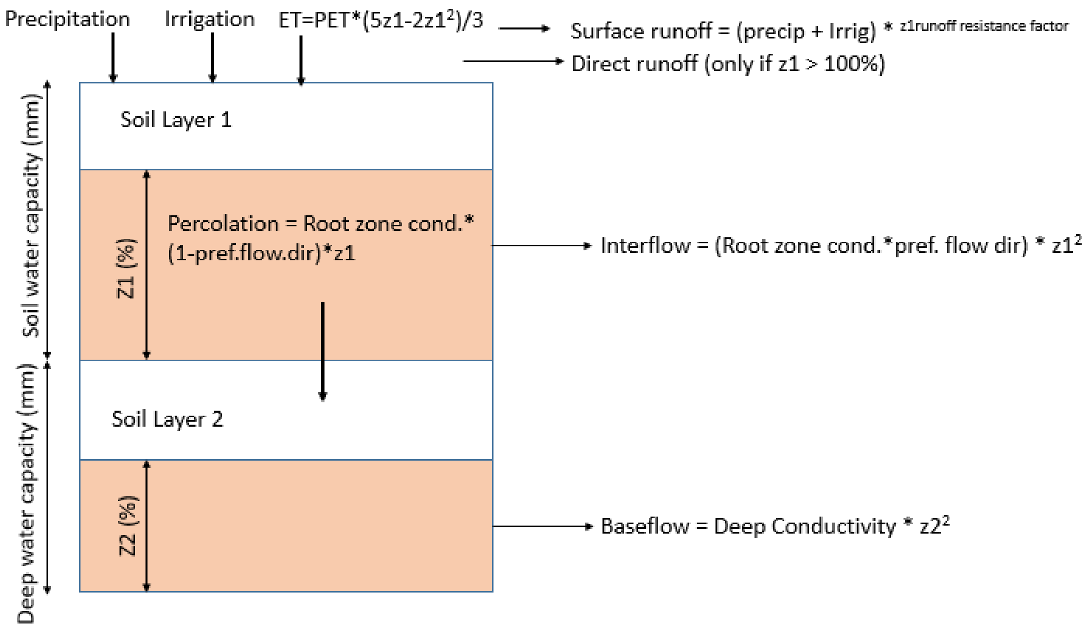


Figure 3.8: Water Balance concept Model

3.4.6.3 Model calibration

The Soil Moisture approach has 6 main parameters namely Crop Coefficient (Kc), Soil Water Capacity (Sw), Runoff Resistance Factor (RRF), Root Zone Conductivity (Ks), Deep Water Conductivity (Dw), Preferred Flow Direction (f). Form the sensitivity analysis, the best fit for runoff from the initial model test runs illustrated that the most sensitive to parameters include Sw, RRF, Kc and Dw. Estimation of model parameters was carried out using an automated tool known as PEST (Parameter Estimation) which is a free software package for Model-Independent Parameter Estimation and Uncertainty Analysis. The tool is an add-in in WEAP but it is also available for download at http://www.pesthomepage.org. To use the PEST tool, ranges of parameter estimates are provided and the tool run by randomly selecting parameters from the provided ranges. The best fit parameter set consists of the values for these parameters that give the best fit to the observations specified.

Figure 3.9: Main Parameters of the Soil Moisture Method

3.4.7 Biodiversity Assessment

The biodiversity assessment survey was undertaken through a preliminary field visit to evaluate logistical needs, characterize major habitat types, and select representative survey sites which emphasizes standardized protocols for ecological assessments (Freeman & Freeman, 2014).

For plants, rapid biodiversity assessments were conducted across the catchment using the DAFOR scale to estimate species cover. Vegetation were characterized per IUCN Red List criteria to identify critically endangered, endangered, or vulnerable taxa, producing an updated flora list, vegetation map, and distribution of conservation-concern species (IUCN, 2025).

Mammal surveys target medium to large ungulates and carnivores via line transect counts and sign-based methods, supplemented by sit, wait, and watch approaches, as recommended by Buckland et al., (2001)for estimating abundance and habitat use. Small mammals will be sampled using Sherman live traps baited with a groundnut's mixture, set for 450 trap nights across three sites (Kasangaki et al., 2012). Bird surveys utilized Timed Species Counts (TSCs) along transects at 200m intervals, scoring species from 6 (first 10 minutes) to 1 (last 10 minutes) to assess abundance. Water birds were counted at open water and wetland sites. Herptile surveys combined Visual Encounter Surveys (VES) for diurnal searches, dip netting for aquatic species and local interviews for reptile evidence.

Detailed methodology and analysis was attached under Appendix H: Ecological Study.

3.4.8 Environmental Flow Assessment

In this study, three methods were assessed i.e. Holistic, hydraulic and hydrological methods for the e-flow assessment to ascertain a variation in each method.

3.4.8.1 Hydrological Methods

Shaeri Karimi et al., (2012), Abdi et al., (2014), Brown & King., (2003), Tharme., (2003) and Dyson et al., (2013) undertook research on the hydrological method which in turn formed a basis for selection this approach for estimating of environmental flow.

Basing on Tennant's method, the river was categorised as one with aquatic life and recreation. The catchment exhibited activities like washing, swimming, bathing and fishing as recreational advantages provided by the River. Presence of Fish like catfish, tilapia downstream was a sign of life in R. Namatala as shown in Figure 3.11 below. This elevates the status of the river to an Eco-sensitive water system coupled with a lot of upstream and downstream users. Tennants method provides for a 30% of MAF for rivers with this status

Figure 3.10: Recreational Activities along R. Namatala
Source: (NWSC et al., 2021)

Figure 3.11: Fish Species in R. Namatala

Two approaches under hydrological method were used i.e. Tenants Method and Tessman modifications. R. Namatala was categorized as “in streams/rivers with fish and recreation” hence a value of 30% was considered (Brij Gopal, 2013).

From the modifications considered by Tessman, classification of “40% MAF, if MMF>MAF”.

3.4.8.2 Hydraulic rating Methods (Wetted Perimeter Method)

Abdi et al., (2014), Brown & King., (2003), Tharme., (2003), Dyson et al., (2013), Lv et al., (2023) undertook studies on the hydraulic method which in turn formed a basis for selection this approach for estimating of environmental flow.

Wetted Perimeter method was done using software of HEC-RAS and Arc SWAT tool 10.7. A digital Elevation Model (DEM) of 30m resolution was used to determine the topography. Given the size of the catchment (626.3 km^3) and river length of more than 45 km, it was expensive to survey the entire catchment hence sectional survey was undertaken. Topographical survey of the sections was done to assist in correction of DEM especially upstream in the mountainous area. The channels of the river were assumed to have a fixed bed and considered to maintain the stratification.

Flood inundation extents and depth were estimated using Hydrological Engineering Centre River Analysis System (HEC-RAS) system under steady flow conditions with river sections selected based on accessibility. HEC-RAS was used to establish river stages at various sections, and determined longitudinal water surface profiles. The downstream slope for normal depth computation was assumed to be ranging from 1 – 6%. The manning's coefficients were taken to be 0.035 on the left and right over bank and 0.035 for the main river channel.

3.4.8.3 Holistic approach

The building block method was considered for holistic e-flow assessment method. Five building blocks were considered; (1) Hydraulic requirement (2) Flora, (3) Fauna and Herptile, (4) Socio-Economic requirements and (5) aquatic requirement.

3.5 Objective 2: To determine land use change trends in R. Namatala Catchment.

3.5.1 Data collection for Land Use Land Cover Changes

Spatial land use/cover data from LANDSAT 7 images were collected and analyzed to build land use systems for the R. Namatala watershed from 1984 to 2021. The supervised Google Earth Engine code was created and used to generate land use pictures (Appendix C: Land Use classification for Google Earth Engine).

Six land use classes were selected and these included: Built up, Cropland, Forestland, Grassland, Water and wetland. Different land cover types were identified and mapped in the catchment with the goal of training the code to recognize land cover patterns (Appendix C: Land Use classification for Google Earth Engine Figures a to h). Google Earth was utilized to map out more areas given the understanding of the study area based on the field land cover types obtained. A total number of 748 sample points were added to the google earth engine to train the imagery.

3.5.2 Land use Data Acquisition

The geographic land use/cover datasets utilized in the study were collected from Google Earth Editor. The study used Landsat dataset (LANDSAT/LE07/C02/T1 L2) with land use images from as far as 1985 to 2021 (Seto et al., 2002). This dataset was chosen because it had the required timeframe dating back as far as 20 years from at least 2021.

The Landsat images included a code that was entered into the code editor.

3.5.3 Land Data Processing

Land use data processing was done using Google earth engine where images, shapefiles, and raster files were uploaded or downloaded. Google earth engine utilized two main components that process data i.e. Google Earth Engine Explorer for viewing data and Google Earth Engine Playground for writing codes (Velastegui-Montoya et al., 2023b).

3.5.4 Land use change period

The land use change period was between 1984 to 2020 in intervals of at least 4 years. The staggering choice of year interval was based on the quality of image and cloud cover captured by the satellite. The selected land use change period was;

1. 1984-1995 (11 years)
2. 1995-1999 (5 years)
3. 1999-2007 (8 years)
4. 2007-2010 (4 years)
5. 2010-2014 (4 years)
6. 2014-2020 (6 years)

3.5.5 Land Use / Land Cover Planning

Landsat imagery was used for various epochs using Arc GIS 10.7. Landsat 7 imagery was classified to determine the land use/land cover types in the study area, as well as the rate at which land use changes between 1984 to 2020. The Landsat data images were georeferenced to Universal Transverse Mercator (UTM) coordinates, zone 36N, WGS84 Datum with a resolution of 30 m.

Google earth engine was used to determine the land use over the specified period. A code was written showcasing imagery to be obtained for R. Namatala catchment (Appendix D: Land Use Code).

3.5.6 Land use Accuracy assessment

To ensure accuracy of the images, a total number of 748 sample points were added to the GEE model. These were categorized as water body (106No.), Agricultural land (159No.), Wetland (54No.), Forestland (120No.), Built up land (217No.) and Grassland (94No.). The resulting Kappa training coefficient was 0.83 while validation accuracy was 0.89 indicating near perfect and excellent model accuracy. The overall training accuracy for the imagery was 97% at a resolution of 30 m.

3.5.7 Land Use / Land Cover change assessment

Land use change assessment followed the subsequent procedure detailed in Figure 3.12 below.

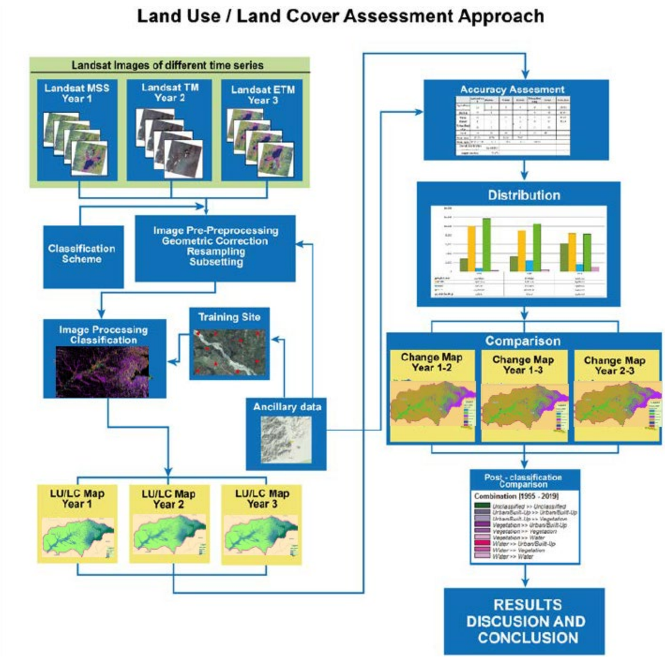


Figure 3.12: Land use change analysis

3.5.7.1 Land Use / Land Cover Change Forecast

Land use forecast was done using Terrset model Version 18.11 designed by Clarks Lab. Terrset Geospatial Monitoring and Modelling system incorporates IDRISI GIS and Image processing tools that are focused on sustainable development. Land change Modeler was used in assessment of projected land use changes in Namatala catchment from 2020 to 2040.

The land use forecast in R. Namatala Catchment was done in line with Uganda's vision 2040.

Figure 3.13: Terrset Modelling software

3.6 Objective 3: To determine the impact of LULC and climate change on the Environmental Flow requirements of R. Namatala

3.6.1 Climate Change Analysis

3.6.1.1 Period of Analysis

The period for climate change analysis to estimate future flows between 2023 and 2040 aligned with Uganda's Vision 2040, which emphasized sustainable water resource management and climate resilience.

3.6.1.2 Historical rainfall Analysis

The precipitation data for R. Namatala was collected from Bugusege AWS recorded as daily precipitation (mm/day) values representing the entire study area. The data in consideration was from 1970-2018 spanning over 49 years. Satellite data from Jan 2000 – May 2024 (23 years) was obtained from CHIRPS using Google Earth Engine (GEE) to help in gap filling of the missing data.

3.6.1.3 Choice of Pathways

CMIP5 was selected for the climate change analysis because of readily available downscaled data on daily basis for R. Namatala catchment. The downscaled data was obtained from Marksim DSSAT weather file generator[3].

3.6.1.4 Choice of RCP

The study utilized RCP 2.6 and RCP 8.5 as the two climatic extremes of high likely and highly unlikely.

3.6.1.5 Choice of GCMs

Marksim DSSAT weather file generator developed by CIAT and CGIAR incorporates 18No. GCMs. These GCMs include; BCC-CSM1-1, BCC-CSM1-1-M,CSIRO-MK3-6-0, FIO-ESM, GFDL-CM3, GFDL-ESM2G, GFDL-ESM2M, GISS-E2-H, GISS-E2-R, HadGEM2-ES, IPSL-CM5A-LR, IPSL-CM5A-MR, MIROC-ESM, MIROC-ESM-CHEM, MIROC5, MRI-CGCM3 and NorESM1-M as detailed below.

Table 3.9: List of CMIP5 GCMs used in the study

[3] https://gisweb.ciat.cgiar.org/MarkSimGCM

No	Modelling Centre	Model	Resolution (Lon × Lat)
1	Beijing Climate Center China	BCC-CSM1.1(m)	2.8° × 2.8°
2	Beijing Climate Center **China**	BCC-CSM1-1	2.8° × 2.8°
3	National Center for Atmospheric Research, USA	CCSM4	1.25° × 0.94°
4	National Center for Atmospheric Research USA	CESM1-CAM5	1.4° × 1.4°
5	Commonwealth Scientific and Industrial Research Organization, **Australia**	CSIRO-Mk3.6.0	1.86° × 1.87°
6	The First Institute of Oceanography, SOA China	FIO-ESM	2.8° × 2.8°
7	Geophysical Fluid Dynamics Laboratory, USA	GFDL-CM3	2.5° × 2.0°
8	Geophysical Fluid Dynamics Laboratory, USA	GFDL-ESM2G	2.5° × 2.0°
9	Geophysical Fluid Dynamics Laboratory, USA	GFDL-ESM2M	2.5° × 2.0°
10	NASA/GISS (Goddard Institute for Space Studies) USA	GISS-E2-H	2.5° × 2.5°
11	NASA/GISS (Goddard Institute for Space Studies) USA	GISS-E2-R	2.5° × 2.5°
12	Met Office Hadley Centre UK	HadGEM2-AO	1.25° × 1.87°
13	Met Office Hadley Centre UK	HadGEM2-ES	1.87° × 1.25°
14	Institut Pierre Simon Laplace France	IPSL-CM5A-LR	1.89° × 3.75°
15	Institut Pierre Simon Laplace France	IPSL-CM5A-MR	1.26° × 2.5°
16	Atmosphere and Ocean Research Institute, The University of Tokyo, Japan	MIROC5	1.4° × 1.4°
17	Atmosphere and Ocean Research Institute, The University of Tokyo, Japan	MIROC-ESM	2.8° × 2.8°
18	Atmosphere and Ocean Research Institute, The University of Tokyo, Japan	MIROC-ESM-CHEM	2.8° × 2.8°
19	Meteorological Research Institute Japan	MRI-CGCM3	1.12° ×1.12°
20	Bjerknes Centre for Climate Research, Norwegian Meteorological Institute, Norway	NorESM1-M	2.5° × 1.9°

Source: (Salman et al., 2018)

GCM resolutions varied, with the maximum being 2.80 x 2.80 for BCC-CSM1.1(m), BCC-CSM1-1, and MICROC-ESM-CHEM, and the lowest being 1.120 x 1.120 for MRI-CGCM. The best results were obtained by carefully choosing each of the 18 Models to account for this uncertainty.

3.6.2 HBV model

The HBV model was developed as a conceptual runoff simulation model with a simple structure. The model is semi-distributed and allows the catchment to be divided into sub basins, elevations, and vegetation zones.

HBV models comes with a set of parameters to which catchment, land use and elevation are characterized (Seibert & Vis, 2012, Lawrence et al., 2009; Seibert, 1998). These default parameters come with software and are changed during manual calibration.

Table 3.10: Catchment parameters used in HBV model

Name	Unit	Valid Range	Default Value	Values used for calibration	Description
PERC	mm/Δt	[0,inf)	1	2500	Threshold parameter
Alpha	-	[0,inf)	0	0	Non-linearity coefficient
SUZ/UZL	mm	[0,inf)	20	2500	Threshold parameter
K0	1/Δt	[0,1)	0.2	0.9	Storage (or recession) coefficient 0
K1	1/Δt	[0,1)	0.1	0.9	Storage (or recession) coefficient 1
K2	1/Δt	[0,1)	0.05	0.15	Storage (or recession) coefficient 2
MAXBAS	Δt	[1,100]	1	1	Length of triangular weighting function
Cet	1/°C	[0,1)	0	0.001	Potential evaporation correction factor
PCALT	%/100m	(-inf, inf)	10	3	Increase of precipitation with elevation
TCALT	°C/100m	(-inf, inf)	0.6	0.6	Decrease of temperature with elevation
Pelev	m	(-inf, inf)	0	0	Elevation of precipitation data in PTQ
Telev	m	(-inf, inf)	0	0	Elevation of temperature data in PTQ
PART	-	[0,1)	0.5	0.5	Portion of the recharge which is added to groundwater box 1
DELAY	Δt	[0,inf)	1	1	Time period over which recharge is evenly distributed
TT	°C	(-inf, inf)	0	0	Threshold temperature
CFMAX	mm/Δt °C	[0,inf)	3	2.5	Degree-Δt factor
SP	-	[0,1]	1	0	Seasonal variability in degree-Δt factor
SFCF	-	[0,inf)	1	0.9	Snowfall correction factor
CFR	-	[0,inf)	0.05	0.05	Refreezing coefficient
CWH	-	[0,inf)	0.1	0.1	Water holding capacity
CFGlacier	-	[0,inf)	1	0	Glacier correction factor
CFSlope	-	[0,inf)	1	0	Slope correction factor
FC	mm	[0,inf)	200	25900	Maximum soil moisture storage
LP	-	[0,1]	1	0.2	Soil moisture value above which Aet reaches pet

Name	Unit	Valid Range	Default Value	Values used for calibration	Description
BETA	-	[0,inf)	1	0.7	Parameter that determines the relative contribution to runoff from rain or snowmelt

Figure 3.14 illustrates a model structure for HBV that incorporates linear reservoir equation. Three water balance routines were interfaced in the HBV model; Snow Routine and Soil Moisture Routine.

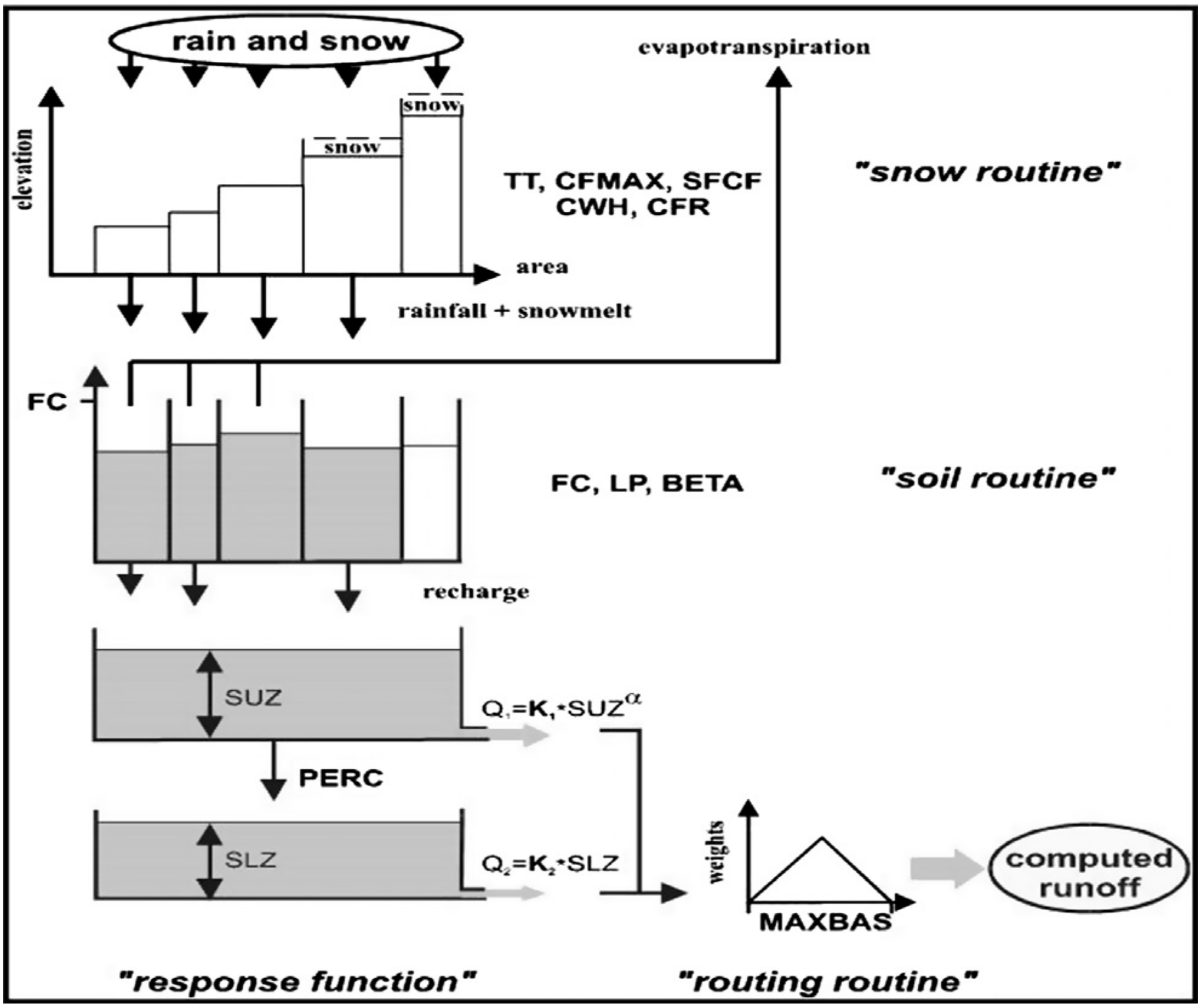


Figure 3.14: HBV-light model structure
Adopted from: (Seibert, 2000)(Seibert, 2000).

These routines are classified as follows;

1. The parameters FC, LP, and BETA fall under Snow Routine. Since there has never been a snow climate in the watershed, this element was left as default (Birundu et al., 2016). This element was kept as default since there has never been a snow climate in the watershed.

2. The soil moisture routine makes use of the potential evapotranspiration data. The wetness index of the basin is determined by the utilization of soil moisture interception and storage (Birundu et al., 2016). The soil moisture routine parameters FC, LP and BETA are classed as catchment parameters. These factors influenced the water flow in terms of the soil's ability to store moisture and the proportionate role that precipitation played in runoff.
3. The response function transforms excess water in the soil moisture zone into run-off. It includes the effect of direct precipitation and evaporation on the part representing lakes, rivers and other wet areas (Birundu et al., 2016). Response Routine parameters include PERC, Alpha, UZL, K_0, K_1, K_2, DELAY, and PART. These factors influence the interaction between runoff and ground water, with factors like PART and DELAY influencing the pace of ground water recharging. Assuming a minimal ground water balance (Gin=Gout), DELAY and PART were left as default.

In terms of sensitivity analysis in calibration, Soil moisture routine parameters and Response function parameters were used in manual calibration as illustrated in Figure 3.14.

3.6.2.1 Model evaluation

Seibert, 2000; Driessen et al., 2010; Al-Safi & Sarukkalige, 2017; Twesige et al., 2019 observed that there is great significance in the way the data are assessed during the calibration process. As a result, the modeling performance was evaluated based on three efficiency criteria: Kling–Gupta efficiency, Model efficiency (Reff or NSE), and (KGE).

3.6.2.2 HBV model Calibration and validation

Due to the sensitivity of the HBV model to parameter calibration, it was calibrated manually using parameters as detailed in Table 3.11 (Bergström, 1992, Driessen et al., 2010, Montero et al., 2016). The river was not divided into basins in order to determine the streamflow order, therefore data from the upstream basins did not need to be computed for the downstream basins right away. Consequently, a more user-friendly single catchment calibration was generated (Addor et al., 2016). The watershed was managed in accordance with the ongoing recognition of the river's flow as a natural phenomenon.

Table 3.11: Parameters ranges used for the calibration

Name	Display Name	Unit	Description	Lower Limit	Upper Limit
PERC	PERC	mm/d	Threshold parameter	0	2500
UZL	UZL	Mm	Threshold parameter	0	2500
K0	K0	1/d	Storage coefficient 0	0.000001	0.9
K1	K1	1/d	Storage coefficient 1	0.000001	0.9
K2	K2	1/d	Storage coefficient 2	0.00000001	0.1
MAXBAS	MAXBAS	d	Length of triangular weighting function	1	2.5
PCALT	PCALT	%/100m	Change of Precipitation with elevation	10	10
TCALT	TCALT	°C/100m	Change of temperature with elevation	0.6	0.6
Pelev	Elev. of P	m	Elevation of precipitation data in the PTQ file	0	0

Also, the three main criteria of fit were used. These were including visual inspection of the expected computed and observed hydrograph, use of the Root Mean Square Error (RMSE), Nash-Sutcliffe Efficiency (NSE), coefficient of determination criterion (R^2) and Kling- Gupta Efficiency (KGE) (Radchenko et al., 2013; Usman et al., 2022; Montero et al., 2016; Seibert, 1998).

Root Mean Square Error (RMSE): represents the residuals' standard deviation (prediction errors). The distance between the data points and the regression line is measured by residuals, and the spread of these residuals is measured by RMSE (Montero et al., 2016; Seibert, 1998). Put otherwise, it indicates the degree to which the data is centered around the line of best fit. Errors in root mean square are frequently utilized to validate experimental results in climatology, forecasting, and regression analysis. This establishes a direct link with the correlation coefficient and was used to determine the standardized observations and forecasts that were utilized as RMSE inputs in the HBV model (Lawrence et al., 2009).

$$RMSE = \sqrt{(f-o)^2} \quad \text{(Equation 11)}$$

Where:

f = forecasts (expected values or unknown results),

o = observed values (known results

Coefficient of Determination Criterion (R^2): indicates the linear relationship between the simulated and observed variables and assesses the proportionate variation in the simulated variable (Lawrence et al., 2009) explainable by the observed variable. R^2 is determined in this way:

$$\frac{(\Sigma(Q_{obs}-\bar{Q}_{obs})(Q_{sim}-\bar{Q}_{sim}))^2}{\Sigma(Q_{obs}-\bar{Q}_{obs})^2\,\Sigma(Q_{sim}-\bar{Q}_{sim})^2} \quad \text{(Equation 12)}$$

Where

Qobs = Observed Discharge

Qsim = Simulated Discharge

Q = mean of the observed Discharge

S = mean of the simulated Discharge

n = number of observations under consideration

The model was calibrated manually using a trial-and-error method (Addor et al., 2016; Radchenko et al., 2013; Seibert, 2000; Twesige et al., 2019; Usman et al., 2022). The match of the simulated runoff to the observed runoff was evaluated using various criteria:

- Visual inspection of plots with Qsim and Qobs
- Accumulated difference
- Statistical criteria

The HBV model often uses the coefficient of efficiency, or R_{eff}, to evaluate simulations. R_{eff} contrasts the model's prediction with the most straightforward forecast—a constant number representing the observed mean value for the full time (Bergström, 1992; Lawrence et al., 2009; Seibert, 1998).

$R_{eff} = 1$ Perfect fit, Qsim (t)= Qobs (t)
$R_{eff} = 0$ Simulation as good (or poor) as the constant-value prediction
$R_{eff} < 0$ Very poor fit

3.6.2.3 Model Calibration

The warmup period of 1991–1999, the calibration period of 2000–2010, and the validation phase of 2011–2020 were used to set up the HBV model. Thirty years of the

R. Namatala basin's daily streamflow measurements were available. The model was calibrated using Powell (GAP) optimization using the Genetic Algorithm. The model parameter ranges selected for the calibration followed the guidelines provided in the HBV handbook. It is important to remember that utilizing unrealistic parameter settings increases the likelihood of producing a decent simulation when the parameter range is overly expanded. A total of 65,000 GAP runs and 1,000 No. runs were used to calibrate the model for local optimization. Table 3.11 and Table 3.10 provide the model's parameter ranges during calibration.

Table 3.12: Warming Up, Calibration and Validation time frame

	Time Period
Warm up Period	1991–1995
Calibration	1996–2005
Validation	2006–2020

3.6.2.4 Prediction of Flows using HBV

The inputs are land use, discharge and rainfall & Temperature under the climate change scenarios of RCP 2.6 & 8.5. In prediction of future flows, parameters used in calibration, downscaled climatic data from 2023 to 2040 for RCP 2.6 & 8.5, projected land use/ land cover change from 2030 to 2040 were added to the HBV Model and run to obtain simulated flows for 2030 and 2040.

The HBV model prediction steps are depicted in the Figure 3.15 below.

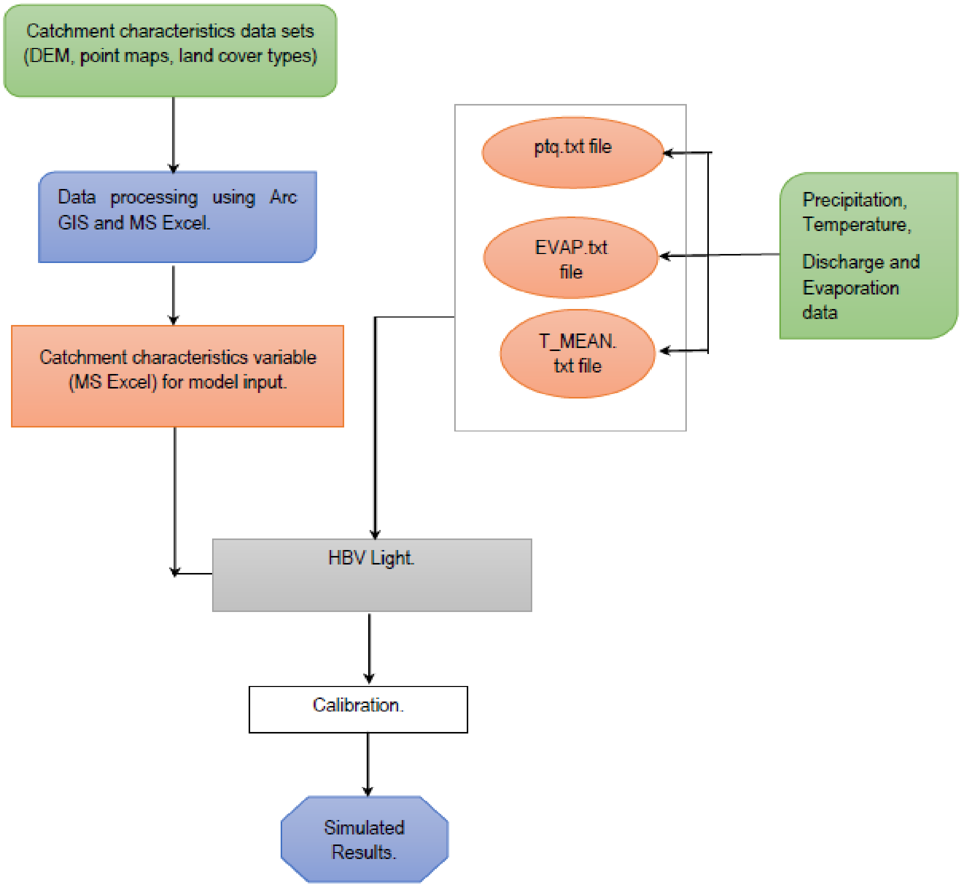


Figure 3.15: Flowchart showing the Input and Output Process of the HBV Light Model

3.6.3 Frequency analysis for projected flows

Frequency analysis was done in accordance to the methodology under Objective 1: To determine the current e-flow requirement, section 3.4.2 Frequency Analysis under RCP 2.6 and 8.5.

3.6.4 E-flow requirement for 2040

Environmental flow requirements was done in accordance to the methodology stipulated under Section 3.4.8 Environmental Flow Assessment under Objective 1: To determine the current e-flow requirement under RCP 2.6 and 8.5.

3.6.5 Proposing management strategies

Basing on the findings, different management strategies were developed to ensure that the ecosystem is restored to an acceptable standard that ensured life. These management strategies will also to ensure that the minimum flow that is required by the ecosystem is met. With this, a limit to which water can be abstracted from R. Namatala was determined.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter is a presentation of the findings and discussions. Charts, tables, and graphs are used for the purpose. Photographs of field observations gathered throughout the study were also used in data analysis and presentation. The results were interpreted in light of the specified study goals.

The flow analyses done were aimed at determining a dependable flow experienced on R. Namatala. Mean annual Flows (MAF) were obtained and used in the determination of environmental flow using Tenant's methods. The MAF was also used as an input to determine the hydraulic environmental flow requirement of R. Namatala.

Mean Monthly Flows (MMF) were used as an input in Water Balance, Tenant's method as well as Tessman's modification in determining environmental flow requirement.

4.2 Objective 1: To determine the current e-flow requirement.

Flow duration analysis was undertaken to enable statistical characterization of the observed stream flow time series data for R. Namatala and its major tributary R. Nabuyonga.

The R. Namatala flow hydrograph demonstrated temporal variation in line with wet and dry season trends, with a high-low alternation in flows. R. Namatala exhibited a sequential variation in flows, with the dry season having flows as low as 0.496 m^3/s and the rainy season exhibiting exceptionally high flows of 41.057 m^3/s (Figure 4.1).

The R. Nabuyonga flow hydrograph demonstrated temporal variation in line with wet and dry season trends, with a high-low alternation in flows. Further to this, the data exhibited a lot of missing data amount to 28% which was excluded from the analysis. R. Nabuyonga exhibited a sequential variation in flows, with the dry season displaying flows as low as 0.156 m^3/s and the rainy season exhibiting exceptionally high flows of 4.11 m^3/s (Figure 4.2).

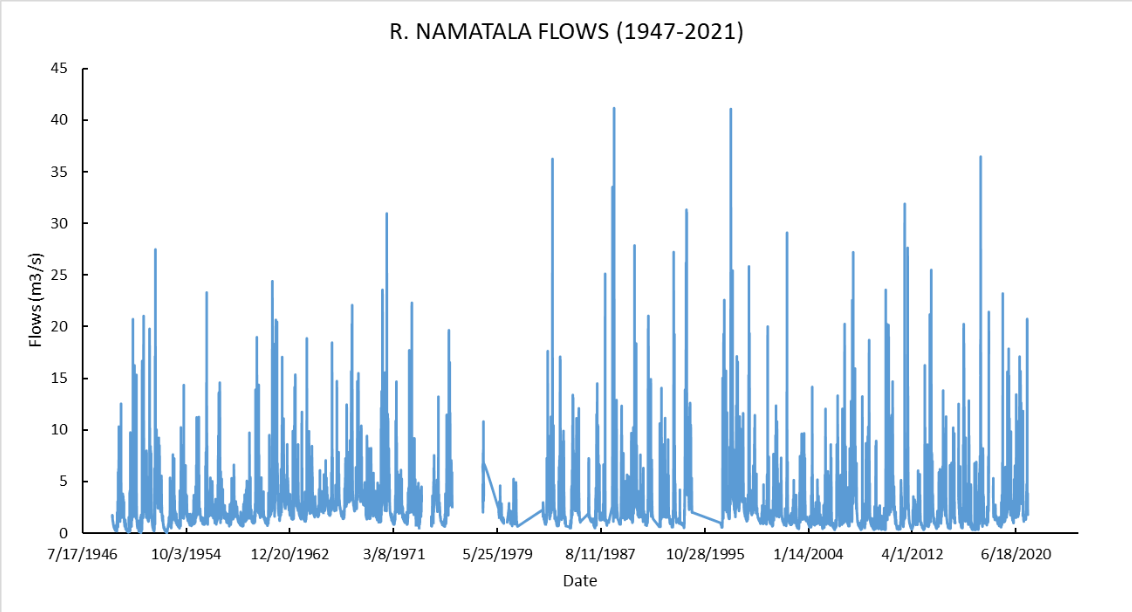


Figure 4.1: R. Namatala flow hydrograph

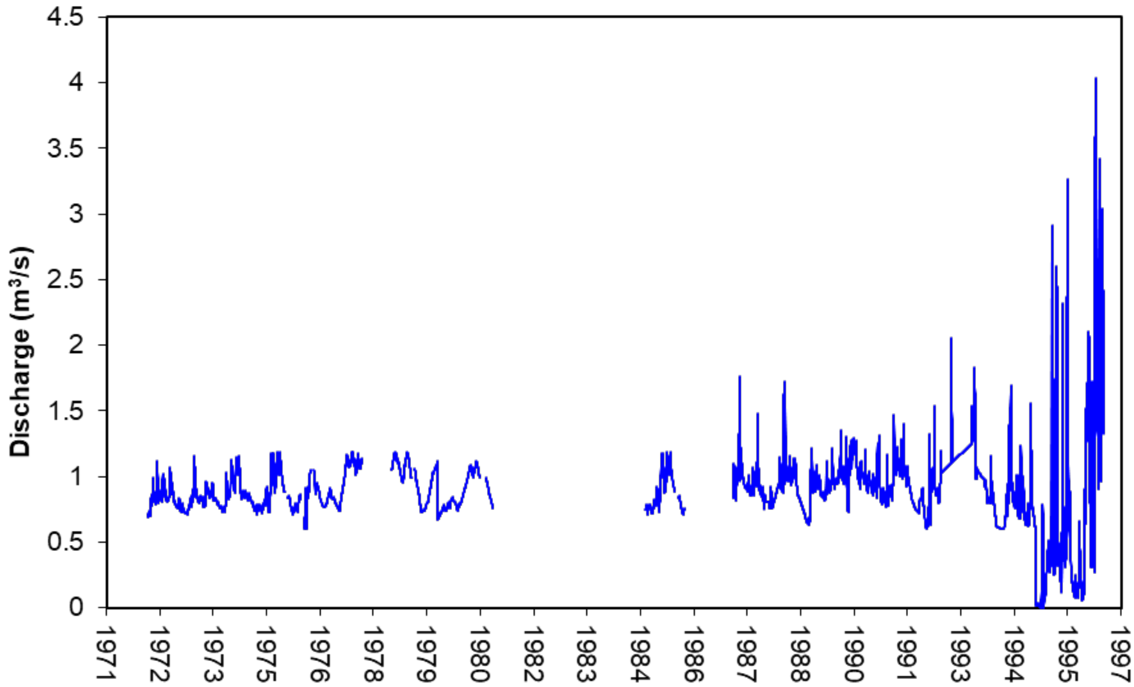


Figure 4.2: R. Nabuyonga flow hydrograph

A flow duration curve was developed from daily discharges at Stn No. 82264 to obtain a flow corresponding at 90% exceedance probability (Figure 4.3).

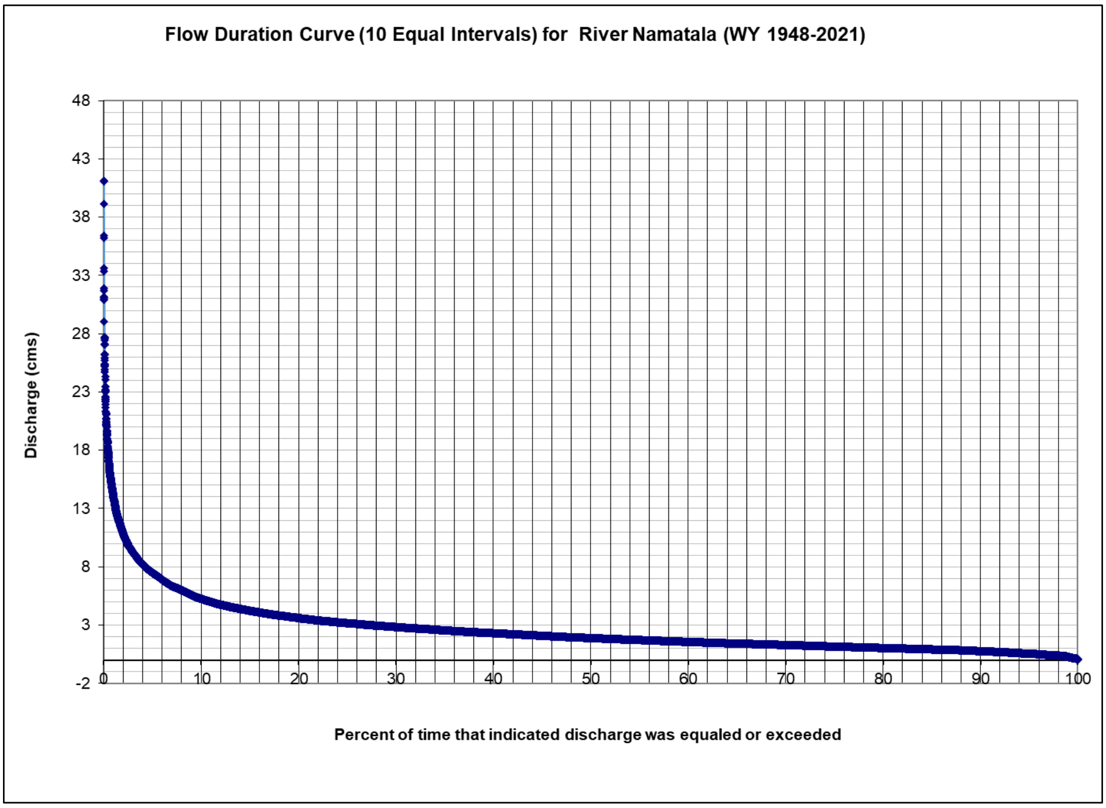


Figure 4.3: Flow Duration Curve for R. Namatala based on measured daily flow

On R. Namatala, the research predicted that at 90%, a daily discharge of 0.76 m^3/s will be matched or exceeded at any given time. Figure 4.3 displayed a curve with a reasonably steep slope indicating a highly changeable stream. The stream's rapid runoff of rainfall was mostly driven by the steep slopes and the catchment's limited storage.

Basing on the data, the mean annual flow of 2.65 m^3/s was obtained from river flows dating back 73 years. According to Figure 4.4, the data showed a temporal variation in flows with R. Namatala fluctuating in respect to the mean (2.65 m^3/s). This illustrated the seasonal variability of R. Namatala over the years with 1978 chosen as the water year and 1953, 2009, 2012 regarded as the dry years.

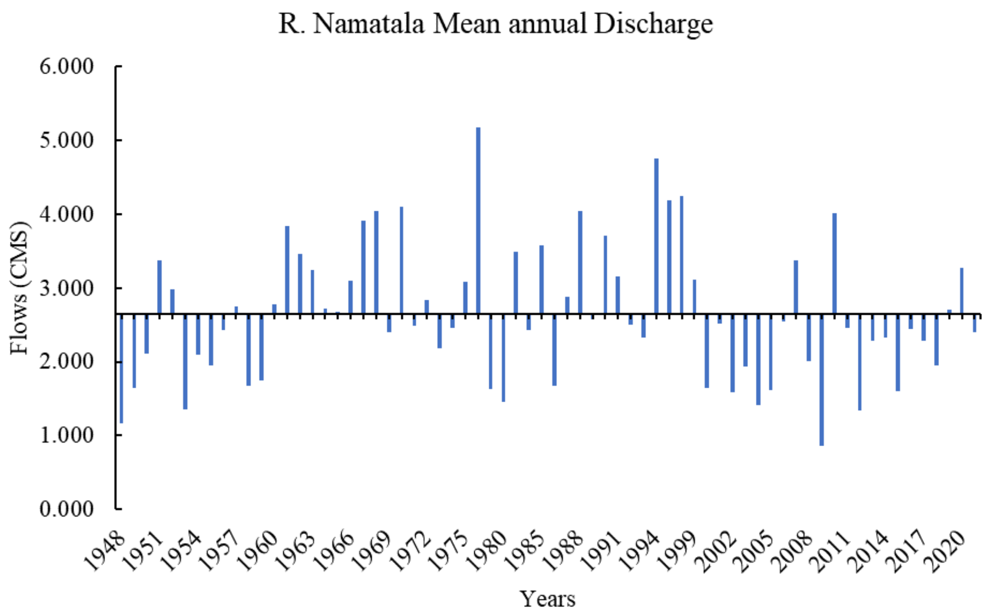


Figure 4.4: R. Namatala Mean Annual Discharge for 73 years

In terms of Mean monthly flows (MMF), R. Namatala flows were categorized monthly from January to December analyzed for the 73 years. Table 4.1 revealed that R. Namatala has a mean monthly flow of 2.68 m^3/s.

Table 4.1: Mean Monthly flow of R. Namatala determined over 73 years period

Month	**Mean Monthly Flows**
January	1.39
February	1.12
March	1.39
April	2.86
May	4.73
June	3.11
July	2.67
August	3.48
September	3.10
October	3.13
November	3.06
December	2.12
MMF	**2.68**

According to Figure 4.4, R. Namatala also experiences a seasonal pattern of December to March (4 Months) as the low flow period and two flood periods of April to June (Large Flood) and August to November (Small Flood).

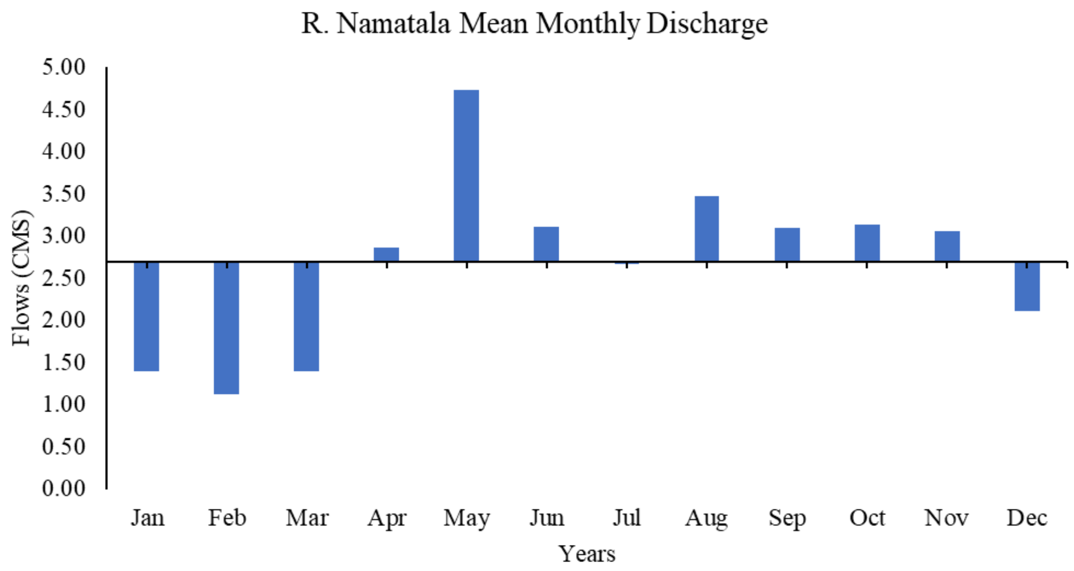


Figure 4.5: R. Namatala Mean Monthly Discharge

4.2.1 Peak Flow Analysis

Flow analysis was done to determine the peak flow, Average flow and the low flows experienced at R. Namatala using HEC-SSP (Table 4.2). Results from the HEC-SSP analysis showed that the minimum annual daily flows at a 25-year return period of 1.474 m^3/s, the maximum annual daily flows at a 25-year return period of 36.9 m^3/s, and the average annual daily flows at a 25-year return period of 4.616 m^3/s. These classifications formed the basis for hydraulic E-flow assessment.

Table 4.2: Representation of flows exceeded at different recurrence intervals

Return Period (Years)	Percentage Exceedance	Maximum Daily Flows (m^3/s)	Average Daily Flows (m^3/s)	Low Daily Flows (m^3/s)
500	0.2	51.3	6.2	1.735
200	0.5	47.4	5.762	1.687
100	1	44.2	5.406	1.636
50	2	40.7	5.026	1.567
25	**4**	**36.9**	**4.616**	**1.474**
10	10	31.1	4.011	1.296
5	20	26	3.48	1.099
2	50	17.5	2.579	0.694
1	80	10.9	1.839	0.352
1	90	8.3	1.517	0.224
1	95	6.5	1.283	0.146
1	99	3.9	0.917	0.057

4.2.2 Socio-Economic Status of R. Namatala Catchment

4.2.2.1 Population and Demographics

The estimated catchment population was derived from UBOS, (2014) data. The percentage of each district in the catchment was matched to the data. Table 4.3 illustrates the combined population of the six districts: Mbale, Sironko, Budaka, Bududa, Butaleja, and Pallisa was 1.4 million. Based on the districts' percentage coverage, the catchment's total population was 355,312; Mbale, with its 249,322 inhabitants, accounted for the majority of this population, followed by Budaka (54,213 people).

Table 4.3: Base Population of R. Namatala Catchment

No	District	Catchment area coverage (%)	Popn UBOS	Catchment Popn
1	Mbale	51	492,804	249,333
2	Pallisa	2	386,074	8,760
3	Sironko	8	246,636	20,158
4	Budaka	26	208,439	54,213
5	Bududa	1	211,683	1,503
6	Butaleja	12	245,873	30,107
Total		**100**	**1,405,435**	**364,074**

Source: (UBOS, 2014)

4.2.2.2 Gender

According to NWSC et al., (2022), male responders made up the majority (54%). This is due to the fact that there were always males in the houses while the women were working on the land and taking care of other household chores like cooking, getting water, and gathering firewood. Though it also suggests that women could not be available for communal activities, this shows that men are readily available in the community (Sempewo et al., 2021).

4.2.2.3 Local Economy and Employment

In the Namatala watershed, agriculture continues to be the main driver of the economy. According to NWSC et al., (2022), mid-catchment, where the city is located, trade and public services are the next most common occupations for households while upper catchment, agriculture is the most dominant.

The high agricultural activities in the watershed are favored by a variety of crops that may be produced all year round because to its favorable environment and generally rich soils. The agricultural areas and communities rely primarily on subsistence farming, just like many other areas of the nation.

Nonetheless, men continue to be the primary administrators of household income and expenditure. As such, their participation in the project's execution ought to be equal. A further finding of the study was that community education will be required regarding the purpose and necessity of the project.

4.2.2.4 Water Sources Used

There are several different water sources in the catchment, such as rainwater harvested, groundwater, and surface water. The population in the upstream areas of the catchment depends on both installed gravity flow systems and surface water passing through the rivers that originate from Mount Elgon. The main sources of water for the residents of Mbale City, Butagansi, and Budaka are boreholes in the midstream of the watershed and piped water systems. The lower stream uses a lot of boreholes because ground water is so nearby.

The study found that during the rainy season, 6No. jerrycans are usually used, and during the dry season, 13No. This water usage covers the needs of livestock as well as households. A minimum of 500 meters, is traveled by most residents in the catchment to obtain water for domestic consumption (NWSC et al., 2022).

4.2.2.5 Ability to Pay

There is willingness to pay for water within the communities. A small portion of the community (1%) are willing to pay 75,000 UGX per month (which is equal to a consumption of 120 l/c/d) while 37% were willing to pay 15,000 UGX per month (24 l/c/d) and 50%, the majority, is able to pay 7,500 UGX per month (12 l/c/d) (NWSC et al., 2022; Sempewo et al., 2021).

4.2.3 R. Namatala Catchment Water Demand Assessment

Water demand is the quantity of water required by different customers to satisfy their needs. Water consumers for home or human consumption, as well as agricultural (which includes irrigation, livestock, and industrial water demands), were considered while calculating the water demand for the R. Namatala Catchment. Currently, hydropower is not planned for R. Namatala catchment (MWE, 2018).

4.2.3.1 Domestic Population Projection

The population of the R. Namatala catchment for the years 2023 – 2040 are 52,966 and 79,479 People respectively.(Table 4.4).

Table 4.4: Summary of Projected Population for the project area

No.	Catchment	District	Projected Population				
			2023	2028	2030	2038	2040
1	R. Namatala Catchment	Mbale	26,788	30,308	34,291	38,797	40,761
		Butebo	1,068	1,145	1,227	1,315	1,352
		Sironko	8,480	9,090	9,745	10,446	10,741
		Budaka	9,560	10,816	12,237	13,845	14,546
		Bududa	531	622	728	852	907
		Butaleja	6,539	7,655	8,960	10,489	11,171
		Total	**52,966**	**59,635**	**67,188**	**75,745**	**79,479**

4.2.3.2 Livestock Projection

According to UBOS (2008), catchment had a total number 273,340 livestock dominated by poultry. Mbale District contributed the most livestock as compared to the other districts. The current and projected (2023 and 2040) livestock populations are 394,376 and 726,245 animals respectively (Appendix B-1: Summary of Livestock Population).

4.2.3.3 Domestic Demand

Table 4.5 below summarizes the domestic water demand (m^3/year) for R. Namatala catchment. The total domestic water demand for R. Namatala catchment will increase by 50.1% from the year 2023 to 2040.

Table 4.5: Current and Projected Domestic demand for R. Namatala Catchment

Catchment	District	Domestic Demand (m^3/year)				
		2023	2028	2030	2038	2040
R. Namatala Catchment	Mbale	244,442	276,563	290,564	328,747	371,947
	Butebo	9,743	10,445	10,739	11,512	12,341
	Sironko	77,378	82,948	85,287	91,427	98,008
	Budaka	87,233	98,697	103,693	117,319	132,736
	Bududa	4,846	5,673	6,042	7,072	8,279
	Butaleja	59,670	69,848	74,390	87,079	101,932
	Total	**483,313**	**544,174**	**570,715**	**643,156**	**725,243**

4.2.3.4 Irrigation Demand

Table 4.6 below summarizes the irrigation demand (m^3/year) for R. Namatala catchment. The total irrigation demand for R. Namatala catchment will increase by 1% from the year 2023 to 2040.

Table 4.6: Current and Projected Irrigation demand for R. Namatala Catchment

Total Irrigation Demand (m^3/year)							
No.	**District**	**2022**	**2023**	**2028**	**2030**	**2038**	**2040**
1	Mbale	1,723,907	1,724,769	1,729,085	1,730,814	1,737,750	1,739,488
2	Butebo	2,651	2,652	2,659	2,662	2,672	2,675
3	Sironko	42,418	42,440	42,546	42,588	42,759	42,802
4	Budaka	448,043	448,267	449,389	449,839	451,641	452,093
5	Bududa	663	663	665	665	668	669
6	Butaleja	95,441	95,489	95,728	95,824	96,208	96,304
	Total	**2,313,123**	**2,314,280**	**2,320,072**	**2,322,392**	**2,331,698**	**2,334,030**

4.2.3.5 Livestock Demand

MAAIF (2017) provided different water needs for each category of livestock through which demand was obtained. The total livestock demand is 952,918 m^3 per year or 0.95 MCM/year and 983,239 m^3 per year or 0.98 MCM/year for 2023 and 2040 respectively (Table 4.7).

Table 4.7: Current and Projected Livestock Water Demand (m^3/year)

Total Livestock Demand (m^3/year)								
No	**Catchment**	**District**	**2008**	**2023**	**2028**	**2030**	**2038**	**2040**
1	River Namatala Catchment	Mbale	499,557	508,913	510,523	517,990	519,940	530,314
		Butebo	41,344	41,730	41,794	41,865	42,197	42,638
		Sironko	115,775	117,257	117,522	117,789	119,028	120,632
		Budaka	148,928	150,726	151,020	151,352	152,914	154,987
		Bududa	7,134	7,233	7,250	7,268	7,352	7,461
		Butaleja	129,220	127,060	127,050	127,058	127,099	127,209
		Total	**941,958**	**952,918**	**955,159**	**963,321**	**968,530**	**983,239**

4.2.3.6 Industrial Demand

Table 4.8 below summarizes the irrigation demand (m^3/year) for R. Namatala catchment. The total irrigation demand for R. Namatala catchment will increase by 64% from the year 2023 to 2040.

Table 4.8:Current and Projected Industrial Water Demand (m^3/year)

Total industrial Demand (m^3/year)						
No.	**Districts**	**2023**	**2028**	**2030**	**2038**	**2040**
1	Mbale	743,178	860,850	912,981	1,057,539	1,224,986
2	Butebo	537	622	660	765	886
3	Sironko	2,356	2,729	2,894	3,352	3,883
4	Budaka	34,210	39,627	42,027	48,681	56,389
5	Bududa	126	146	155	180	208
6	Butaleja	17,060	19,761	20,958	24,276	28,120
	Total	**797,468**	**923,736**	**979,675**	**1,134,793**	**1,314,472**

4.2.3.7 Total Catchment Water Demand

Table 4.9 summarizes the average total water demand in the catchment for each type of customer. In the future year 2040, Irrigation requires the majority of the water in the catchment 43.6% followed by Livestock water demand (18.3%) The combined demand from all other categories was 0.33% of the catchment's total water demand.

Table 4.9: Total Water Demand (m^3/yr) for R. Namatala Catchment

District	Total Demand (m^3/year)				
	2023	2028	2030	2038	2040
Mbale	3,220,439	3,372,706	3,450,620	3,637,040	3,864,996
Butebo	54,276	55,450	55,853	56,804	58,096
Sironko	237,927	245,373	248,249	255,156	263,678
Budaka	718,415	737,317	746,129	767,191	793,680
Bududa	12,769	13,715	14,112	15,185	16,507
Butaleja	301,391	312,158	318,126	334,236	353,359
R. Namatala Catchment	**4,545,218**	**4,736,719**	**4,833,088**	**5,065,612**	**5,350,316**

4.2.3.8 Total Permitted Users

The permitted users were projected to increase as the catchment tends to the future year 2040. The permitted users are 0.279 m^3/s and 0.378 m^3/s for 2030 and 2040 respectively.

4.2.4 R. Namatala catchment Water Balance

After careful review of the documents, the results of the simulation above and studies of the water resources of R. Namatala catchment, the water balance was carried out. Water Demand for the buffer villages, proposed water supply systems, existing wastewater systems as well as major tributaries in the catchment (Figure 4.6).

The current and future water balance of R. Namatala catchment is summarized in Table 4.10 below. From the water balance analysis for current year 2023, it was observed that R. Namatala has sufficient water for the estimated baseline year with available annual flows of 2.65 m^3/s available annually. It also was observed that R. Namatala will have sufficient water for the future years of 2030 and 2040 with available annual flows of 2.14 & 2.34 m^3/s available annually respectively.

Table 4.10: Estimated current and future water balance of the R. Namatala Catchment

Parameter	Available Water - 2023	Water Demand - 2023	Available Water - 2030	Water Demand - 2030	Available Water - 2040	Water Demand - 2040	Comments
Annual Rainfall (m^3/Year)	25,661,633		25,690,547		35,226,894		From WEAP
Surface Flow (m^3/Year)	84,798,940		85,704,764		86,068,666		From WEAP
Actual Evaporation (m^3/Year)		17,781,828		33,853,906		36,733,180	From WEAP
Water Demand (m^3/Year)		9,090,436		9,933,753		10,695,390	Based on the Water Demand Estimates
Totals (m^3/Year)	110,460,573	26,872,263	111,395,311	43,787,659	121,295,560	47,428,570	
Water Balance (m^3/Year)	**83,588,310**		**67,607,652**		**73,866,990**		**Available water**

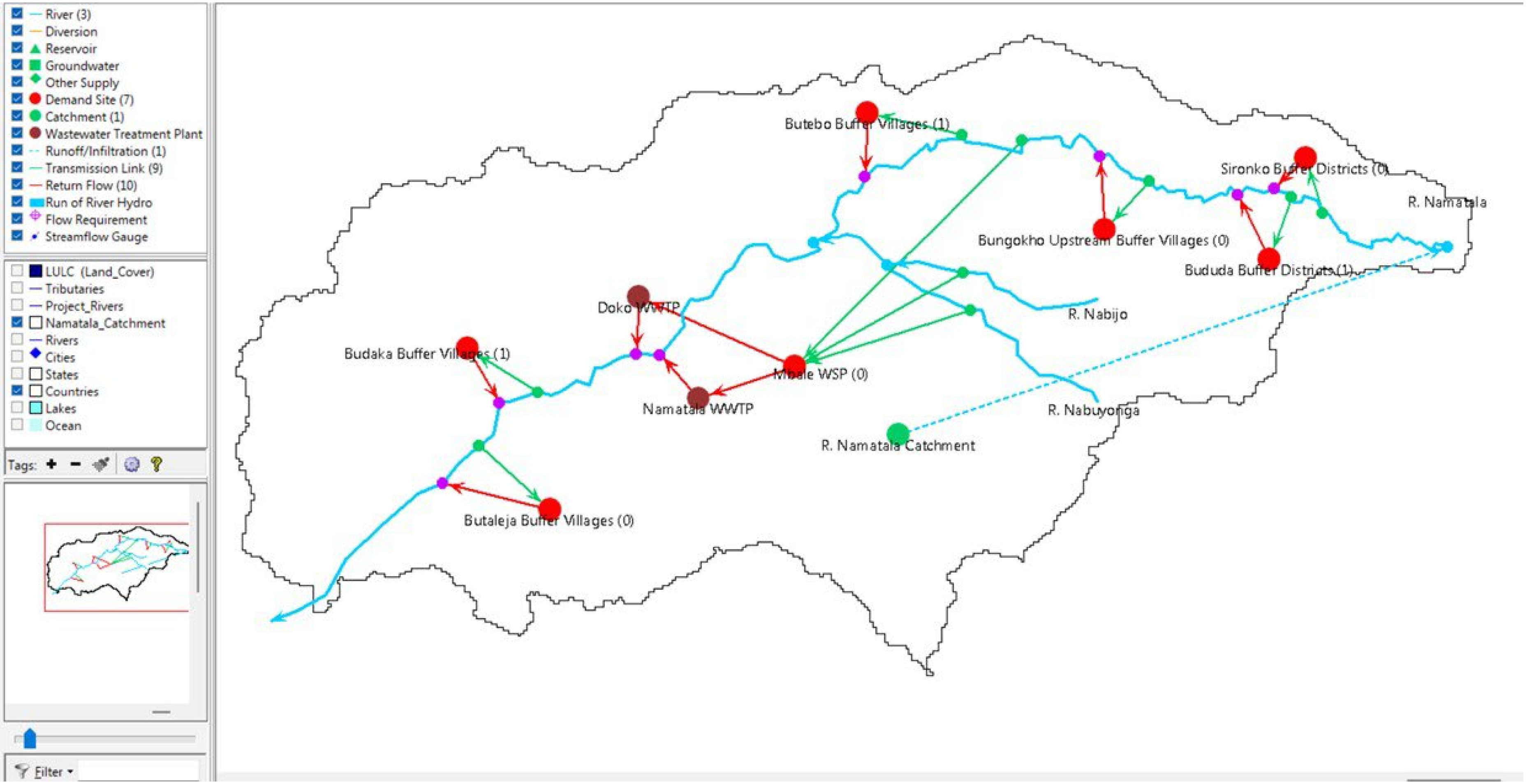


Figure 4.6: Water balance projection for R. Namatala Catchment using WEAP

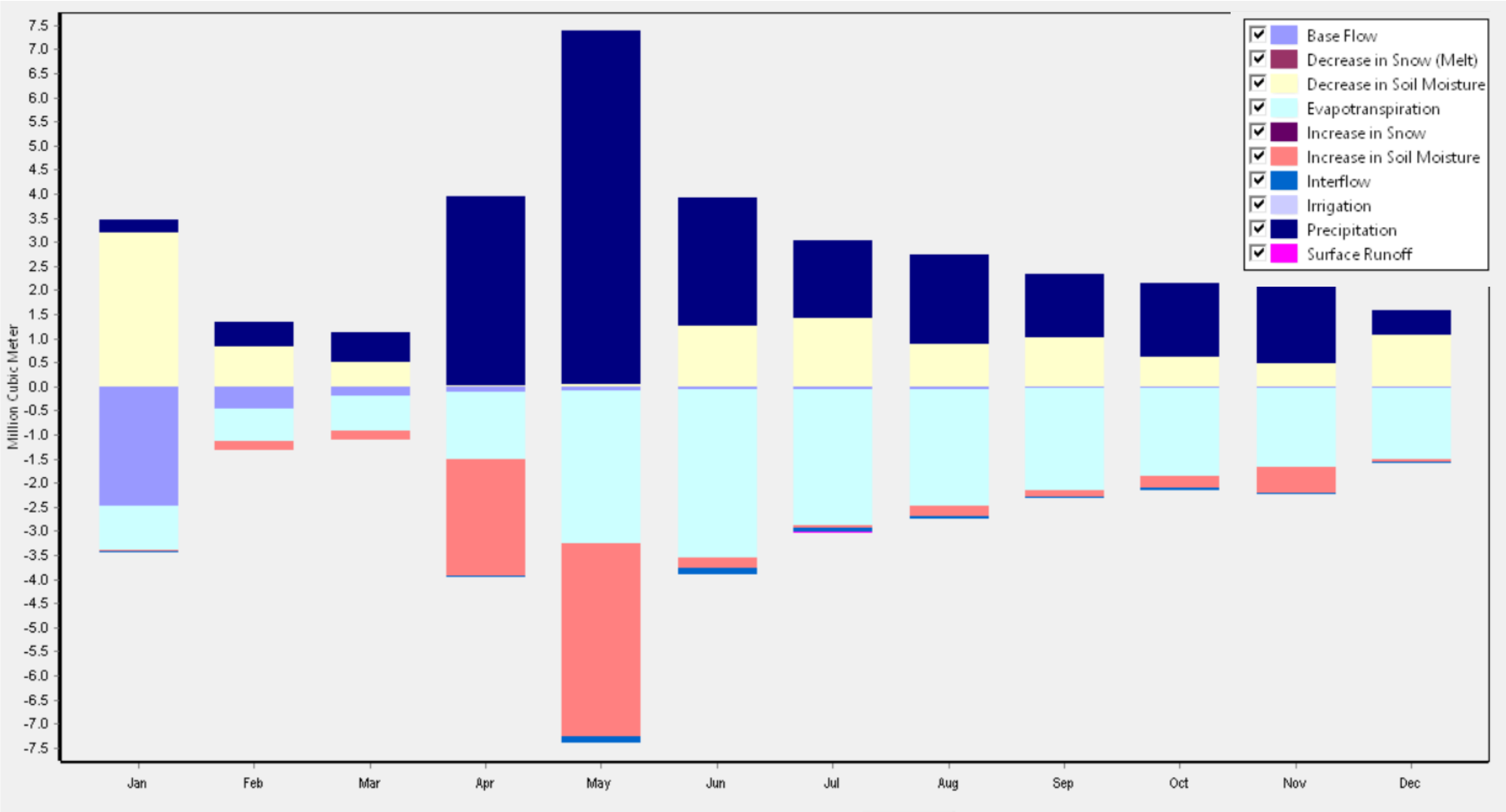


Figure 4.7: Catchment Contribution

4.2.5 Hydrological E-flow Assessment

Based on the 30% of Mean annual flow (MAF), R. Namatala exhibited a 0.8 m^3/s environmental flow requirement (Table 4.11). The environmental flow requirement estimated caters for minimum flows required to keep the ecosystem inclusive of flora and fauna. The catchment has an average available flow recommended for usage in the catchment as 1.88 m^3/s with a seasonal low flow variability during the months of January to March.

Table 4.11: R. Namatala's environmental requirement flow due to Tennant's Method

Month	MM Flows	Tennant's Methods	
		Tenants *30%	Available Flows - Tenants
Jan	1.39	30% MAF	0.59
Feb	1.12		0.32
Mar	1.39		0.59
Apr	2.86		2.06
May	4.73		3.93
Jun	3.11		2.31
Jul	2.67		1.87
Aug	3.48		2.67
Sep	3.10		2.30
Oct	3.13		2.33
Nov	3.06		2.26
Dec	2.12		1.31
MMF	**2.68**	**0.80**	**1.88**
MAF	**2.65**		

Based on Tessman's modifications, the average environmental Flow requirement is 1.072 m^3/s with deficits in months of December to March and July (Figure 4.8). May exhibited the highest environmental flow requirement given that this period receives the highest flows due to contributions from precipitation.

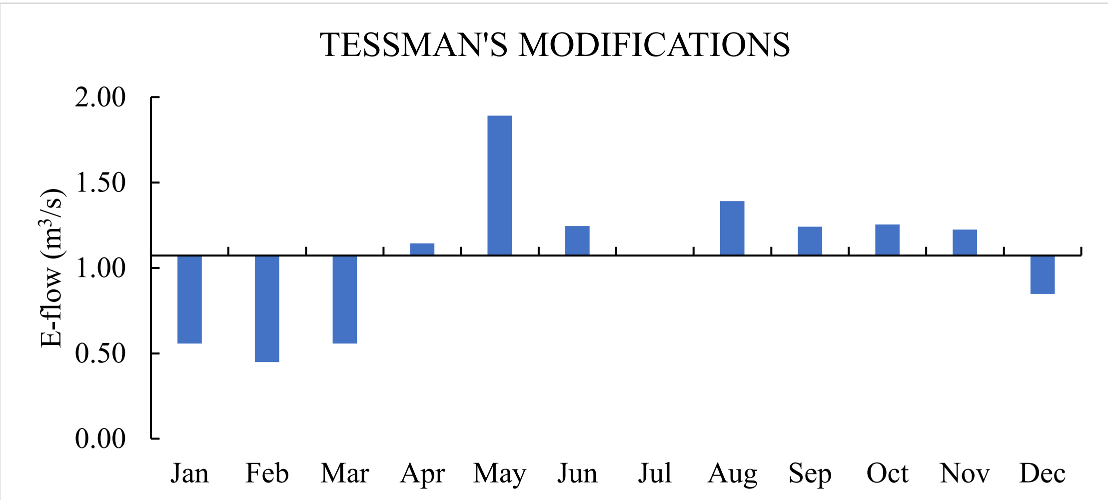


Figure 4.8: environmental flow variations from the averages

Table 4.12: Analysis of R. Namatala's environmental flow requirement due to Tessman's Method

Month	MM Flows	TESSMAN'S MODIFICATIONS						
		40% OF MAF (m^3/s)	100% OF MAF (m^3/s)	Option - 1	Option - 2	Option - 3	E-Flow Due to MMF (m^3/s)	Water Available (m^3/s)
Jan	1.39	**1.06**	**2.65**	0.33	(1.26)	(1.26)	0.56	0.83
Feb	1.12			0.06	(1.53)	(1.53)	0.45	0.67
Mar	1.39			0.33	(1.26)	(1.26)	0.56	0.84
Apr	2.86			1.80	0.21	0.21	1.14	1.72
May	4.73			3.67	2.08	2.08	1.89	2.84
Jun	3.11			2.05	0.46	0.46	1.24	1.87
Jul	2.67			1.61	0.02	0.02	1.07	1.60
Aug	3.48			2.42	0.83	0.83	1.39	2.09
Sep	3.10			2.04	0.45	0.45	1.24	1.86
Oct	3.13			2.07	0.48	0.48	1.25	1.88
Nov	3.06			2.00	0.41	0.41	1.22	1.84
Dec	2.12			1.06	(0.53)	(0.53)	0.85	1.27
MMF	**2.68**			NO GO	NO GO	GO		

4.2.6 Hydraulic E-flow Assessment

Based on the wetted perimeter method of the hydraulic E-flow, the environmental flow requirement for R. Namatala is 1.036 m^3/s ranging from 0.62 m^3/s & 1.47 m^3/s upstream and downstream of the catchment respectively. In the upstream areas, the low flows (0.62 m^3/s) exhibited as the environmental flow. As the River moves through the mid-stream and it tends to the Namatala – Doho wetland system, the environmental flow requirement increases from 0.79 m^3/s to 1.47 m^3/s (Appendix G-1: Hydraulic simulation for Current E-flow Estimation).

4.2.7 Holistic E-flow Assessment

Hydrological flow studies were done under section 4.2.5 Hydrological E-flow Assessment where E-flow due to historical flow data was obtained. The data obtained was scaled on a monthly basis using Tessman's modifications. However, the E-flow requirement based on historical flow data gave a generic E-flow requirement for the catchment as a whole based on the Catchment. To be able to determine site specific E-flow requirement on the selected river section along R. Namatala, hydraulic E-flow was undertaken with detailed assessment under section 4.2.6 Hydraulic E-flow Assessment.

A comparison between Hydrological and Hydraulic E-flow was done (Figure 4.9). During the months of January to March, the minimum hydraulic E-flow requirement was more than the hydrological E-flow requirement as compared to the rest of the months. The Hydraulic E-flow was chosen because of its site specificity and hence required for E-flow.

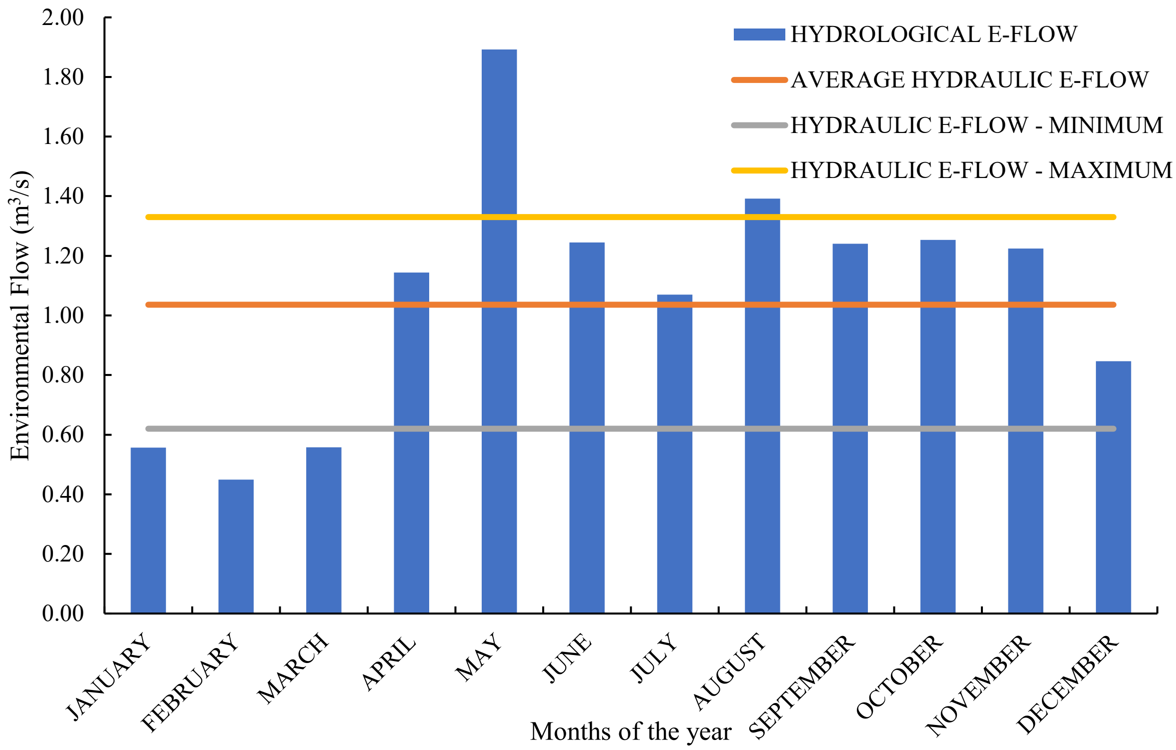


Figure 4.9: Comparison between Hydrological and Hydraulic E-flow

Jorda-Capdevila & Rodríguez-Labajos (2017) noted that people's views toward the environment are influenced by their socioeconomic circumstances, and this in turn influences how motivated they are to save water and lessen pollution in order to improve the amount of water recovered and so raise E-flows. To cater for this, socio-economic component was added to the holistic approach by considering the aspects of already existing water needs as part of the E-flow. From socio-economic studies undertaken, it was noted that R. Namatala catchment had a water requirement of 0.015 m^3/s in 2023 and 0.0226 m^3/s (Table 4.13).

Table 4.13: Socio-economic Water requirement

Socio-economic Water Need	**2023**	**2028**	**2033**	**2038**	**2040**
R. Namatala Catchment (m^3/s)	0.0150	0.0169	0.0191	0.0215	0.0226

Based on the building block method, five blocks were considered for the current Holistic E-flow requirement for R. Namatala. These were Hydraulic flow, Flora, Fauna, Socio-economic considerations and Aquatic life. These blocks have been broken down as follows;

1. In terms of hydraulic requirement of the river considering a fixed channel bed, the hydraulic E-flow was considered to cater for the flows required so as to sustain the river system. This flow was calculated under section 4.2.6 Hydraulic

E-flow Assessment. From this a hydraulic flow requirement was observed to be **1.036 m^3/s**.

2. In terms of Flora, the findings from the biodiversity assessment showed that plants near the river were catered for in regards to water needs by the flows in the rivers. This then assumes that the needs of plants on the river banks is taken care of by the hydraulic e-flow while plants away from the river system utilize a number of sources such as ground water, soil moisture and precipitation (Appendix H-1: Vegetation and Flora of R. Namatala).

In terms of Fauna and Herpertiles, the findings from the biodiversity assessment showed that Herpertiles and Fauna near the river were catered for in regards to water needs by the flows in the rivers. Also, to note that the water requirements for the Herpertiles was minimal hence can be catered for by the hydraulic E-flow (Appendix H-2: Herpertiles Study along R. Namatala, Appendix H-3: Mammals Study along R. Namatala

3. **Appendix H-3: Mammals Study along R. Namatala**and Appendix H-4: Birds Study along R. Namatala)
4. In terms of Socio-Economic requirements, the projected demand for 2023 is **0.015 m^3/s** catering for socio-economic activities undertaken on a 100m buffer zone.
5. In terms of aquatic requirement, there was noticeable decrease in fish population attributed to overfishing downstream in the Namatala – Doho wetland system. Given the challenges in determining fish numbers, a 5% of the hydraulic E-flow was taken to cater for the fish spawning, change in flows and fish migration. The aquatic fish requirement for 2040 was estimated as **0.0518 m^3/s** (Appendix H-5: Aquatic Study of R. Namatala)**.**

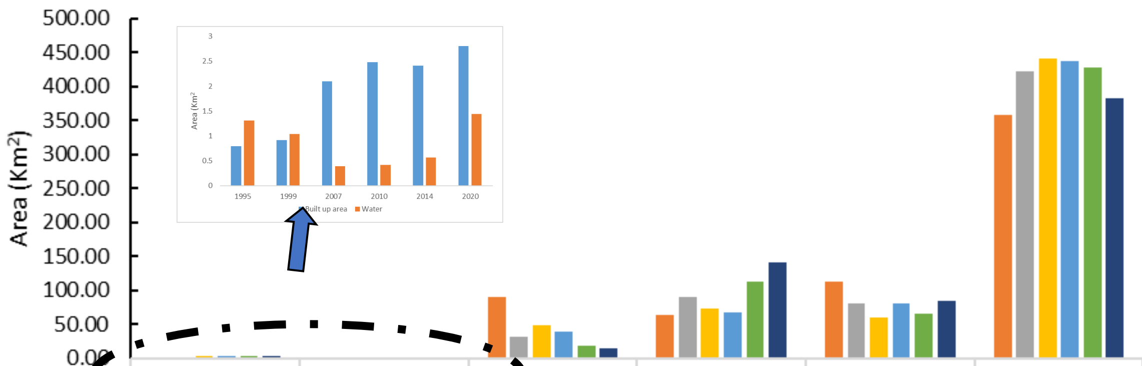
Based on these, the holistic environmental flow requirement for 2023 is **1. 1028 m^3/s**

4.3 Objective 2: To determine land use change trends in R. Namatala Catchment.

4.3.1 Assessment of Historical LULC Change trend

Following model validation and training, 6No. land cover raster images for 1995, 1999, 2007, 2010, 2014, and 2020 were created. These raster files were edited to remove any cloud cover and cropped to the area of the R. Namatala catchment using ARCGIS 10.7.

Over the years (1995-2020), R. Namatala is dominated by Grassland followed by Cropland with built up and water (Figure 4.10). Table 4.14 demonstrates the temporal variation of land use and cover change from over a period of 26 years. Grassland which is the main land cover in the catchment ranged from 357.92 km^2 (1995) to 383.62 km^2 (2020). This was followed by a decrease in forest land from 112.42 km^2 in 1995 to 83.76 km^2 (2020). Cropland observed an increase in acreage from 63.92 km^2 (1995) to 140.58 km^2 (2020) while built up area also observed an increase in acreage from 0.79 km^2 (1995) to 2.8 km^2 (2020).



	Built Up Land	Water	Wetland	Cropland	Forest Land	Grassland
1995	0.79	1.31	89.95	63.92	112.42	357.92
1999	0.92	1.04	31.51	90.21	80.90	421.72
2007	2.10	0.39	49.04	72.31	60.46	442.00
2010	2.48	0.42	38.13	66.98	80.31	437.99
2014	2.41	0.57	18.61	111.68	65.26	427.78
2020	2.80	1.44	14.09	140.58	83.76	383.62

Figure 4.10: Comparison of Land use and land cover of 1995 to 2020

Table 4.14: Land use cover in R. Namatala Catchment from 1995 to 2020

LAND USE / LAND COVER	1995		1999		2007		2010		2014		2020	
	Sq Km	%	Sq Km	%	Sq Km	%	Sq Km	%	Sq Km	%	Sq Km	%
Built Up Land	0.79	0.13%	0.92	0.15%	2.10	0.34%	2.48	0.40%	2.41	0.38%	2.80	0.45%
Water	1.31	0.21%	1.04	0.17%	0.39	0.06%	0.42	0.07%	0.57	0.09%	1.44	0.23%
Wetland	89.95	14.36%	31.51	5.03%	49.04	7.83%	38.13	6.09%	18.61	2.97%	14.09	2.25%
Cropland	63.92	10.21%	90.21	14.40%	72.31	11.55%	66.98	10.69%	111.68	17.83%	140.58	22.45%
Forest Land	112.42	17.95%	80.90	12.92%	60.46	9.65%	80.31	12.82%	65.26	10.42%	83.76	13.37%
Grassland	357.92	57.15%	421.72	67.34%	442.00	70.57%	437.99	69.93%	427.78	68.30%	383.62	61.25%
TOTAL	**626.30**	**100%**	**626.30**	**100%**	**626.30**	**100%**	**626.30**	**100%**	**626.30**	**100%**	**626.30**	**100%**

Table 4.15: Land use and Land Cover Change rate

LAND USE / LAND COVER	1995-1999		1999-2007		2007-2010		2010-2014		2014-2020		1995-2020	
	Sq Km	%	Sq Km	%	Sq Km	%	Sq Km	%	Sq Km	%	Sq Km	%
Built Up Land	0.14	0.02%	1.18	0.19%	0.38	0.06%	-0.08	-0.01%	0.39	0.06%	2.01	0.32%
Water	-0.27	-0.04%	-0.65	-0.10%	0.03	0.00%	0.15	0.02%	0.88	0.14%	0.14	0.02%
Wetland	-58.43	-9.33%	17.52	2.80%	-10.91	-1.74%	-19.52	-3.12%	-4.52	-0.72%	-75.85	-12.11%
Cropland	26.28	4.20%	-17.90	-2.86%	-5.33	-0.85%	44.71	7.14%	28.90	4.61%	76.66	12.24%
Forest Land	-31.52	-5.03%	-20.44	-3.26%	19.85	3.17%	-15.05	-2.40%	18.51	2.96%	-28.66	-4.58%
Grassland	63.80	10.19%	20.28	3.24%	-4.02	-0.64%	-10.21	-1.63%	-44.15	-7.05%	25.70	4.10%

Table 4.16: Land use and Land Cover Change rate per annum

LAND USE / LAND COVER	1995-1999	1999-2007	2007-2010	2010-2014	2014-2020	1995-2020
	% per Annum	% per Annum	% per Annum	% per Annum	% per Annum	% per Annum
Built Up Land	0.006%	0.023%	0.020%	-0.003%	0.009%	0.012%
Water	-0.011%	-0.013%	0.002%	0.006%	0.020%	0.001%
Wetland	-2.332%	0.350%	-0.580%	-0.779%	-0.103%	-0.466%
Cropland	1.049%	-0.357%	-0.284%	1.785%	0.659%	0.471%
Forest Land	-1.258%	-0.408%	1.056%	-0.601%	0.422%	-0.176%
Grassland	2.547%	0.405%	-0.214%	-0.408%	-1.007%	0.158%

In 1995, R. Namatala catchment land cover was comprised of grassland (59.49%), forestland (19.95%), Wetland (14.36%), Cropland (10.21%), Water (0.21%) and built up area (0.13%) (Figure 4.11 (a)). This year was characterized by low development urge and low population growth. With the less human land use practices in 1995 compared to ecologically approved land use activities, 1995 served as a baseline for the study

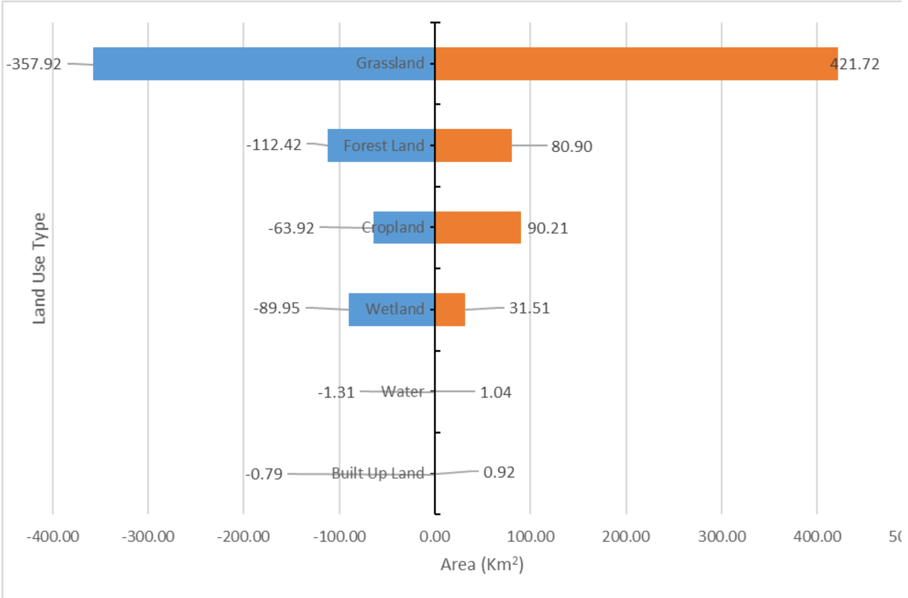
In 1999, R. Namatala catchment land cover was comprised of grassland (67.34%), forestland (12.92%), Wetland (5.03%), Cropland (14.40%), Water (0.17%) and built up area (0.15%) (Figure 4.11 (a) (b)). Between 1995 to 1999, three land uses exhibited a positive change i.e. Built up (0.02%), cropland (4.2%) and grass land (10.19%) at the expense of Forestland (-5.03%) and Wetland (-9.33%) (Table 3.5). The average annual rate of LULC incremental change for Built up, cropland and grass land are 0.006%, 1.049% and 2.547% respectively while forest land reducing at 1.258%. (Table 4.16).

In 2007, R. Namatala catchment land cover was comprised of grassland (70.57%), forestland (9.65%), Wetland (8.23%), Cropland (19.77%), Water (0.06%) and built up area (0.34%) (Figure 4.11 (b) (c)) . Between 1999 to 2007, three land uses exhibited a positive change i.e. Built up (0.19%), wetland (2.8%) and grass land (3.24%) at the expense of Forestland (-3.26%), Water (-0.1%) and Cropland (-2.86%) (Table 3.5). The average annual rate of LULC incremental change for Built up, Wetland and grass land are 0.023%, 0.35% and 0.405% respectively while forestland reducing at 0.408%. (Table 4.16).

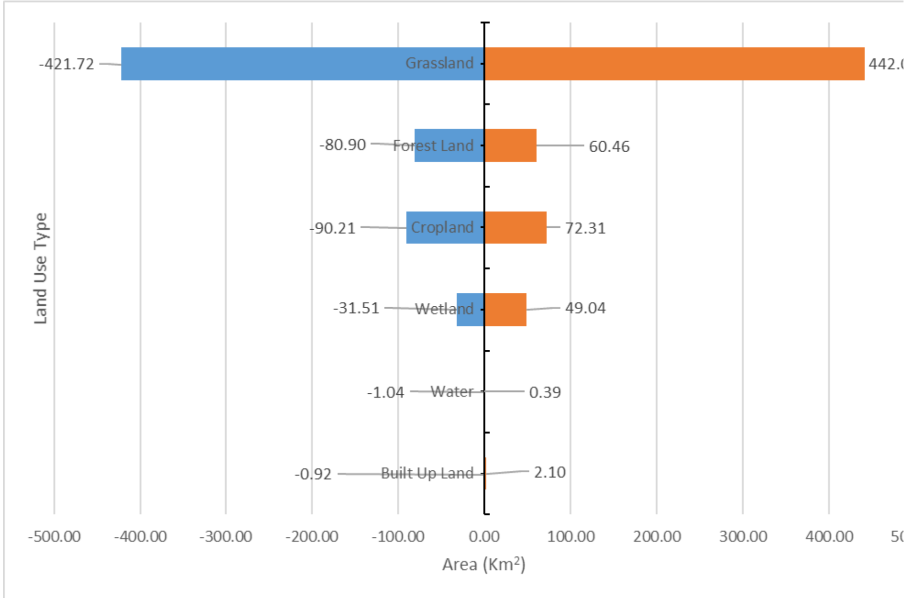
In 2010, R. Namatala catchment land cover was comprised of grassland (69.93%), forestland (12.82%), Wetland (6.09%), Cropland (10.69%), Water (0.07%) and built up area (0.40%) (Figure 4.11 (c) (d)) . Between 2007 to 2010, two land uses exhibited a positive change i.e. Built up (0.06%) and Forestland (3.17%) at the expense of Cropland (-0.85%), Wetland (-1.74%) and grassland (-0.64%) (Table 3.5). The average annual rate of LULC incremental change for Built up and forestland are 0.02% and 1.056% respectively while wetland, grassland and cropland reducing at 0.58%, 0.284% and 0.214% respectively (Table 4.16).

In 2014, R. Namatala catchment land cover was comprised of grassland (68.3%), forestland (10.42%), Wetland (3.45%), Cropland (17.83%), Water (0.48%) and built up area (0.38%) (Figure 4.11 (d) (e)) . Between 2010 to 2014, two land uses exhibited a positive change i.e. Cropland (7.14%) and Water (0.02%) at the expense of Forestland (-2.4%), Wetland (-3.12%) and Grassland (-1.63%) (Table 3.5). The average annual rate of LULC incremental change for cropland is 1.785% while Forestland, Wetland and Grassland reducing at 0.601%, 0.779% and 0.408% respectively (Table 4.16).

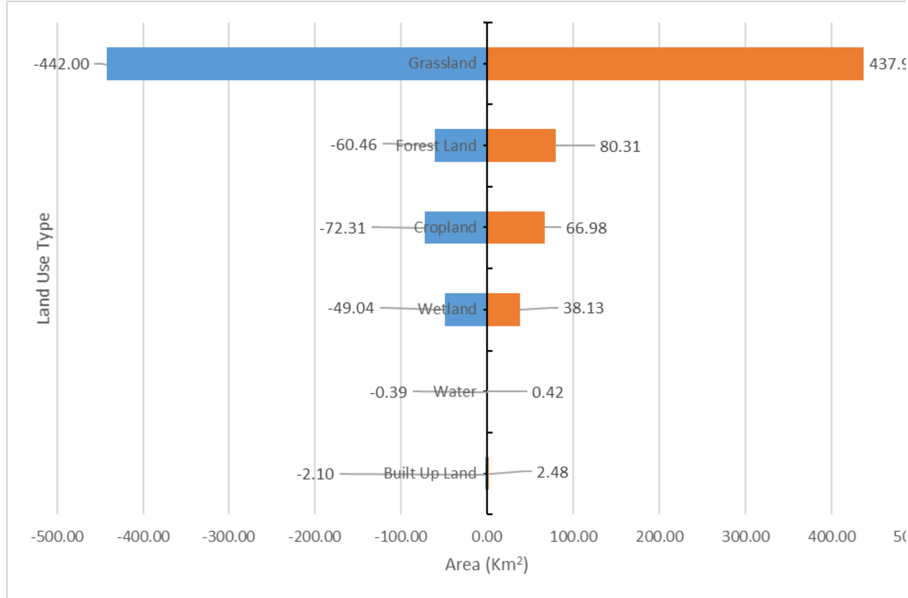
In 2020, R. Namatala catchment land cover was comprised of grassland (61.25%), forestland (13.37%), Wetland (2.25%), Cropland (22.45%), Water (0.23%) and built up area (0.45%) (Figure 4.11 (f)) . Between 2014 to 2020, four land uses exhibited a positive change i.e. Forestland (2.96%), Built up (0.06%), Cropland (4.61%), Water (0.14%) at the expense of Wetland (-0.72%) and Grassland (-7.05%) (Table 3.5). The average annual rate of LULC incremental change for Forestland, Built-up, Cropland and Water is 0.422%, 0.009%, 0.659% and 0.02% while Wetland and Grassland reducing at 0.103% and 1.007% respectively (Table 4.16).



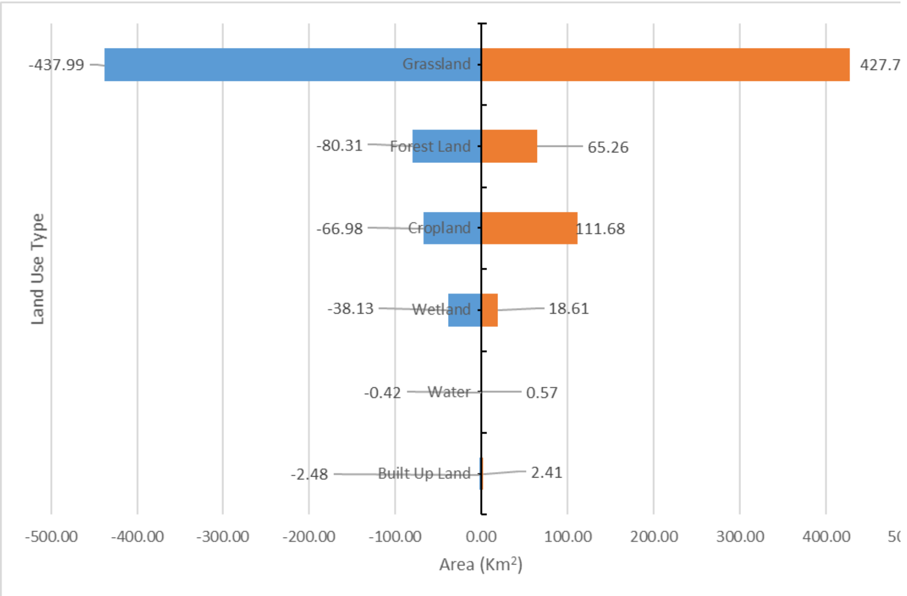
(a) Land use change from 1995 to 1999



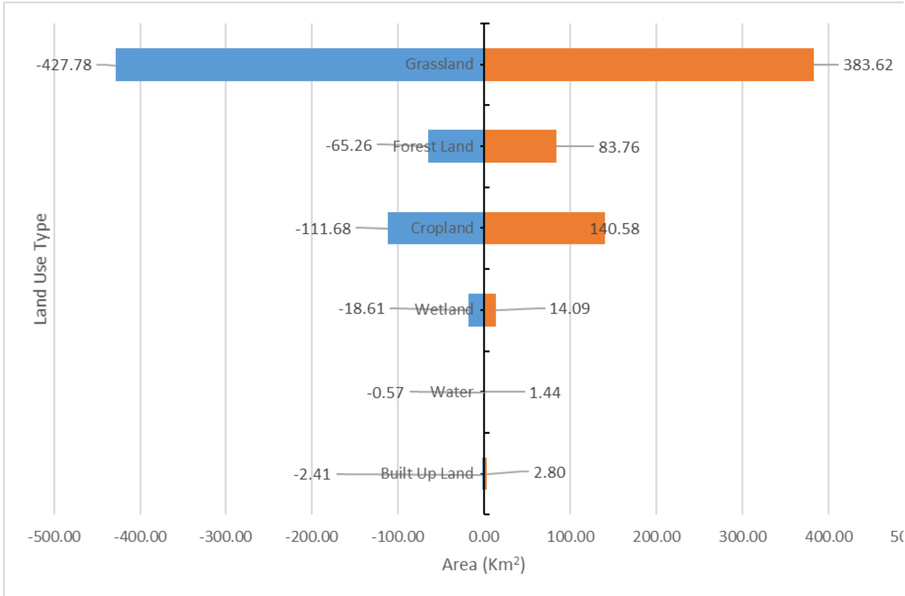
(b) Land use change from 1999 to 2007



(c) Land use change from 2007 to 2010



(d) Land use change from 2010 to 2014



(e) Land use change from 2014 to 2020

Figure 4.11: Comparison of Land use change from 1995 to 2020

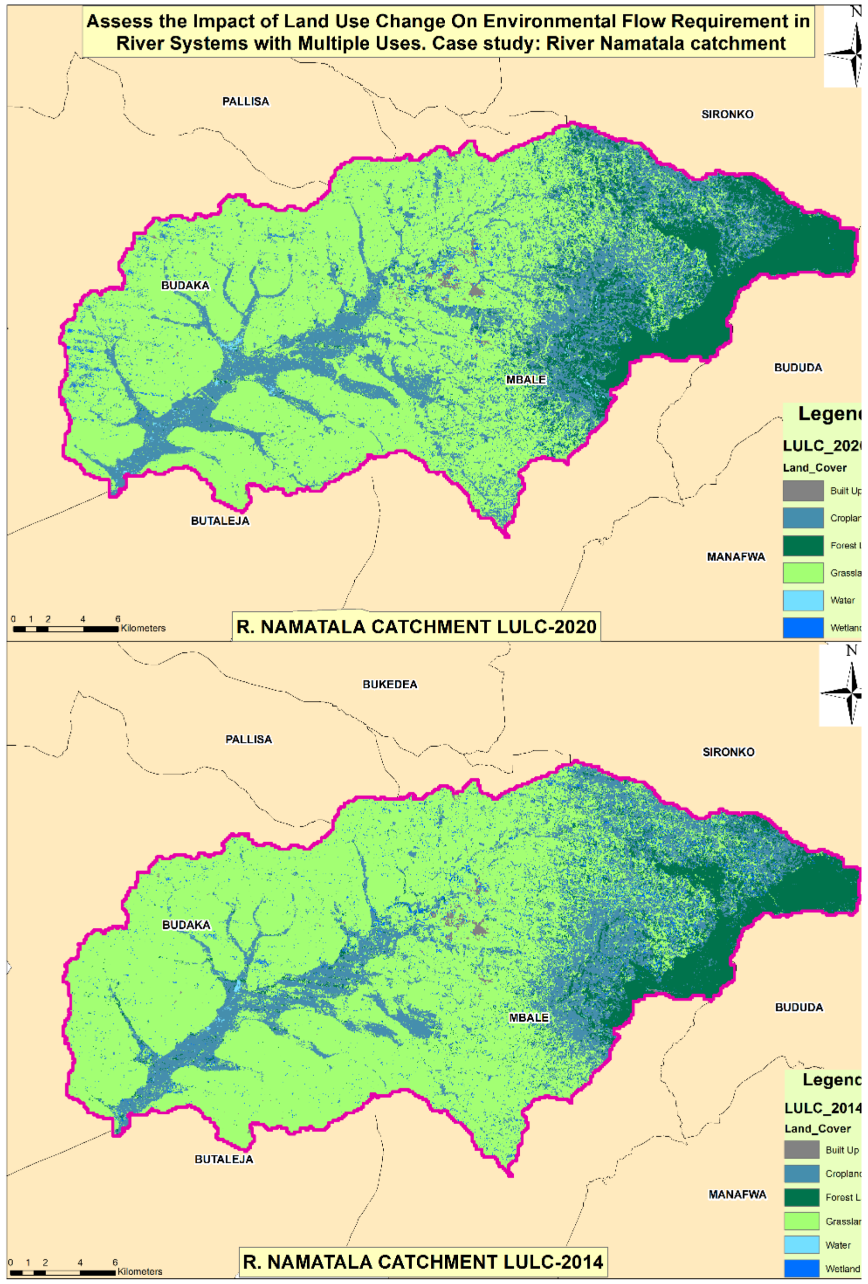
In 2007, the change from forestland to Built-up and cropland was created by the urge for fertile soils for cultivation, deforestation for timber for construction and charcoal with Global Forest Watch, (2023) estimating Mbale district to lose at least 8 ha of forest land per annum. The marginal increment in grassland was attributed to the model matching with the period of land preparation being re-classified grassland rather than agricultural land

In 2010, the reduction of cropland was attributed to the dry season where the study area exhibited less agricultural activities. On the other hand, the change from grassland, wetland and partly cropland to forested area was attributed to the interventions through the policies and enforcements done by MWE through its agencies like NFA, UWA etc. (MWE, 2002). These policies like national tree planting act 2003 and The Uganda Forestry Policy 2001 helped improve the state of forestry in the study area (IUCN, 2006).

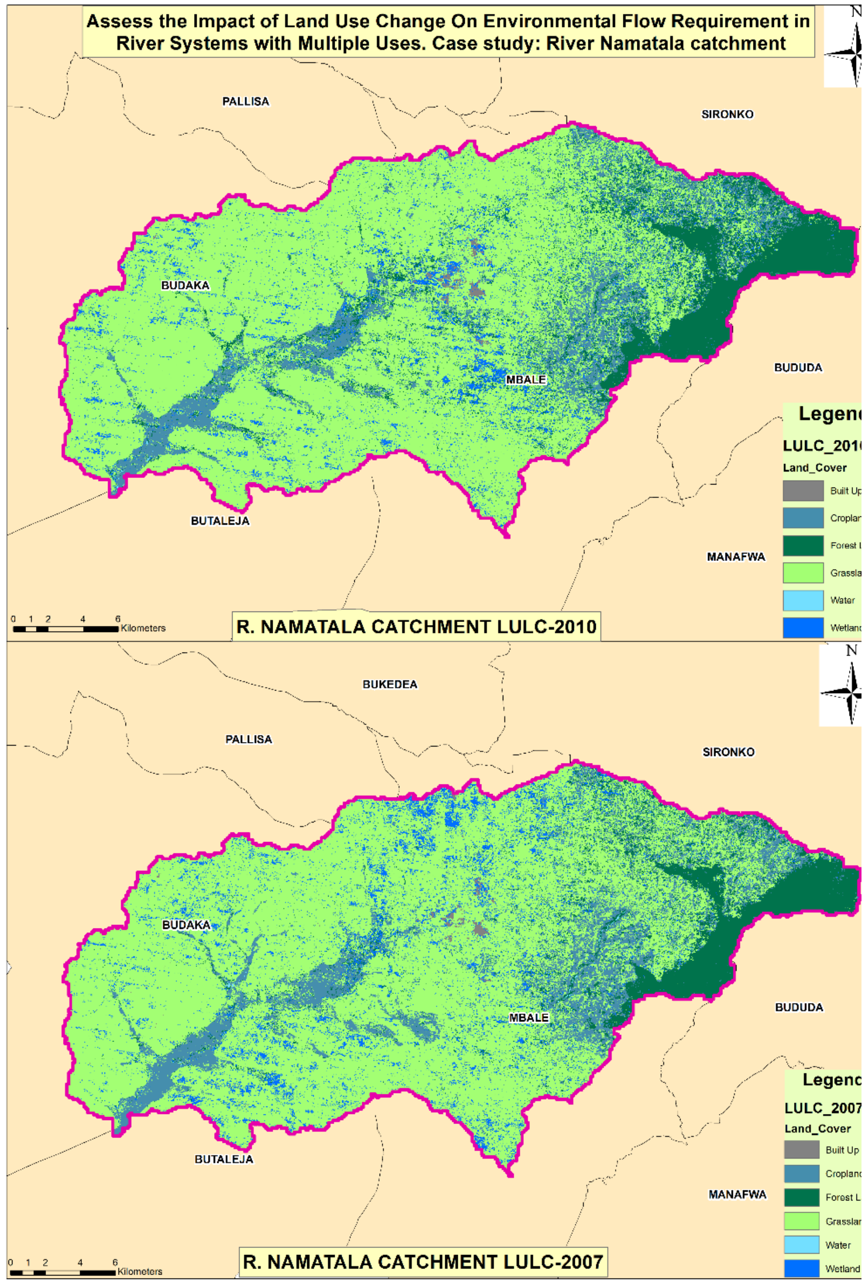
In 2014, the changes from grassland, wetland and forestland to cropland was partially caused by advocacy for agricultural as a backbone for the country. This created a hunger for more agricultural activities in order to earn a living and contribute to the NDP II.

In 2020, the change from grassland and wetland to cropland was partially caused by advocacy for agricultural as a backbone for the country. This created a hunger for more agricultural activities in order to earn a living and contribute to the NDP III. Government also gazetted a number of forested areas as Central Forest Reserves (CFR) together with a number of directives on deforestation coupled with strict penalties.

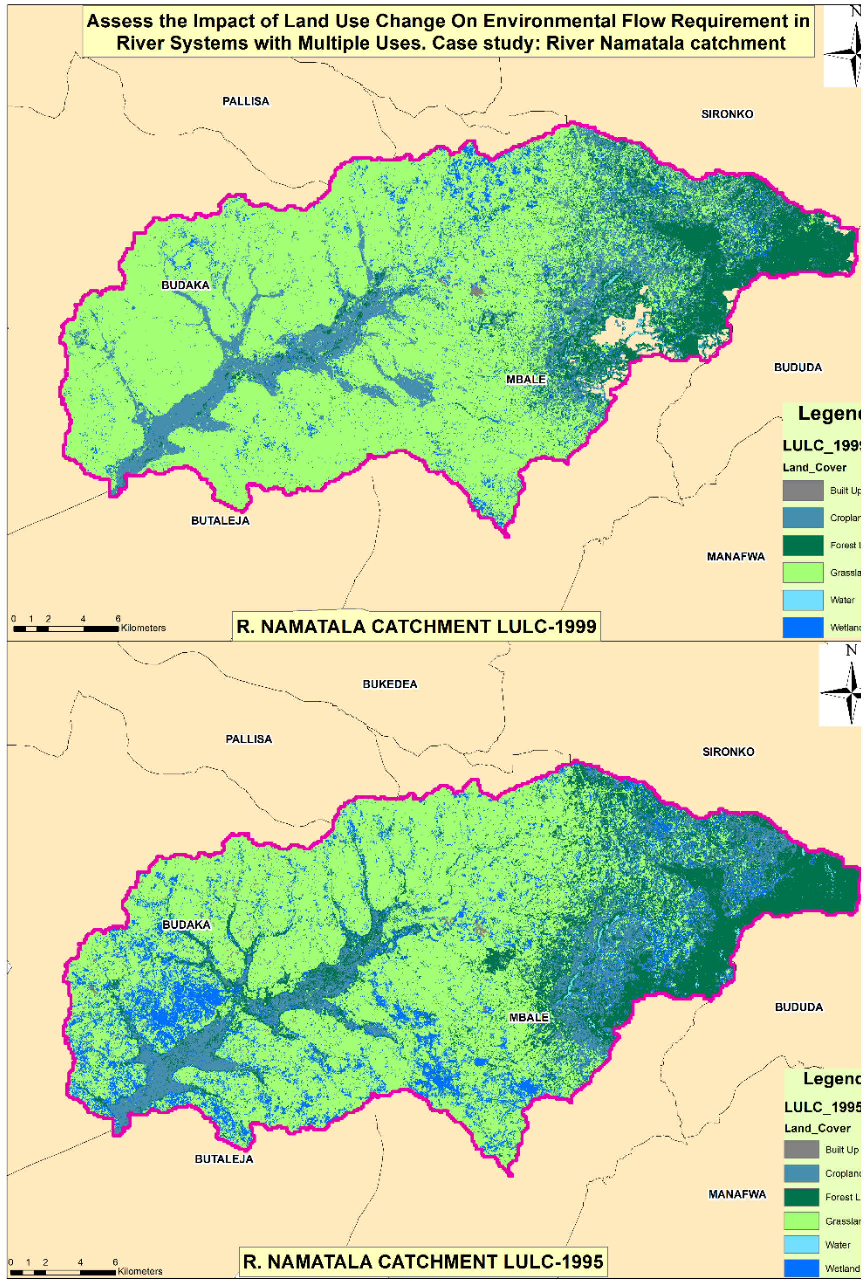
Figure 4.12 show the LULC changes over a period of 1995 – 2020 visualizing the discussions above.



Map for Land use change between 2020 to 2014



Map for Land use change between 2010 to 2007



Map for Land use change between 1999 to 1995

Figure 4.12: Map for Land use change between 2020 to 1995

4.3.2 Predicting Land Use change in R. Namatala catchment

4.3.2.1 LULC Prediction Period

The LULC prediction period was estimated to be between 2020 to 2040 in intervals of 5 years. The period coincides with Proposed Mbale WSSP (2030), Uganda Vision 2040 and NDP III, which is conceptualized around strengthening the fundamentals of the economy to harness the abundant opportunities in the country.

4.3.2.2 LULC Transition Potential

Terrset land change modeler was used to evaluate the trend of change from one land use system category to another. Table 4.16 showed the average annual rate of LULC incremental LULC change which in turn displayed the different transition potential over the years. Using the historical images, different transitions were identified by Land change modeler (LCM) (Figure 4.13). The LULC transitions were categorized into two; anthropogenic and afforestation. Under anthropogenic disturbances, six transition potentials were identified; Forestland to Built-up, Wetland to Cropland, Forestland to Cropland, Grassland to Built-up, Forestland to Grassland and Grassland to Cropland. Afforestation on the other hand had two transitional potentials that were identified; Cropland to Forestland and Grassland to Forestland.

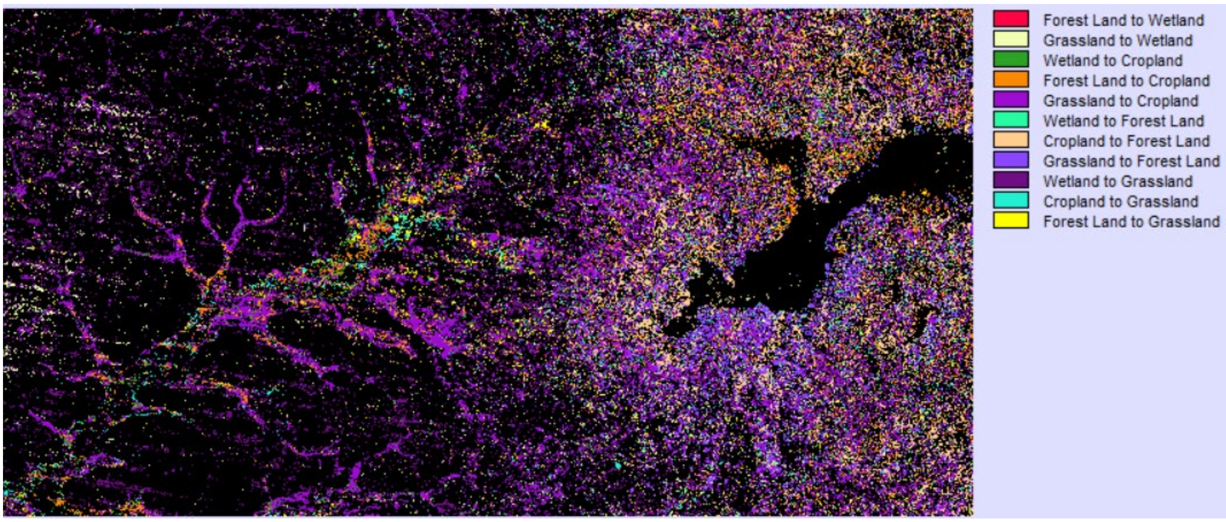


Figure 4.13: Identified LULC transitional changes identified

Table 4.17: Selected LULC transitional changes.

LAND USE / LAND COVER	Built Up Land	Water	Wetland	Cropland	Forest Land	Grassland
Built Up Land						
Water						
Wetland						
Cropland						
Forest Land						
Grassland						

KEY	
Anthropogenic Activities	
Afforestation	
N/A	

4.3.2.3 Driving factors for Land use change

Campbell et al., (2005) stated that there a number of factors that affect land use and land cover change including; social, economic, cultural, political and policy changes. Basing on the understanding of the project area and historical land use change, five drivers were selected which were used in the Terrset Land change modeler. These included;

- Road development
- Water supply
- Water source
- Policy and intervention
- Slope

Road development is an important indication of land use change, particularly in built-up areas, as well as of people's socioeconomic well-being. Road building benefits agriculture and built-up regions while opening up harming hard-to-reach wooded areas. Figure 4.14 shows that Mountain Elgon forest reserve region, Namatala wetland area, and Doho irrigation area were designated as three significant places to be left out by the road development as a driving force.

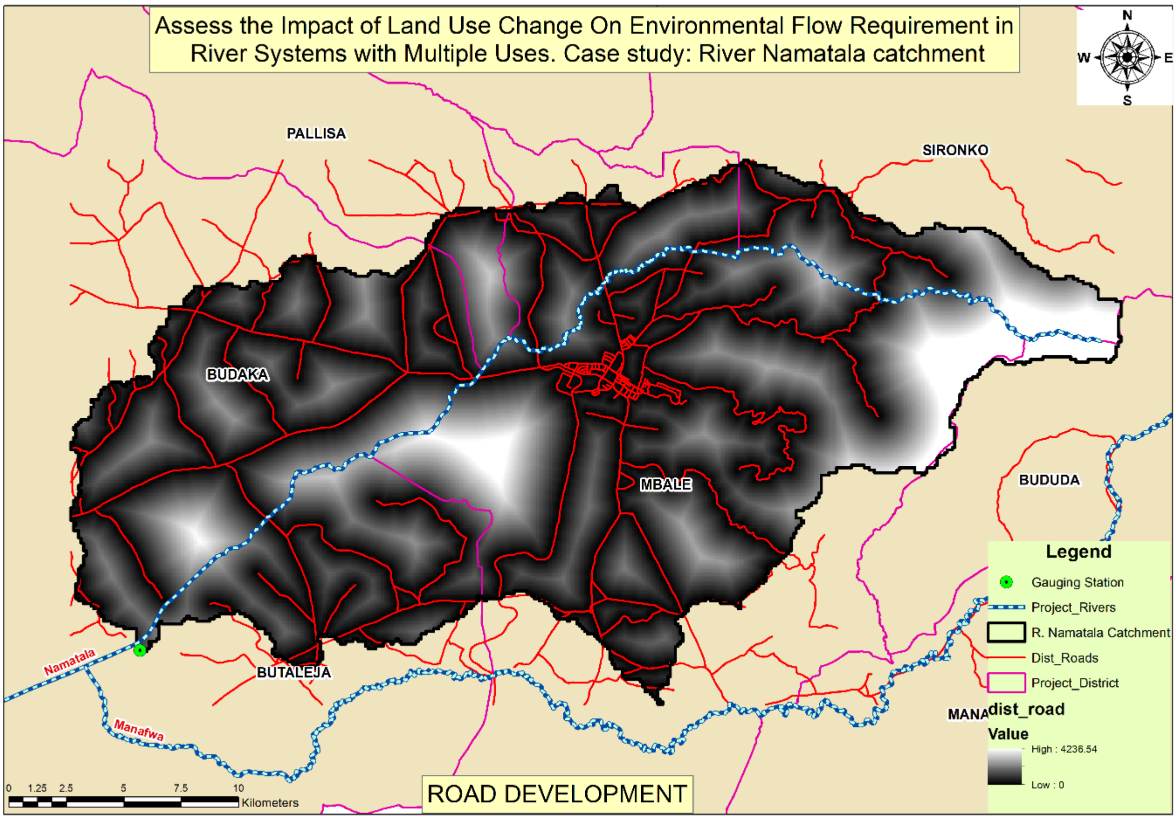


Figure 4.14: Road Network in R. Namatala catchment

Water supply and sanitation is also an important indicator of land use change, particularly in built-up areas greatl influencing people's socioeconomic well-being. Water supply opens up previously inaccessible places, promoting the transformation of current land cover to built-up land. Figure 4.15 shows the extent of the proposed Mbale WSSP aimed at upgrading the system to be able to meet the future demand of 2030 (NWSC et al., 2021).

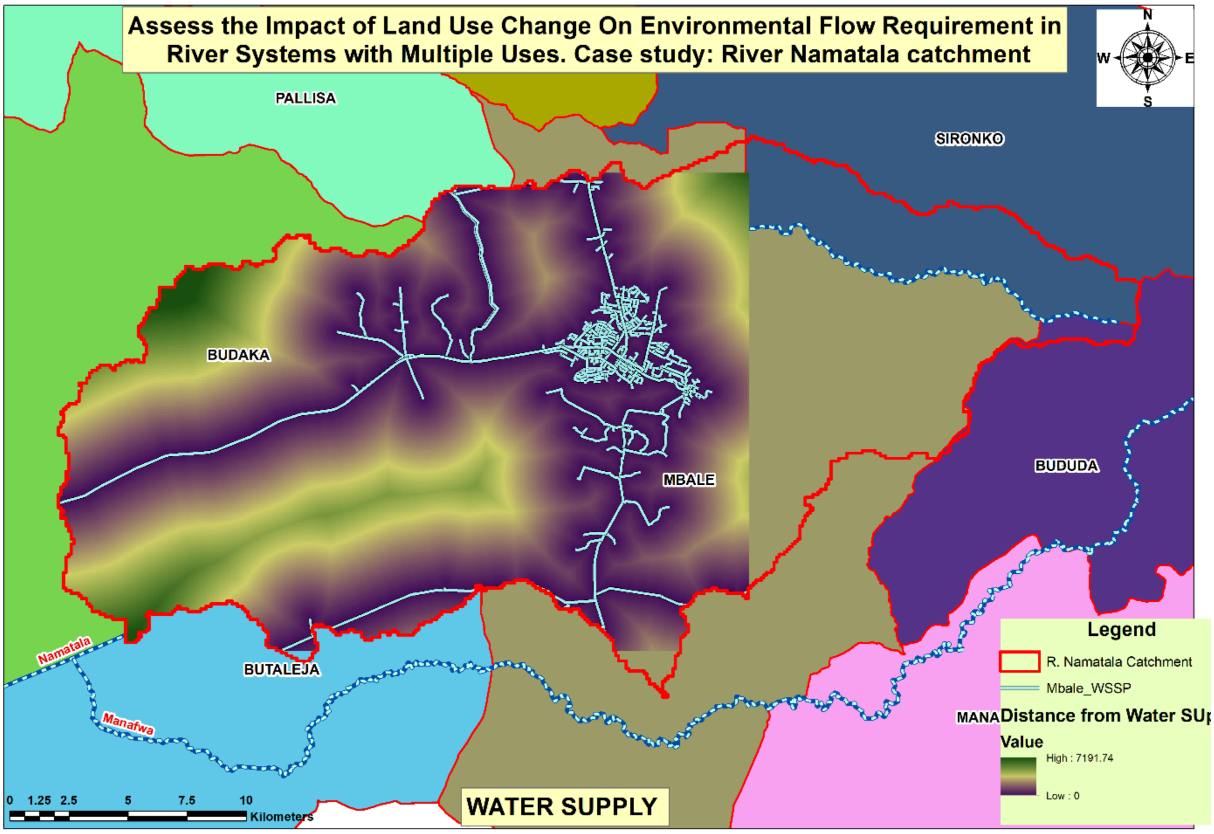


Figure 4.15: Proposed Water Supply in R. Namatala catchment

River and wetland system is also an important driver of land use change, particularly in cropland. Need for water for production especially for agriculture can affect the land cover close to the water systems. Figure 4.16 showed the river systems found in the catchment with R. Namatala as the main river with a number of tributaries.

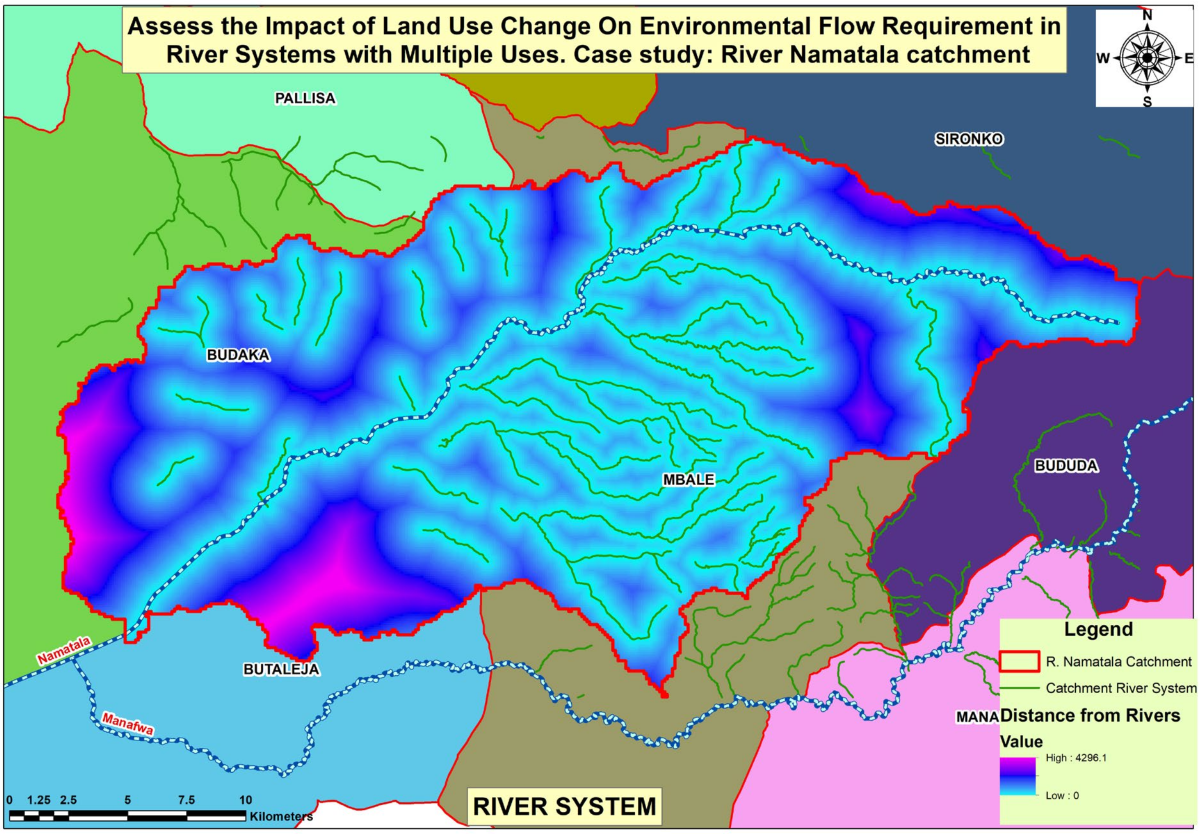


Figure 4.16: River System in R. Namatala catchment

Mt Elgon has an impact on the study area's slopes. The highest in the catchment has a slope of 67 on the ranges of Mt Elgon and almost 0 as the catchment tends towards its outlet (Figure 4.17). Slope affects a number of land cover changes like built up, cropland and forestland.

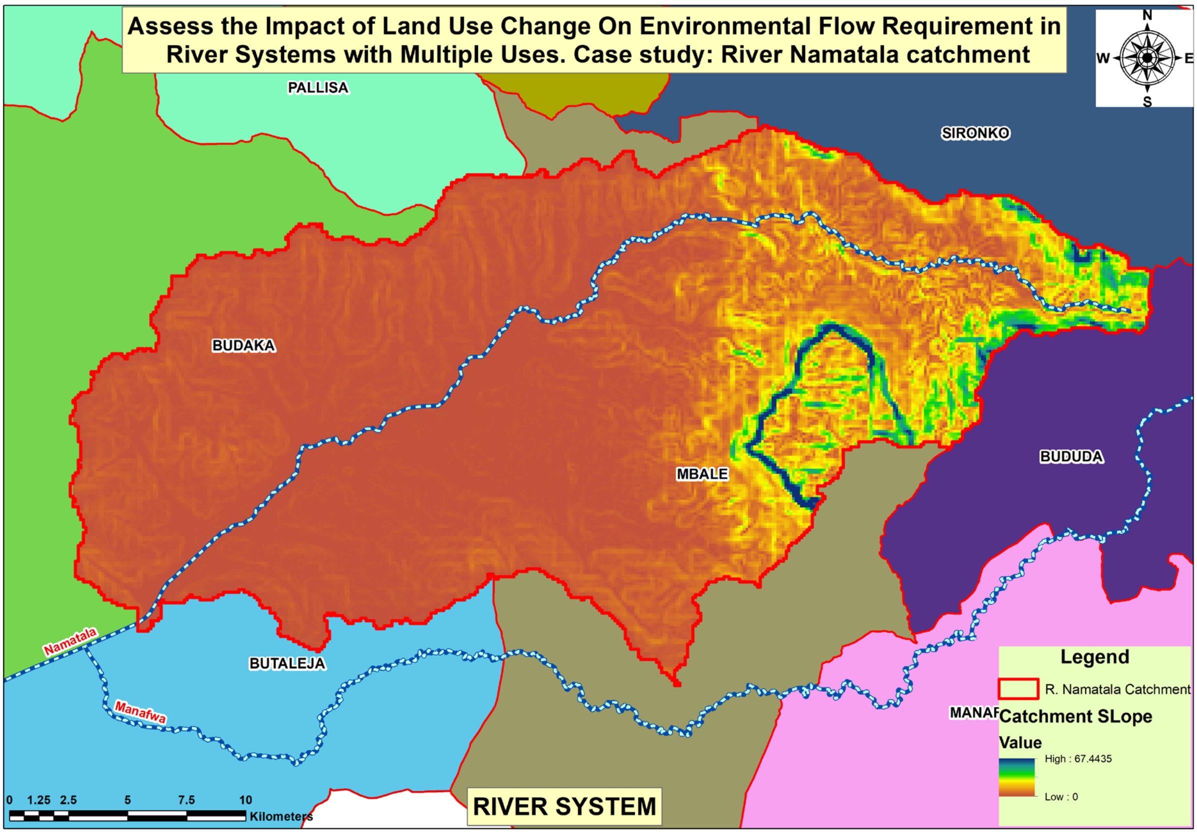


Figure 4.17: Slope in R. Namatala catchment

The study considered a variety of government regulations and Acts pertaining to line catchment restoration and conservation. These policies had a significant impact on three land cover transitions: built up to wetland, built up to forestland, and wetland to cropland. These policies and acts considered included;

- The National Environment Management Policy, 1994
- The National Policy for the Conservation and Management of Wetland Resources 1995
- Uganda National Land Policy, 2013
- Water Act, Cap 152
- Land Act, Cap 227
- The National Environment (Wetlands, River Banks and Lake Shores Management) Regulations, No. 3 (MWE, 2000)

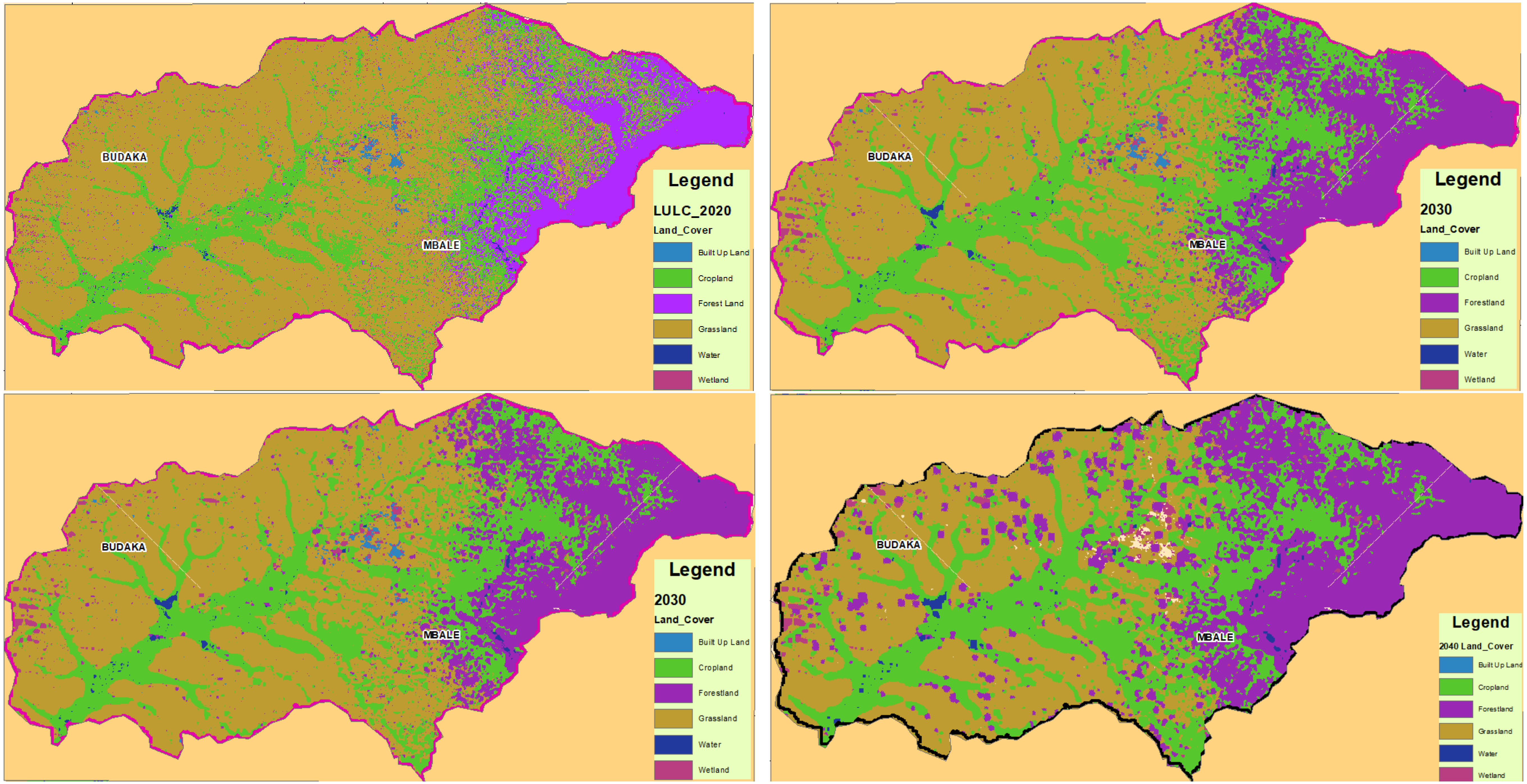
4.3.2.4 Projected LULC Change

Land Change Modeler estimated land cover imagery for 2030 and 2040 using the Markov chain model. ARCGIS 10.7 was used to label, edit and crop these raster files to the R. Namatala watershed.

According to the LULC projection, Grassland would likely dominate R. Namatala, followed by Cropland, built up and water. Table 4.18 illustrates the temporal variation of probable land use and cover change over a 20-year timeframe. The R. Namatala catchment's principal land cover, grassland, ranged from 355.64 km^2 (2030) to 334.16 km^2 (2040). Following this, farmland increased from 152.90 km^2 in 2030 to 157.37 km^2 in 2040. Forestland acreage grew from 101.23 km^2 in 2030 to 117.73 km^2 in 2040, while built-up area increased from 3.82 km^2 in 2030 to 4.73 km^2 in 2040.

Table 4.18: Projected LULC in R. Namatala Catchment

LAND USE / LAND COVER	2020		2030		2040	
	Sq Km	%	Sq Km	%	Sq Km	%
Built Up Land	2.80	0.45%	3.82	0.61%	4.73	0.75%
Water	1.44	0.23%	1.26	0.20%	1.34	0.21%
Wetland	14.09	2.25%	11.45	1.83%	10.99	1.75%
Cropland	140.58	22.45%	152.90	24.41%	157.37	25.13%
Forest Land	83.76	13.37%	101.23	16.16%	117.73	18.80%
Grassland	383.62	61.25%	355.64	56.78%	334.16	53.35%
TOTAL	**626.30**	**100%**	**626.30**	**100%**	**626.30**	**100%**



Map for Land use change between 2020 to 2030

Map for Land use change between 2030 to 2040

Figure 4.18: Map for Land use change between 2020 to 2030

Between 2020 and 2030, three land uses are expected to grow: forestland (2.79%), built up (0.16%), and cropland (1.97%), at the expense of wetland (-0.42%) and grassland (-4.47%). Between 2030 and 2040, three land uses are expected to grow: forestland (2.63%), built up (0.14%), and cropland (0.71%), at the expense of wetland (-0.07%) and grassland (-3.43%) (Table 4.19). The average annual rate of forecasted LULC incremental change for Forestland, Built-up and Cropland for 2030 are 0.279%, 0.016%,0.197% respectively and while 2040 are 0.263%, 0.014% and 0.071% (Table 4.19)).

Table 4.19: Land use / Land Cover Change and Annual rate for Projected LULC

Land Use / Land Cover	2020-2030			2030-2040		
	Sq Km	%	% per Annum	Sq Km	%	% per Annum
Built Up Land	1.02	0.16%	0.016%	0.91	0.14%	0.014%
Water	-0.18	-0.03%	-0.003%	0.08	0.01%	0.001%
Wetland	-2.64	-0.42%	-0.042%	-0.46	-0.07%	-0.007%
Cropland	12.32	1.97%	0.197%	4.46	0.71%	0.071%
Forest Land	17.47	2.79%	0.279%	16.50	2.63%	0.263%
Grassland	-27.98	-4.47%	-0.447%	-21.48	-3.43%	-0.343%

From these findings, it was clear that each of the five drivers had an effect on the projected land use and land cover change. Policies and acts put in place will increase forestland coverage from -0.176% loss per annum (1995 to 2020) to a gain of 0.263% per annum (2020 to 2040). Wetland degradation will also reduce from -0.466% loss per annum (1995 to 2020) to a gain of -0.007% per annum (2020 to 2040). These policies also will reduce the rapid agricultural expansion in gazetted areas with cropland reducing in annual gain from 0.471% (1995 to 2020) to 0.071% (2020 to 2040). Water supply and road developments are envisaged to have a positive impact on Built up area with a gain in annual LULC change of 0.012% (1995 to 2020) to 0.014% (2020 to 2040). Slope and river systems also governed the rate at which horizontal built up grows and so the study envisages vertical built up growth through high rise buildings (Table 4.16 & Table 4.19)).

4.4 Objective 3: To determine the impact of LULC and Climate change on the environmental Flow requirements of R. Namatala

4.4.1 Rainfall Analysis

4.4.1.1 Historical Rainfall Data

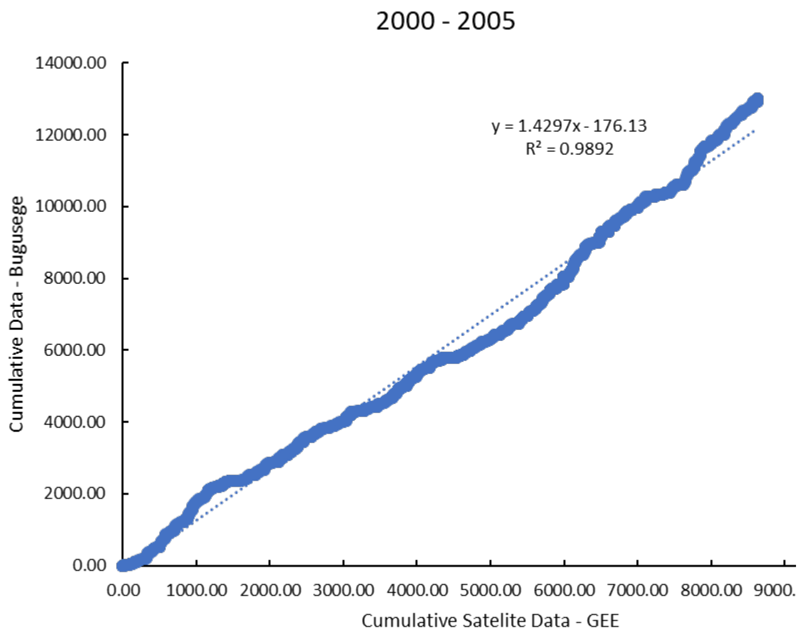
Data from Google Earth Engine was calibrated and validated with data between 2000 – 2010 using Precipitation data from Bugusege. The Data was split into two i.e. 2000-2005 used for calibration and 2006 to 2011 used for validation. Precipitation data for Bugusege and GEE was cumulated and plotted.

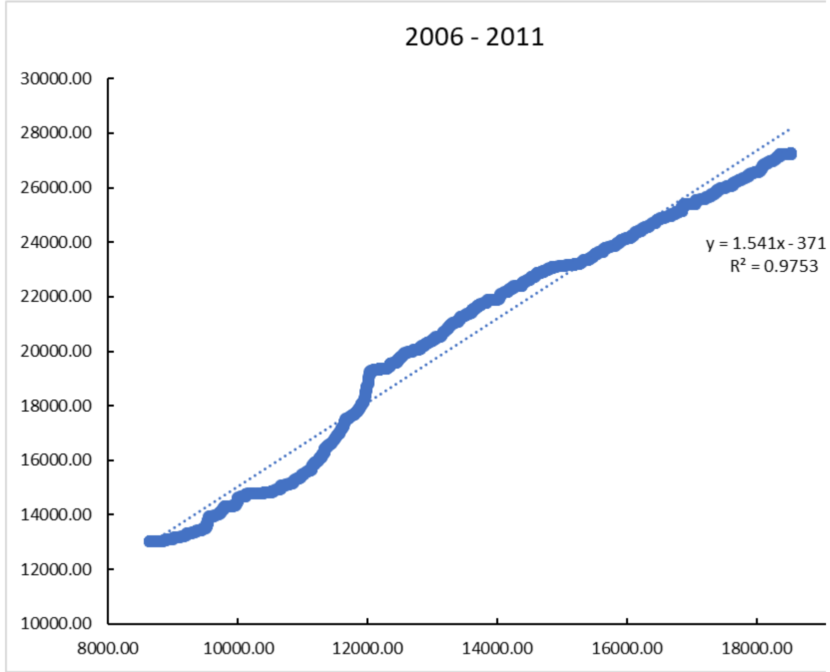
Table 4.20: Correlation between Observed and Satellite Precipitation

Sn.	Dataset	Correlation	Correction Factor (Observed Vs Satellite)
1	2000 - 2005	0.9892	1.0778485
2	2006 - 2010	0.9753	

The assessment showed that from 2000 – 2005, observed data had a high correlation (R^2 = 0.9892) with satellite data from GEE (

Figure 1.2). Data from 2006 to 2011 had a high correlation of R^2 = 0.9892. This showed that the data from GEE can be used to gap fill the 19% of precipitation data missing in the dataset obtained from Bugusege AWS. The correction factor used to correct satellite data to gap fill Bugusege AWS was obtained as 1.0778485 (Table 4.20).





Observed Vs Satellite Precipitation for 2000 - 2005 Observed Vs Satellite Precipitation for 2006 - 2011

Figure 4.19: Correlation between Observed Vs Satellite data for Gap filling

The R. Namatala historical rainfall data from 1979 to 2023 had an overall mean of 1746.71 with a standard deviation of 492.42 mm every year. Mekonnen et al., (2024) noted that the catchment experiences an overall variability of 28% between 1979 to 2023 which is classified as moderate in accordance to classification scale: low (CV < 20%), moderate (20 < CV < 30), high (CV > 30), extremely high (CV > 40), and extreme (CV > 70).

R. Namatala catchment exhibited changes in annual rainfall with 1997 and2007 as the water year exhibiting high rainfall in months of August to September. Between 1979 to 2023, the lowest ever recorded rainfall was experienced in years of 1984 and 1993 thus categorized as dry years in terms of rainfall (Figure 4.20)

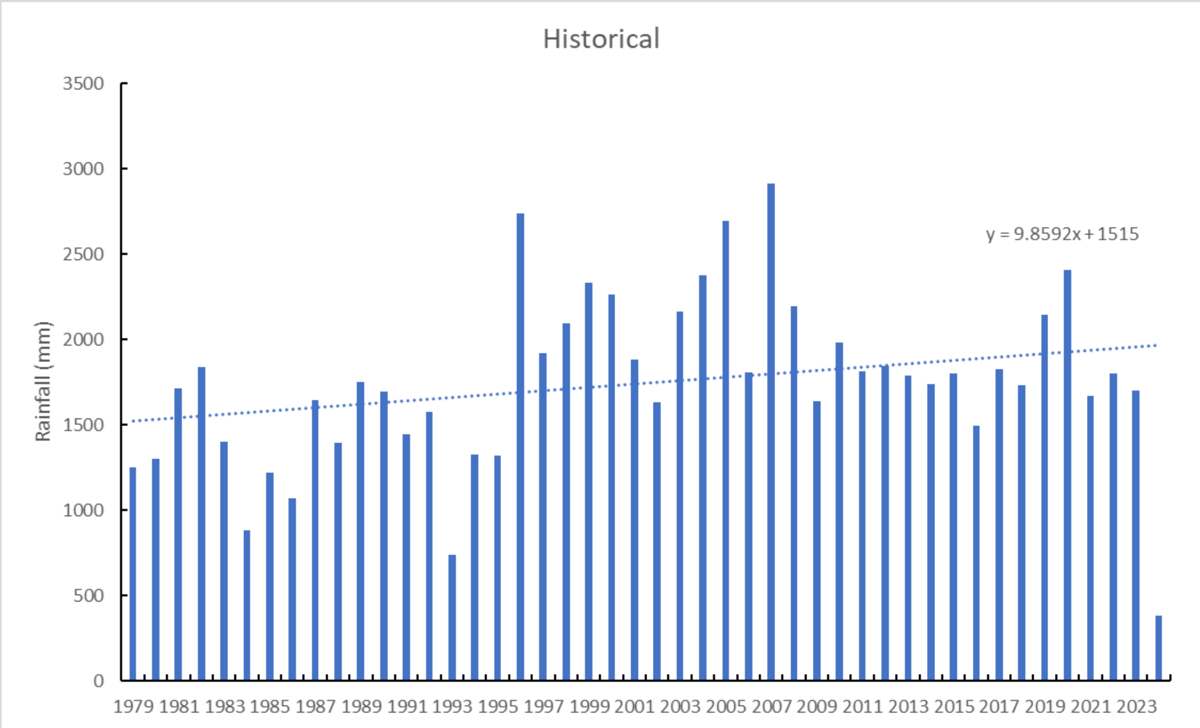


Figure 4.20: Historical Trends of Precipitation in the catchment

In terms of season variability, the catchment experienced on average a total of 1830.90 mm over 45 years. The data showed that on average, the catchment experienced a dry season between December to February and two rainy seasons of March to May (High intensity Low duration) as well as July to October (low intensity high duration) (Figure 4.21).

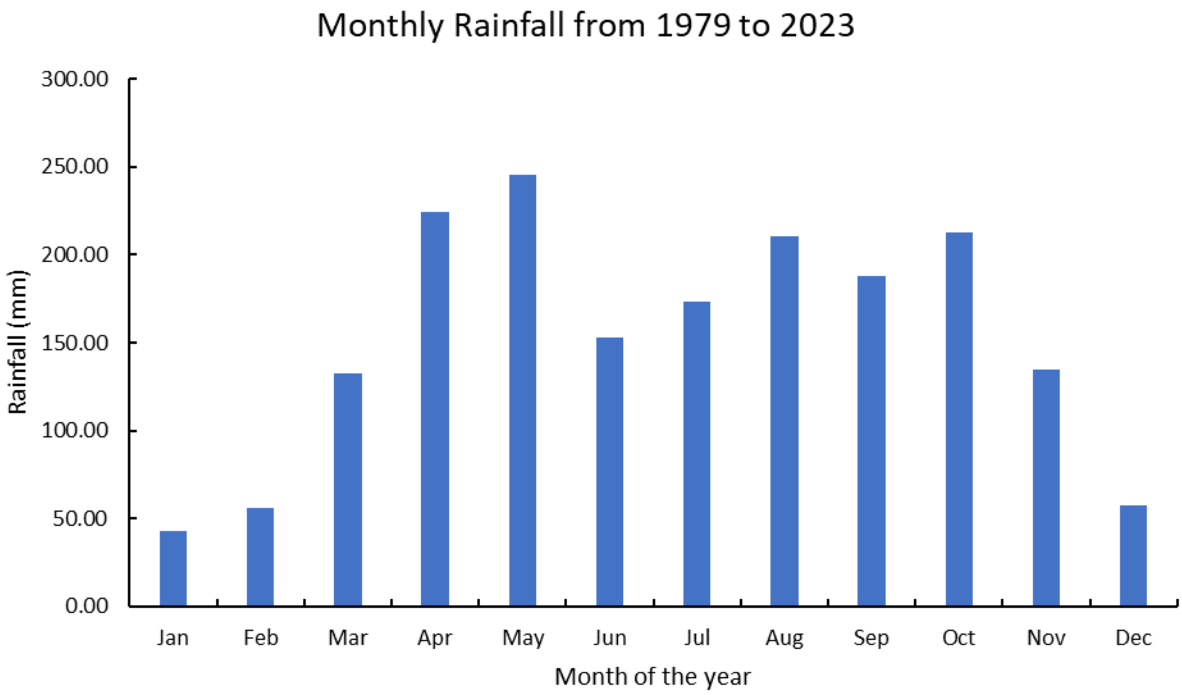


Figure 4.21: Seasonal Precipitation (1979 - 2023) for R. Namatala Catchment

4.4.1.2 Projected Rainfall Data

Two RCPs were considered in obtaining projected precipitation up to the study year 2040 and these included;

1. RCP 2.6 Most likely
2. RCP 8.5 Most Unlikely (Silva Lelis et al., 2018)

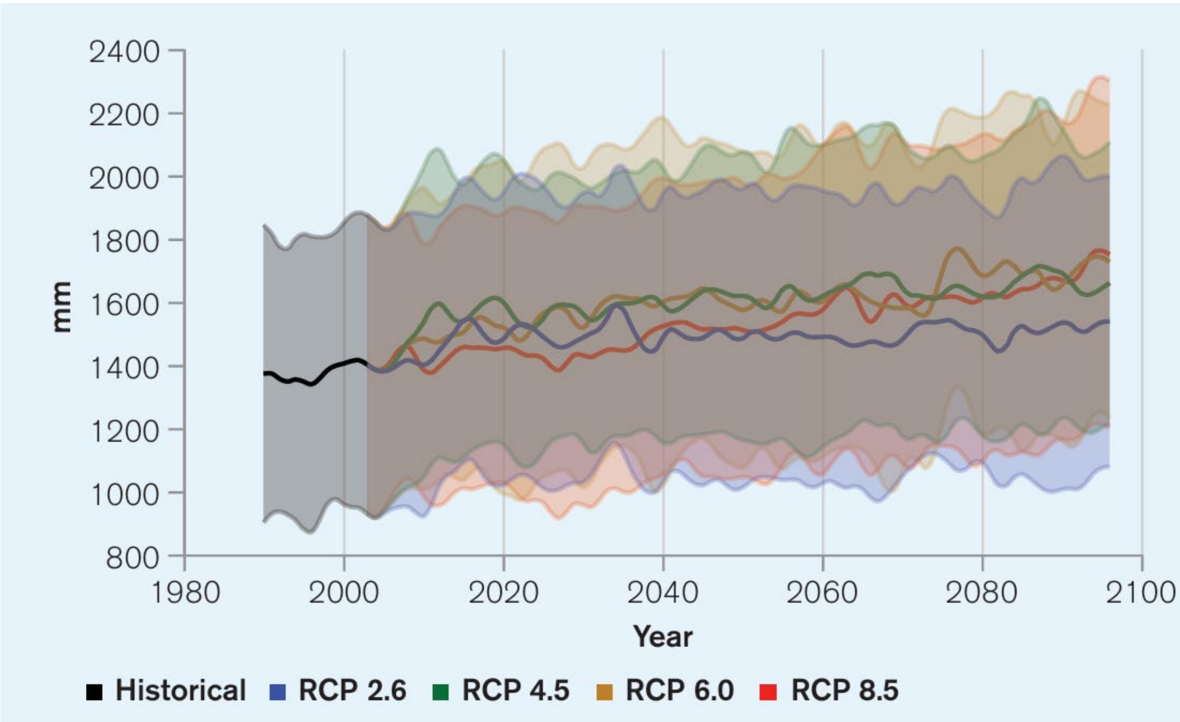


Figure 4.22: Annual average precipitation in Uganda for 1986 to 2099

Source: (World Bank, 2021a)

From the data obtained from Marksim DSSAT weather file generator, daily precipitation data were obtained from 2024 to 2040. The data showed that precipitation patterns will change in 2030 with the rainy season changing from March to May as per historical to April to July for both RCP 2.6 and RCP 8.5. Comparing results for RCP 2.6 and 8.5, data showed a reduction in rainfall of 22% and 26% respectively (Figure 4.23). This is due to the assumptions curated by each RCP.

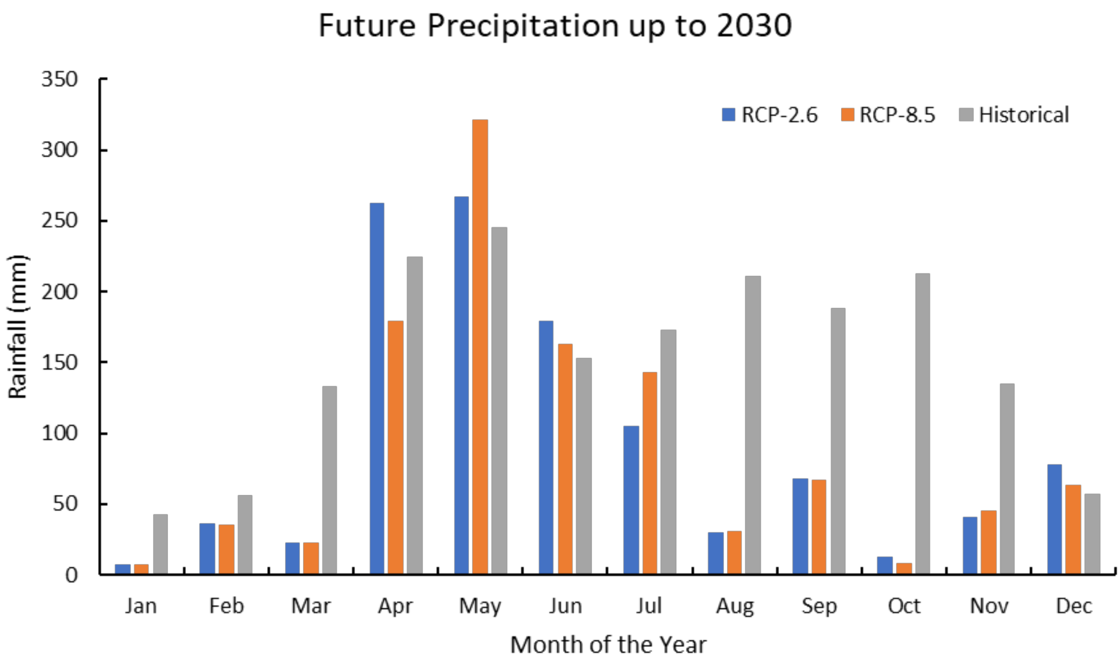


Figure 4.23: Projected Annual precipitation to 2030

The data showed that precipitation patterns will change in 2040 with the rainy season changing from March to May as per historical to April to July for both RCP 2.6 and RCP 8.5. The dry season will change from December to Feb in history to October – March for RCP 2.6 and January to March for RCP 8.5 (Figure 4.24). Comparing results for RCP 2.6 and 8.5 with historical rainfall (1979 – 2023) showed a reduction in rainfall of 18% and 11% respectively. This was attributed to the assumption and conditions of the RCPs.

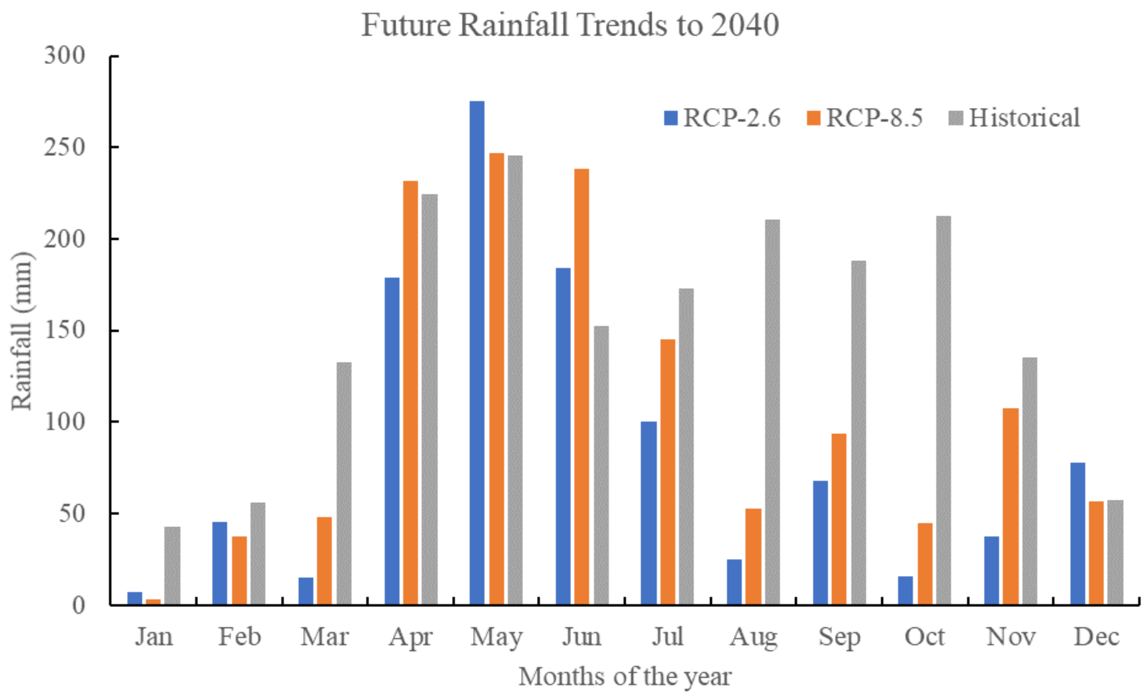


Figure 4.24: Projected Annual rainfall to 2040

A comparison was also undertaken between precipitation data for 2030 and 2040. The data showed that in 2040, rainfall for RCP 2.6 will further decrease by 6.2% as compared to 2030 while RCP 8.5 will increase by 11% as compared to 2030 (Figure 4.25). The seasonal trends were envisaged to remain the same for 2030 and 2040 with Jan to March as dry season, April to June as wet season with high intensiy and Sepember to December with low intensity high duration.

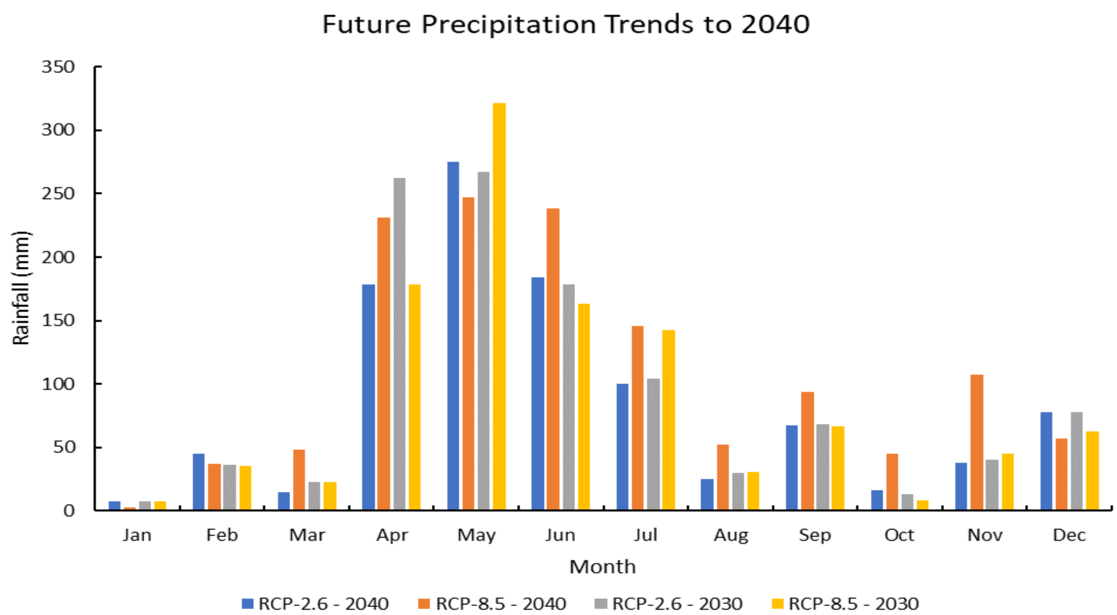


Figure 4.25: Projected Annual precipitation comparison between 2030 and 2040

4.4.2 Data used for Prediction of Projected Flows for R. Namatala

4.4.2.1 Projected Land use changes

The projected land use changes adopted for prediction of projected E-flow requirements are stipulated under section 4.3.2.4 Projected LULC Change. Three land use classes were selected i.e. Built up, Cropland and Forestland which showed a significant variation over a temporal and spatial scale (Table 4.18). These Land use classes also are envisaged to have an effect on the hydrology.

Table 4.21: Projected LULC in R. Namatala Catchment for selected Land use Classes

Land Use / Land Cover	2020		2030		2040	
	Sq. Km	%	Sq. Km	%	Sq. Km	%
Built Up Land	2.80	0.45%	3.82	0.61%	4.73	0.75%
Cropland	140.58	22.45%	152.90	24.41%	157.37	25.13%
Forest Land	83.76	13.37%	101.23	16.16%	117.73	18.80%

4.4.2.2 Elevation Zoning of the catchment

The catchment was distributed into four elevation zones;

1. Elevation Zone 1: 1160 m.a.s.l
2. Elevation Zone 2: 1160 - 1298 m.a.s.l
3. Elevation Zone 1: 1298 - 1580 m.a.s.l
4. Elevation Zone 1: 1580 - 2038 m.a.s.l

4.4.3 HBV Model Set up and Calibration

The calibration and validation periods of the model were compared to the normal rainfall patterns slated as per Figure 4.21 of the catchment using the SPI. The Standardized Precipitation Index of the catchment for the period indicates that 1991-2020 both calibration and validation periods are near normal. Warm up period, calibration and validation had an SPI of 0.4312, 0.6842,0.6775, 0.6688, 0.6132 respectively (Table 4.22). The values were categorized to be mild wet in accordance to SPI Index scale which categorizes two extremes of -0.9 as Dry and 0.9 as wet (Bouaziz et al., 2021). 65% of the available data reflected the normal climate of the catchment and reflect the annual rainfall pattern in the catchment.

Table 4.22: The normalized SPI Index years used for calibration and validation

Time Frame	SPI	
1996 – 2000	0.4312	Warm up
2001 – 2005	0.6842	Calibration
2006 - 2010	0.6775	
2010 – 2015	0.6688	Validation
2015 – 2020	0.6132	

Table 4.23 shows the results of the calibration and validation of the HBV-Light model. Model efficiencies of 0.6221 and 0.667 were achieved for the calibration and validation respectively for years 1996 – 2000 and 2001 – 2006. One can notice that the sum of simulated discharge is lower than observed discharge for calibration and opposite for validation.

Table 4.23: Water balance and model performances for the calibration and validation periods

Water Balance[mm/year]:	***Calibration***	***Validation***
Sum Qsim	514	648
Sum Qobs	831	828
Sum Precipitation	2096	2106
Sum AET	1514	1522
Sum PET	1547	1556
Goodness of fit:	***Calibration***	***Validation***
Coefficient of determination	0.518	0.526
Model efficiency	0.6221	0.667

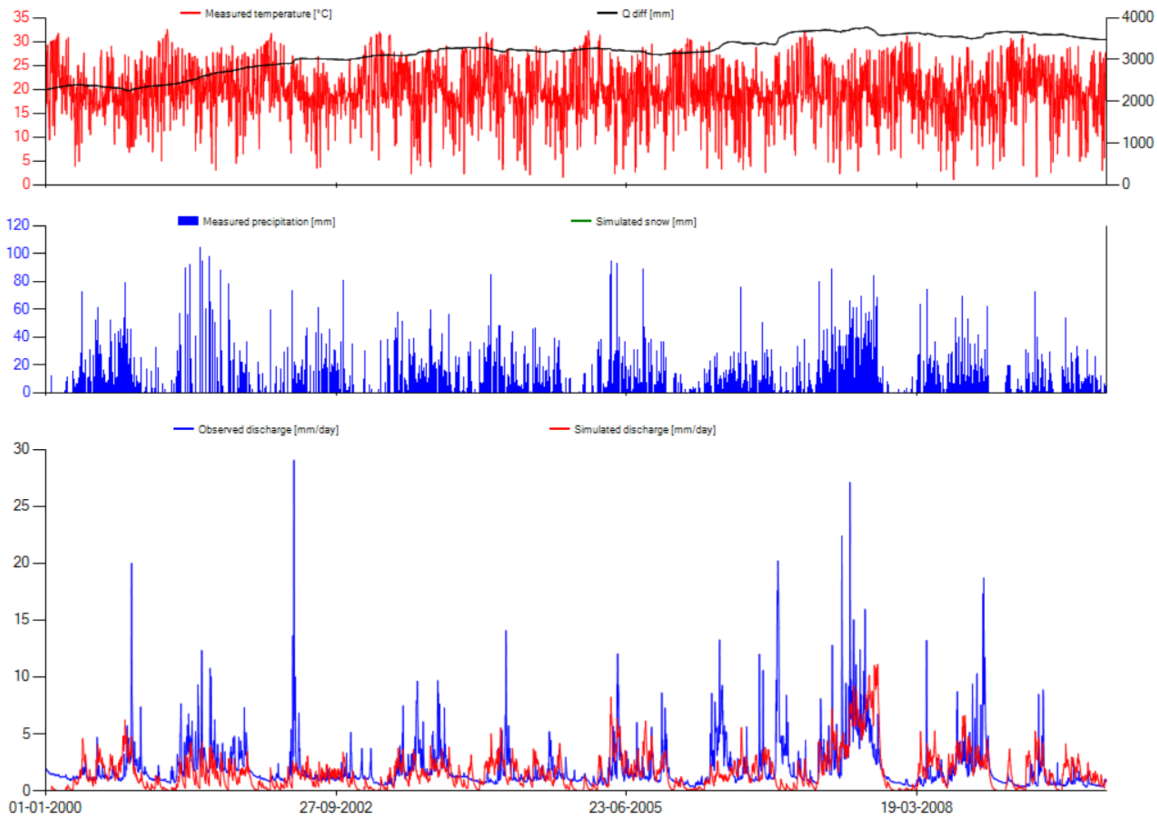


Figure 4.26: HBV Calibration and validation from 2001 - 2006

The degree of collinearity between simulated and measured data is described by the model's coefficient of determination (R^2), according to a number of studies (Al-Safi & Sarukkalige, 2017; Driessen et al., 2010; Montero et al., 2016; Radchenko et al., 2013; Usman et al., 2022). The calibration R^2 value in this study was found to be more than 0.5, indicating a good match, however, the study under estimated the peaks flows exhibited in the river system. All things considered, the model accurately captures the catchment's permissible hydrological regime.

4.4.4 Projected flows on R. Namatala

To determine projected flows, HBV required the following inputs; projected Land use, projected climatic data (Precipitation and Temperature) for RCP 2.6 and 8.5 as well as model parameters obtained during calibration and validation. The future projections were split into two i.e. 2030 as Midterm and 2040 and long-term. Simulated flows for 2030 acted as observed data for 2040.

4.4.4.1 Projected flows Based on RCP 2.6

Under the most likely scenario 2.6, the model exhibited a high efficiency of 0.6740, 0.9985 with a correlation R^2 – 0.7192, 1.0 for 2030 and 2040 respectively. The mean difference in projected flows were 66 and (-10) for 2030 and 2040 respectively (Table 4.24, Figure 4.27, Figure 4.28).

Table 4.24: Water balance and model performances for the 2030 and 2040 periods

Water Balance[mm/year]:	**RCP 2.6 2030**	**RCP 2.6 2040**
Sum Qsim	468	473
Sum Qobs	534	462
Sum Precipitation	1975	1767
Sum AET	1404	1410
Sum PET	1548	1548
Goodness of fit:	**RCP 2.6 2030**	**RCP 2.6 2040**
Coefficient of determination	0.7192	1.00
Model efficiency	0.6740	0.9985
Efficiency for Log (Q)	0.6096	0.9996
Flow weighted Efficiency	0.504	0.9981
Mean difference	66	-10

Figure 4.27 and Figure 4.28 displayed three graphs i.e. measured precipitation, temperature, simulated discharge over the same temporal scale (2021 to 2040). The temperature and graph show trends and effect on the simulated flows. According to Table 4.24, 2021 - 2030 is envisaged to experience a decrease in simulated discharge by 12% as compared to the observed data (2010 – 2021) with precipitation also reducing by 7% on average to 2030. 2030 – 2040 is also envisaged to follow the same flow trend as 2021 – 2030 under RCP 2.6 however, there will be an increase in simulated discharge by 2.16% as compared to the 2021-2030 period with precipitation also reducing by 10.5% on average to 2040.

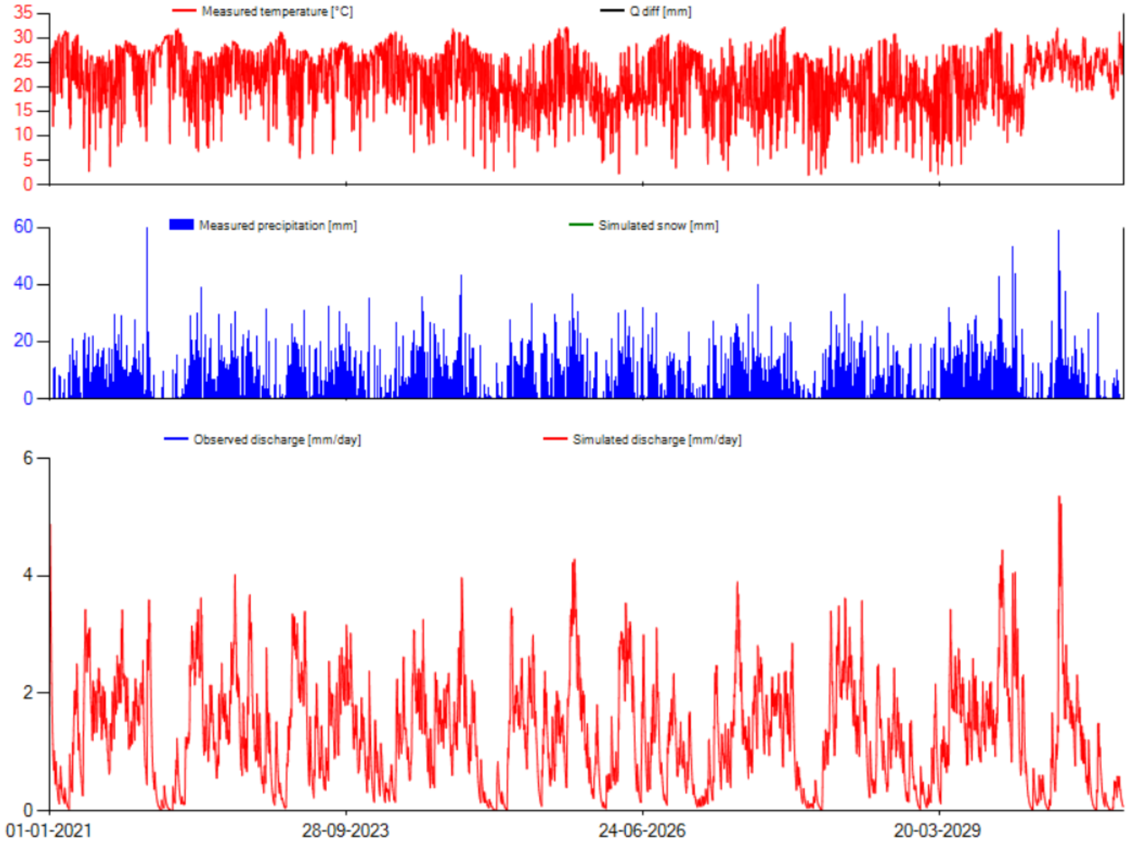


Figure 4.27: Projected Annual flows 2021 to 2030 under RCP 2.6

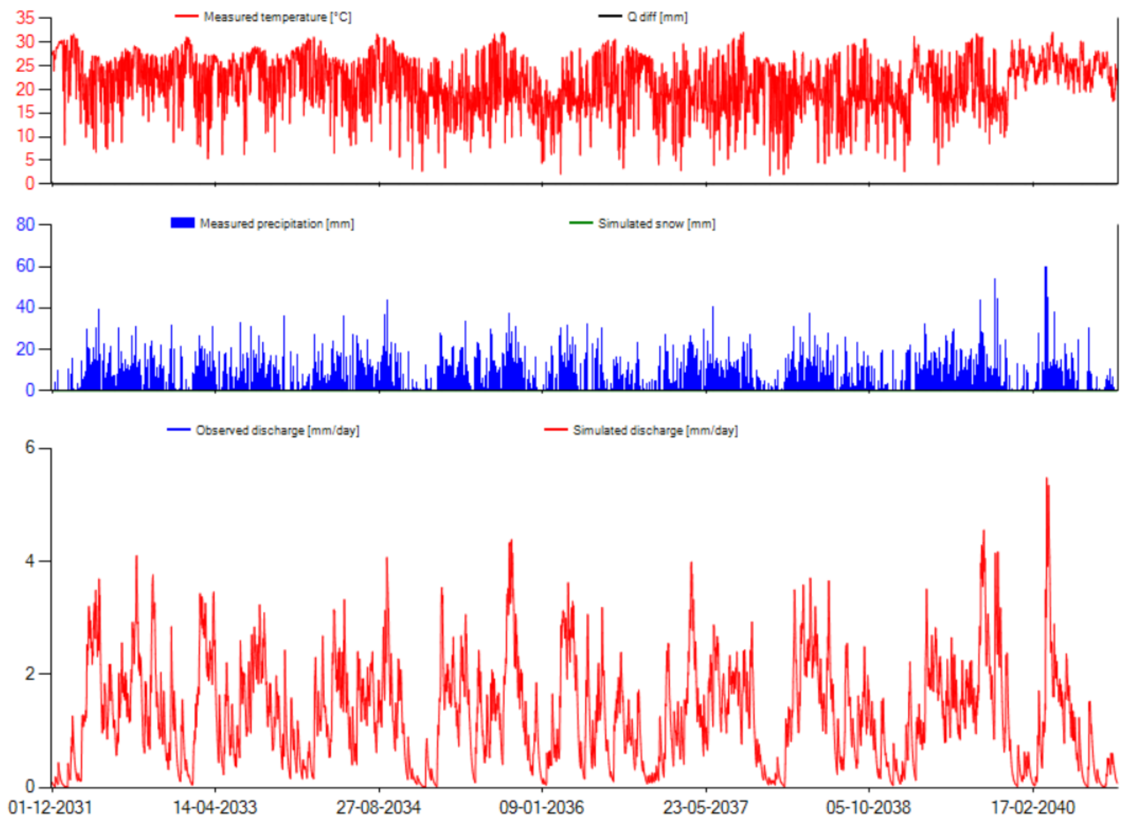


Figure 4.28: Projected predicted flows from 2030 to 2040 under RCP 2.6

Based on projected river flows, statistical analysis was undertaken to obtain the mean flows. Based on the results, the mean annual flow for R. Namatala was estimated to be 2.19 m^3/s. According to Figure 4.4, the data showed a temporal variation in flows with R. Namatala fluctuating in respect to the mean (2.19 m^3/s). This illustrated the seasonal variability of R. Namatala over the years with 2039 chosen as the water year and 2031, 2036 and 2040 regarded as the dry years.

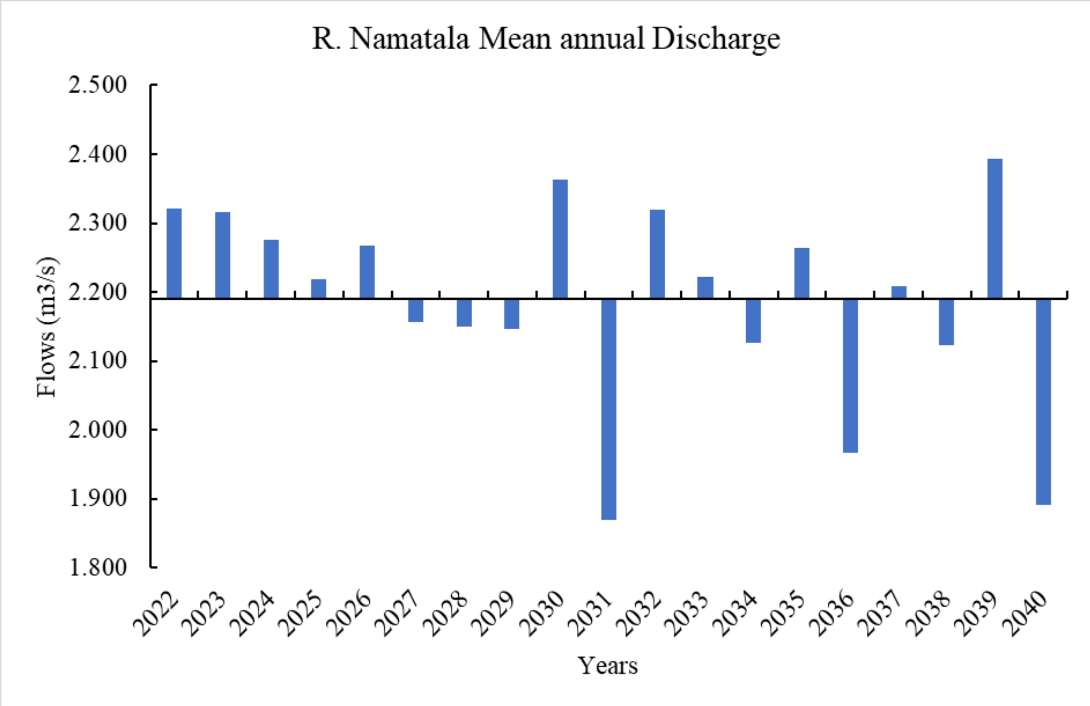


Figure 4.29: R. Namatala Mean Annual Discharge for Projected flows under RCP 2.6

Seasonal variability of flows for RCP 2.6 over a monthly scale for years 2022 to 2040 was determined. Table 4.1 revealed that R. Namatala has a mean monthly flow of 2.185 m^3/s.

Table 4.25: Mean Monthly flow of R. Namatala under RCP 2.6

Month	**Mean Monthly Flows (m^3/s)**
January	1.61
February	1.74
March	2.21
April	2.82
May	2.63
June	2.17
July	2.16
August	2.23
September	2.42
October	2.40
November	2.05
December	1.78
	MMF: 2.185

According to Figure 4.30, R. Namatala catchment is envisaged to experience a seasonal pattern of Nov to Feb (4 Months) as the low flow period and two high flow periods of April to May and Sept to Oct above the average (2.185 m^3/s).

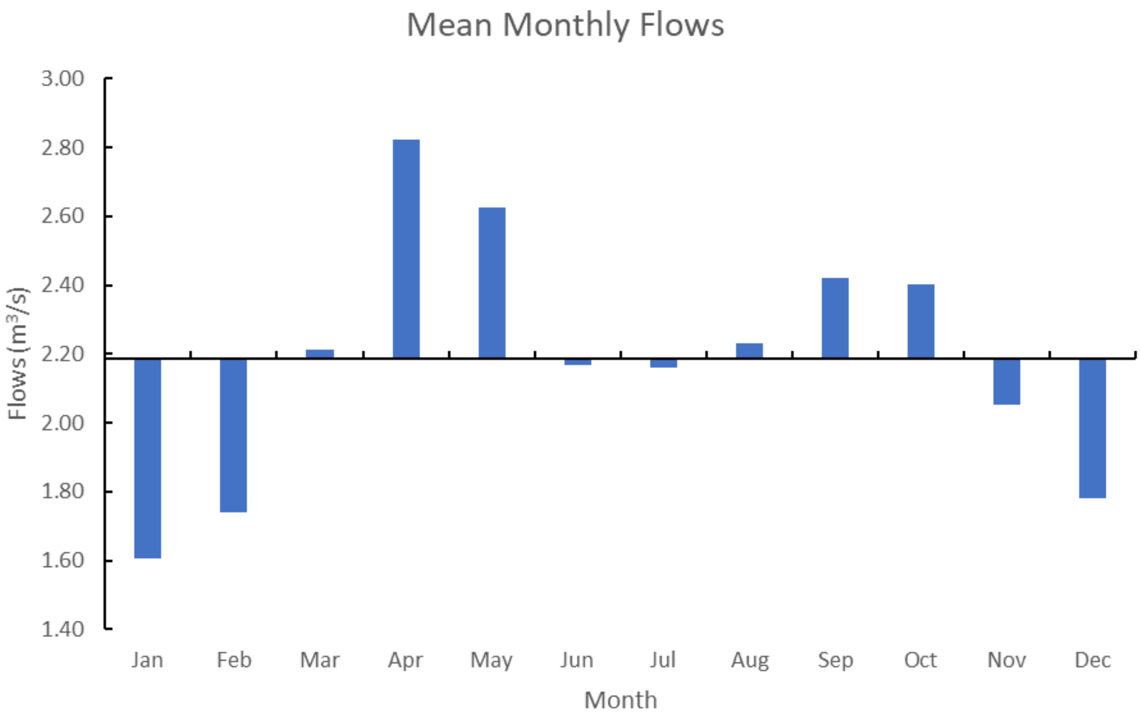


Figure 4.30: R. Namatala Mean Monthly Discharge for 2022 to 2040 under RCP 2.6

4.4.4.2 Projected flows Based on RCP 8.5

Under the most unlikely scenario RCP 8.5, the model exhibited a high efficiency of 0.6384, 0.5812 with a correlation R^2 – 0.6886, 0.6423 for 2030 and 2040 respectively. The mean difference in projected flows were 65 and 56 for 2030 and 2040 respectively (Table 4.26, Figure 4.31, Figure 4.32).

Table 4.26: Water balance and model performances for the 2030 and 2040 periods

Water Balance[mm/year]:	**RCP 8.5 2030**	**RCP 8.5 2040**
Sum Qsim	462	467
Sum Qobs	527	523
Sum Precipitation	1729	1748
Sum AET	1399	1403
Sum PET	1548	1548
Goodness of fit:	**RCP 8.5 2030**	**RCP 8.5 2040**
Coefficient of determination	0.6886	0.6423
Model efficiency	0.6384	0.5815

Efficiency for Log (Q)	0.5671	0.4675
Flow weighted Efficiency	0.4582	0.3686
Mean difference	65	56

As shown in Table 4.26, 2023 - 2030 is envisaged to experience a decrease in simulated discharge by 12.5% as compared to the observed data (2010 – 2021) with precipitation also reducing by 8% on average to 2030. 2030 – 2040 is also envisaged to follow the same flow trend as 2023 – 2030 under RCP 8.5 however, there will be an increase in simulated discharge by 1.01% as compared to the 2023-2030 period with precipitation also increasing by 1.1% on average up to 2040.

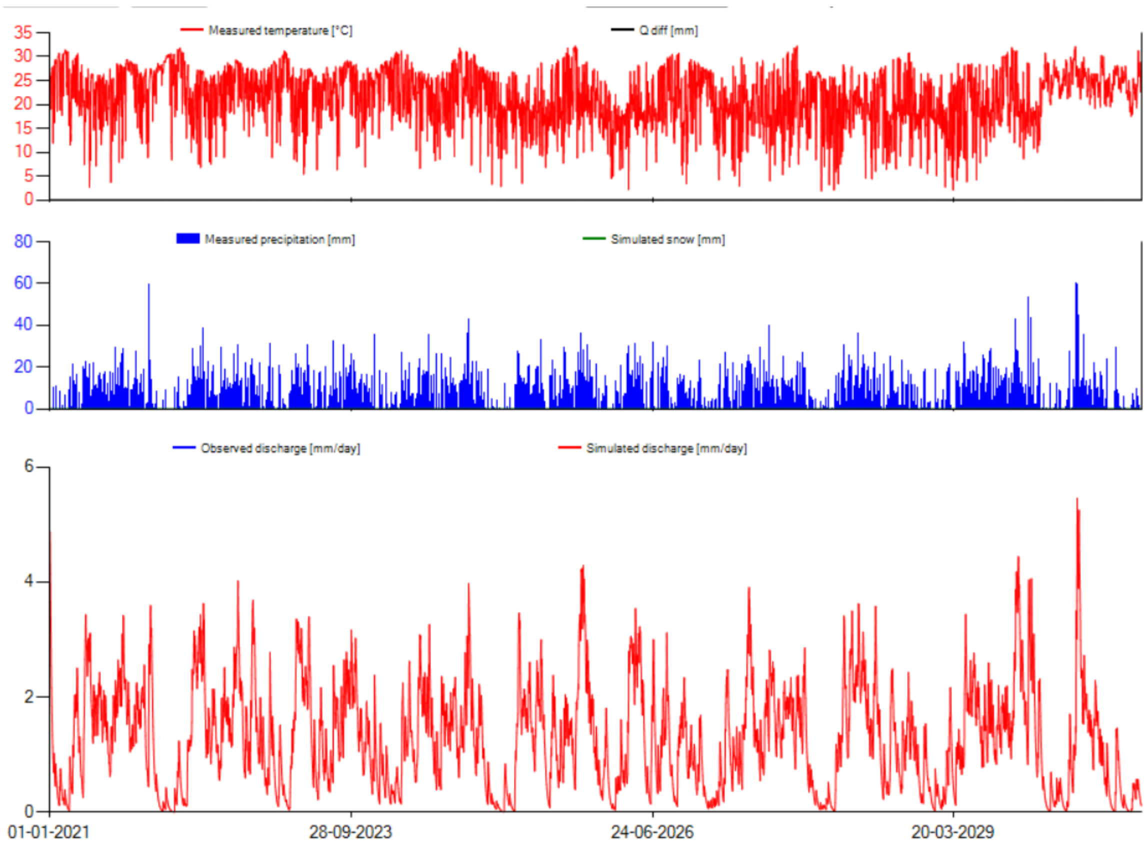


Figure 4.31: Projected Annual precipitation 2023 to 2030 under RCP 8.5

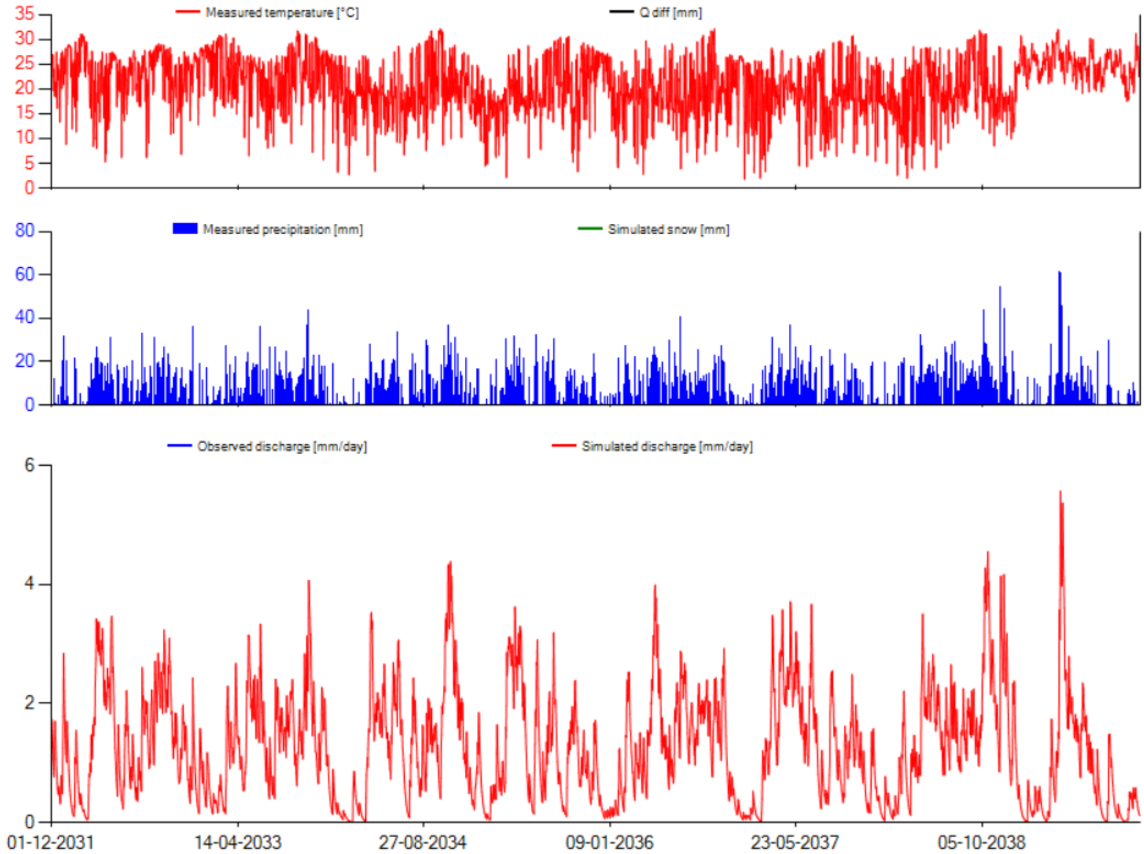


Figure 4.32: Projected predicted flows from 2030 to 2040 under RCP 8.5

Results showed that the mean annual flow for R. Namatala was estimated to be 2.273 m^3/s. According to Figure 4.33, the data showed a temporal variation in flows with R. Namatala fluctuating in respect to the mean (2.273 m^3/s). This illustrated the seasonal variability of R. Namatala over the years with 2031 chosen as the water year and 2027, 2025, 2029, and 2040 regarded as the dry years.

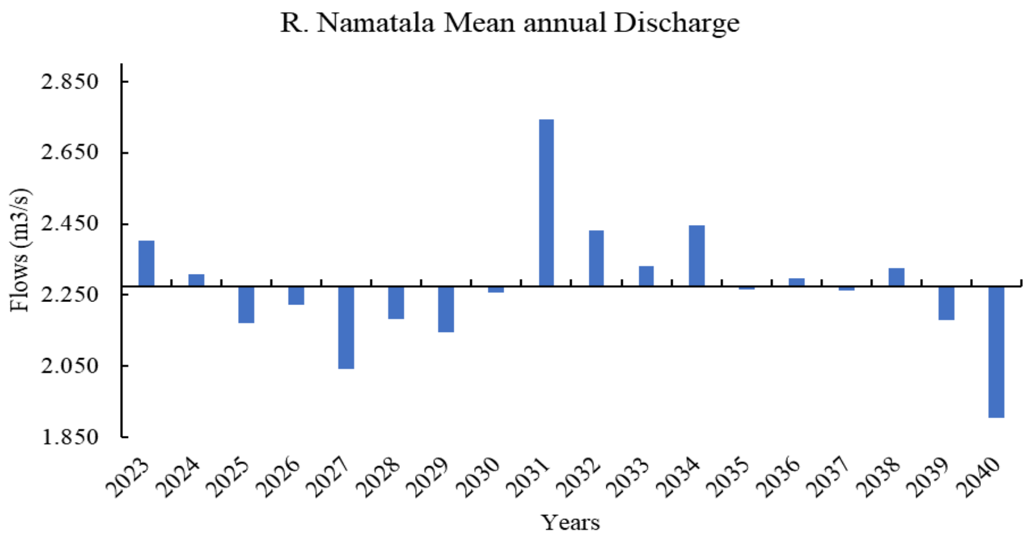


Figure 4.33: R. Namatala Mean Annual Discharge for projected flows under RCP 8.5

Seasonal variability of flows for RCP 8.5 over a monthly scale for years 2023 to 2040 was determined. Table 4.27 revealed that R. Namatala has a mean monthly flow of 2.29 m^3/s.

Table 4.27: Mean Monthly flow of R. Namatala under RCP 8.5

Month	Mean Monthly Flows
January	1.93
February	1.75
March	1.81
April	2.04
May	2.64
June	3.02
July	2.26
August	2.24
September	2.22
October	2.33
November	2.70
December	2.51
	MMF – 2.29

According to Figure 4.34, R. Namatala catchment is envisaged to experience a seasonal pattern of January to April (4 Months) as the low flow period and two high flow periods of April to May and Sept to Oct above the average (2.29 m^3/s).

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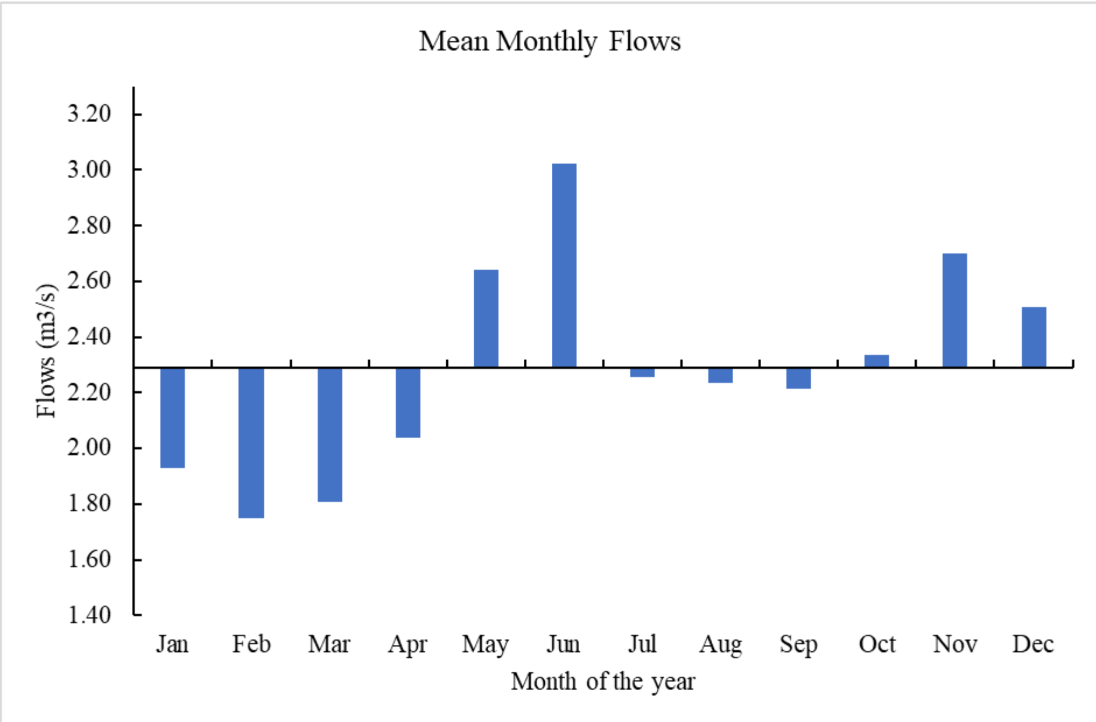

Figure 4.34: R. Namatala Mean Monthly Discharge for 20232 to 2040 under RCP 8.5

4.4.5 Projected E-flows Based on RCP 2.6

4.4.5.1 Hydrological E-flow Assessment for RCP 2.6

Based on the 30% of Mean annual flow (MAF), R. Namatala is envisaged to exhibit a hydrological environmental flow requirement of 0.66 m^3/s (Table 4.11). The environmental flow requirement estimated caters for minimum flows required to keep the ecosystem inclusive of flora and fauna. The catchment has an average available flow recommended for usage in the catchment as 1.53 m^3/s with a seasonal low flow variability during the months of November to March and June to July.

Table 4.28: R. Namatala's environmental requirement flow due to Tennant's Method for RCP 2.6

Month	MM Flows	Tennant's Methods	
		Tenants *30%	Available Flows - Tenants
Jan	1.61	30% MAF	0.95
Feb	1.74		1.09
Mar	2.21		1.56
Apr	2.82		2.17
May	2.63		1.97
Jun	2.17		1.51
Jul	2.16		1.50
Aug	2.23		1.58
Sep	2.42		1.77
Oct	2.40		1.75
Nov	2.05		1.40
Dec	1.78		1.13
MMF	**2.185**	**0.66**	**1.53**
MAF	**2.19**		

Using Tessman's modifications to the Tennant method, the findings showed the average environmental Flow requirement is 0.874 m^3/s with deficits in months of November to March and June to July (Figure 4.8). April is envisaged to exhibit the highest environmental flow requirement given that this period receives the highest flows due to contributions from precipitation.

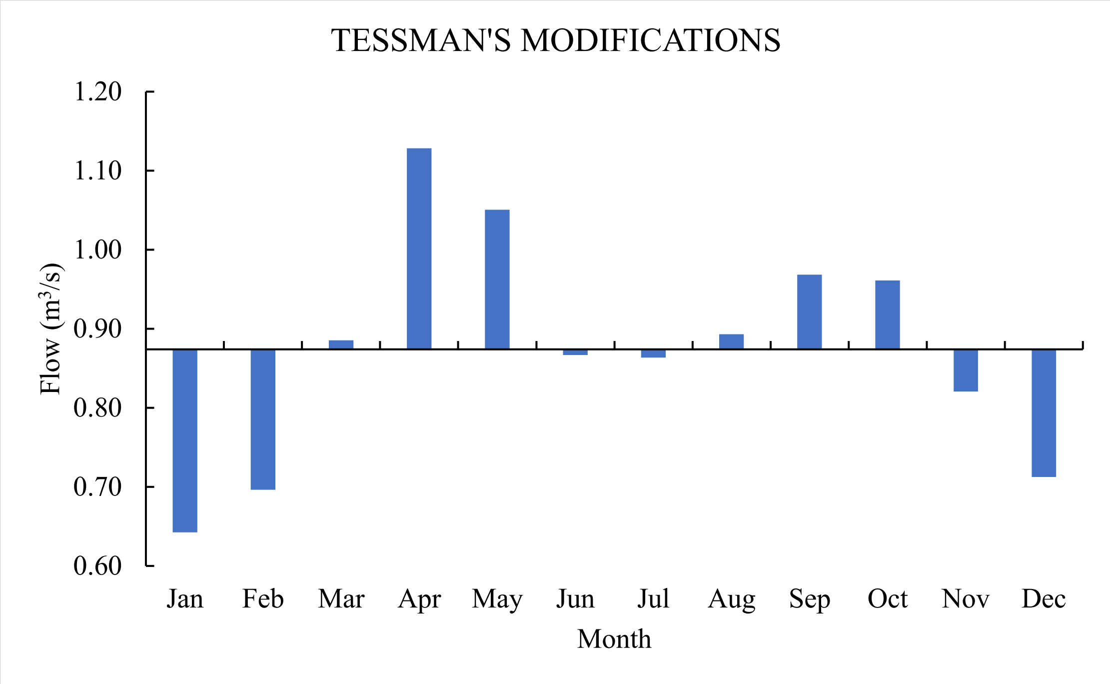

Figure 4.35: environmental flow monthly variations from the average for 2023 to 2041 under RCP 2.6

Table 4.29: R. Namatala's environmental flow requirement due to Tessman's Method due to RCP 2.6

Month	MM Flows	Tessman's Modification		
		Tessman *40%	E-flow Due to MMF	Water Available
Jan	1.61	40% MAF	0.64	0.96
Feb	1.74		0.70	1.04
Mar	2.21		0.89	1.33
Apr	2.82		1.13	1.69
May	2.63		1.05	1.58
Jun	2.17		0.87	1.30
Jul	2.16		0.86	1.30
Aug	2.23		0.89	1.34
Sep	2.42		0.97	1.45
Oct	2.40		0.96	1.44
Nov	2.05		0.82	1.23
Dec	1.78		0.71	1.07
MMF	**2.185**	**0.88**	**0.874**	**1.31**
MAF	**2.19**			

4.4.5.2 Hydraulic E-flow Assessment for RCP 2.6

Projected flows between 2023 to 2040 for RCP 2.6 were utilized for hydraulic E-flow estimation. The channels of the river were assumed to have a fixed bed and considered to maintain the stratification they currently have till 2040.

Figure below(a) provided an analysis of the wetted perimeter and from this, the environmental flow requirement ranged from 0.69 m^3/s upstream of the catchment and 1.47 m^3/s as you tend downstream of the catchment.

Basing on the findings, the average hydraulic environmental Flow requirement for RCP 2.6 for 2022 to 2040 is 1.082 m^3/s. In the upstream areas, the low flows (0.69 m^3/s) exhibited as the environmental flow ((a) to (e)). As the River moves through the mid-stream and it tends to the Namatala – Doho wetland system, the environmental flow requirement increases from 0.86 m^3/s to 1.47 m^3/s ((f) to (n)). This shows that the environmental flow requirement more required in the downstream as compared to upstream.

4.4.5.3 Holistic E-flow Assessment for RCP 2.6

Based on the building block method, five blocks were considered for the projected Holistic E-flow requirement for R. Namatala under RCP 2.6. These were Hydraulic flow, Flora, Fauna, Socio-economic considerations and Aquatic life. These blocks have been broken down as follows;

1. In terms of hydraulic requirement of the river considering a fixed channel bed, the hydraulic E-flow was considered to cater for the flows required so as to sustain the river system. This flow was calculated under section 4.4.5.2 Hydraulic E-flow Assessment for RCP 2.6. From this a hydraulic flow requirement was observed to be 1.082 m^3/s.
2. In terms of Flora, the findings from the biodiversity assessment showed that plants near the river were catered for in regards to water needs by the flows in the rivers. This then assumes that the needs of plants on the river banks is taken care of by the hydraulic e-flow while plants away from the river system utilize a number of sources such as ground water, soil moisture and precipitation.
3. In terms of Fauna and Herpertiles, the findings from the biodiversity assessment showed that Herpertiles and Fauna near the river were catered for in regards to water needs by the flows in the rivers. Also, to note that the water requirements for the Herpertiles was minimal hence can be catered for by the hydraulic E-flow.
4. In terms of Socio-Economic requirements, the projected demand for 2040 is 0.023 m^3/s catering for socio-economic activities undertaken on a 100m buffer zone.

5. In terms of aquatic requirement, there was noticeable decrease in fish population attributed to overfishing downstream in the Namatala – Doho wetland system. Given the challenges in determining fish numbers, 5% of the hydraulic E-flow was taken to cater for the fish spawning, change in flows and fish migration. The aquatic fish requirement for 2040 was estimated as 0.0541 m^3/s.

Based on these, the holistic environmental flow requirement for RCP 2.6 is 1.1591 m^3/s

4.4.6 Projected E-flows Based on RCP 8.5

4.4.6.1 Hydrological E-flow Assessment for RCP 8.5

Based on the 30% of Mean annual flow (MAF), R. Namatala is envisaged to exhibit a hydrological environmental flow requirement of 0.69 m^3/s (Table 4.30). The environmental flow requirement estimated caters for minimum flows required to keep the ecosystem inclusive of flora and fauna. The catchment has an average available flow recommended for usage in the catchment as 1.60 m^3/s with a seasonal low flow variability during the months of January to April and July to September.

Table 4.30: R. Namatala's environmental requirement flow due to Tennant's Method for RCP 8.5

Month	MM Flows	TENNANT'S METHODS	
		TENANTS *30%	AVAILABLE FLOWS - TENANTS
Jan	1.93	30% MAF	1.24
Feb	1.75		1.06
Mar	1.81		1.12
Apr	2.04		1.35
May	2.64		1.95
Jun	3.02		2.34
Jul	2.26		1.57
Aug	2.24		1.55
Sep	2.22		1.53
Oct	2.33		1.65
Nov	2.70		2.02
Dec	2.51		1.82
MMF	**2.29**	**0.69**	**1.60**
MAF	**2.27**		

Using Tessman's modifications to the Tennant method, the findings showed the average environmental Flow requirement is 0.915 m^3/s with deficits in months of January to April and July to September (Figure 4.36). June is envisaged to exhibit the highest environmental flow requirement given that this period receives the highest flows due to contributions from precipitation.

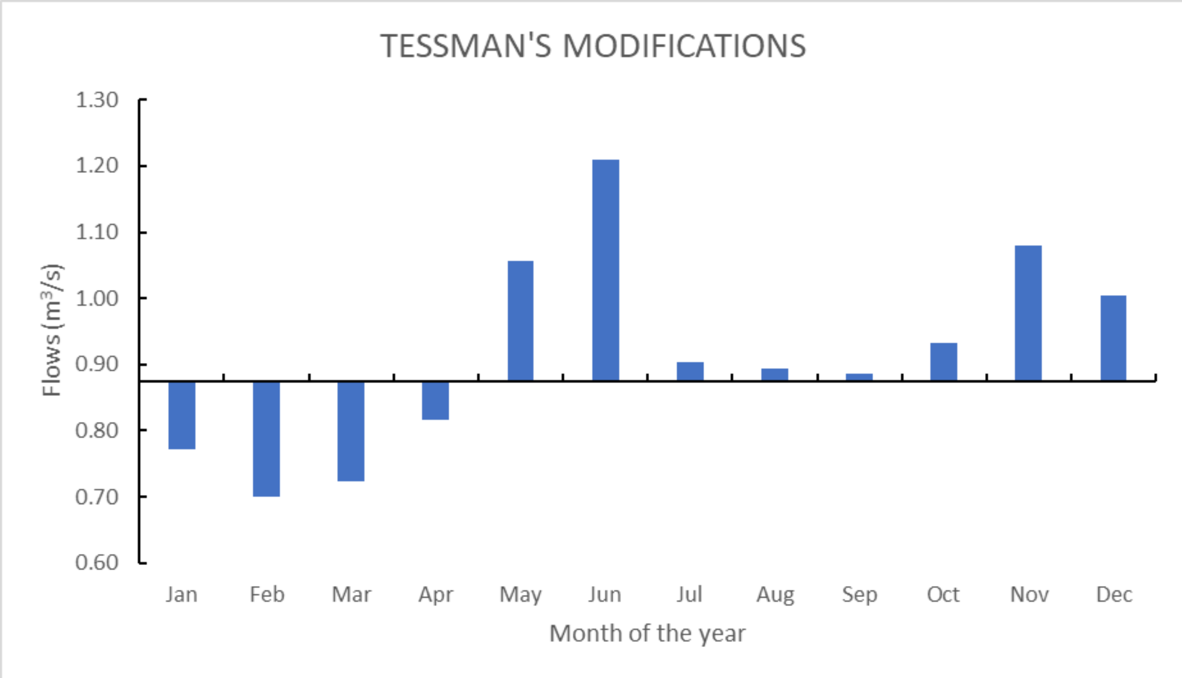

Figure 4.36: Environmental flow monthly variations from the average for 2023 to 2041 under RCP8.6

Table 4.31: R. Namatala's environmental flow requirement due to Tessman's Method due to RCP 2.6

Month	**MM Flows**	**TESSMAN'S MODIFICATION**		
		Tessman *40%	**E-flow Due to MMF**	**Water Available**
Jan	1.93	40% MAF	0.77	1.16
Feb	1.75		0.70	1.05
Mar	1.81		0.72	1.08
Apr	2.04		0.82	1.22
May	2.64		1.06	1.58
Jun	3.02		1.21	1.81
Jul	2.26		0.90	1.35
Aug	2.24		0.89	1.34
Sep	2.22		0.89	1.33
Oct	2.33		0.93	1.40
Nov	2.70		1.08	1.62
Dec	2.51		1.00	1.50
MMF	**2.29**	**0.91**	**0.915**	**1.37**
MAF	**2.27**			

4.4.6.2 Hydraulic E-flow Assessment for RCP 8.5

Projected flows between 2023 to 2040 for RCP 8.5 were utilized for hydraulic E-flow estimation. The channels of the river were assumed to have a fixed bed and considered to maintain the stratification they currently have till 2040.

(n) RCP 8.5 Station ID – 491 provided an analysis of the wetted perimeter and from this, the environmental flow requirement ranged from 0.69 m^3/s upstream of the catchment and 1.47 m^3/s as you tend downstream of the catchment.

Basing on the findings, the average hydraulic environmental Flow requirement for RCP 8.5 for 2023 to 2040 is 1.076 m^3/s. In the upstream areas, the low flows (0.69 m^3/s) exhibited as the environmental flow ((a) to (e)). As the River moves through the mid-stream and it tends to the Namatala – Doho wetland system, the environmental flow requirement increases from 0.86 m^3/s to 1.47 m^3/s ((n) RCP 8.5 Station ID – 491). This shows that the environmental flow requirement more required in the downstream as compared to upstream.

4.4.6.3 Holistic E-flow Assessment for RCP 8.5

Based on the building block method, five blocks were considered for the projected Holistic E-flow requirement for R. Namatala under RCP 8.5. These were Hydraulic flow, Flora, Fauna, Socio-economic considerations and Aquatic life. These blocks have been broken down as follows;

1. In terms of hydraulic requirement of the river considering a fixed channel bed, the hydraulic E-flow was considered to cater for the flows required so as to sustain the river system. This flow was calculated under section 4.4.6.2 Hydraulic E-flow Assessment for RCP 8.5. From this a hydraulic flow requirement was observed to be 1.076 m^3/s.
2. In terms of Flora, the findings from the biodiversity assessment showed that plants near the river were catered for in regards to water needs by the flows in the rivers. This then assumes that the needs of plants on the river banks is taken care of by the hydraulic e-flow while plants away from the river system utilize a number of sources such as ground water, soil moisture and precipitation.
3. In terms of Fauna and Herpertiles, the findings from the biodiversity assessment showed that Herpertiles and Fauna near the river were catered for in regards to water needs by the flows in the rivers. Also, to note that the water requirements for the Herpertiles was minimal hence can be catered for by the hydraulic E-flow.
4. In terms of Socio-Economic requirements, the projected demand for 2040 is 0.023 m^3/s catering for socio-economic activities undertaken on a 100m buffer zone.

5. In terms of aquatic requirement, there was noticeable decrease in fish population attributed to overfishing downstream in the Namatala – Doho wetland system. Given the challenges in determining fish numbers, 5% of the hydraulic E-flow was taken to cater for the fish spawning, change in flows and fish migration. The aquatic fish requirement for 2040 was estimated as 0.0538 m^3/s.

Based on these, the holistic environmental flow requirement for RCP 8.5 is 1.1528 m^3/s

4.5 Catchment Management Strategies for R. Namatala

4.5.1 Water Supply Vs Water Demand Assessment

From the analysis, R. Namatala together with its tributaries have the capacity to supply the at least 75% of the catchment requirements up to the study year of 2040. A value that is corresponding to permitted users demand was recommended to be left in the river to account for uncertainty in future infrastructures in the catchment.

The findings noted that in current year 2023, R. Namatala can sufficiently meet the water demand requirements inclusive of the ecological function (1.414 m^3/s) in months of April to December while falling short in months of January to March (Table 4.32). The unmet demand for the months of January to March is 0.023, 0.292, 0.021 m^3/s respectively.

For the climate Scenarios RCP 2.6, the findings showed that in 2030 R. Namatala is envisaged to experience a deficit in months of January to February amounting to 0.067 m^3/s and 0.114 m^3/s respectively. For the study year 2040, there will be a shortage in water available for the catchment for months of January to February amounting to 0.101 m^3/s and 0.034 m^3/s respectively (Table 4.33). The trends between 2030 and 2040 showed that January to February is the most critical time where the river will lack enough water to meet the demand requirements.

For the climate Scenarios RCP 8.5, the findings showed that in 2030 R. Namatala is envisaged to experience a deficit in months of January to March amounting to 0.043 m^3/s, 0.080m^3/s, 0.056 m^3/s respectively. For the study year 2040, there will be a shortage in water available for the catchment for months of February to March amounting to 0.049 m^3/s and 0.106 m^3/s respectively (Table 4.34). The trends between 2030 and 2040 showed that critically, months of February to March is the most critical time where the river will lack enough water to meet the demand requirements.

Table 4.32: Current Supply Vs Demand for 2023

CURRENT YEAR - 2023													
CATCHMENT	Month	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
R. Namatala	Namatala Flows (m^3/s)	1.391	1.122	1.393	2.861	4.730	3.111	2.674	3.478	3.101	3.134	3.061	2.117
	Current Water Demand (m^3/s) - 2023	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146
	Permitted Users	0.165	0.165	0.165	0.165	0.165	0.165	0.165	0.165	0.165	0.165	0.165	0.165
	Environmental Flow Requirement	1.103	1.103	1.103	1.103	1.103	1.103	1.103	1.103	1.103	1.103	1.103	1.103
	Monthly Water Availability	Dry month	Dry month	Dry month	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok
	Unmet demand -2030 (m^3/s)	0.023	0.292	0.021	0	0	0	0	0	0	0	0	0
	Unmet demand -2030 (m^3/d)	1,964	25,197	1,784	0	0	0	0	0	0	0	0	0

Table 4.33: Projected Supply Vs Demand Under RCP 2.6

CLIMATE SCENARIO - RCP-2.6													
INTERMEDIATE YEAR - 2030													
CATCHMENT	Month	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
R. Namatala	Namatala Flows (m^3/s)	1.659	1.706	1.907	2.628	2.937	2.259	2.227	2.204	2.424	2.626	2.412	1.832
	Intermediate Water Demand (m^3/s) - 2030	0.153	0.153	0.153	0.153	0.153	0.153	0.153	0.153	0.153	0.153	0.153	0.153
	Permitted Users	0.279	0.279	0.279	0.279	0.279	0.279	0.279	0.279	0.279	0.279	0.279	0.279
	Environmental Flow Requirement	1.159	1.159	1.159	1.159	1.159	1.159	1.159	1.159	1.159	1.159	1.159	1.159
	Monthly Water Availability	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok
	Unmet demand -2030 (m^3/s)	-0.067	-0.114	0	0	0	0	0	0	0	0	0	0
	Unmet demand -2030 (m^3/d)	- 5,810	- 9,861	0	0	0	0	0	0	0	0	0	0
FUTURE YEAR - 2040													
CATCHMENT	Month	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
R. Namatala	Namatala Flows (m^3/s)	1.606	1.741	2.214	2.821	2.626	2.168	2.159	2.233	2.422	2.403	2.052	1.781
	Current Water Demand (m^3/s) - 2023	0.170	0.170	0.170	0.170	0.170	0.170	0.170	0.170	0.170	0.170	0.170	0.170
	Permitted Users	0.378	0.378	0.378	0.378	0.378	0.378	0.378	0.378	0.378	0.378	0.378	0.378
	Environmental Flow Requirement	1.159	1.159	1.159	1.159	1.159	1.159	1.159	1.159	1.159	1.159	1.159	1.159
	Monthly Water Availability	Dry month	Dry Month	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok
	Unmet demand -2030 (m^3/s)	0.101	-0.034	0	0	0	0	0	0	0	0	0	0
	Unmet demand -2030 (m^3/d)	8,723	- 2,912	0	0	0	0	0	0	0	0	0	0

Table 4.34: Projected Supply Vs Demand Under RCP 8.5

CLIMATE SCENARIO - RCP-8.5													
	INTERMEDIATE YEAR - 2030												
CATCHMENT	Month	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
R. Namatala	Namatala Flows (m^3/s)	1.628	1.506	1.529	1.869	2.718	2.974	2.249	2.126	2.170	2.335	2.757	2.387
	Intermediate Water Demand (m^3/s) - 2030	0.153	0.153	0.153	0.153	0.153	0.153	0.153	0.153	0.153	0.153	0.153	0.153
	Permitted Users	0.279	0.279	0.279	0.279	0.279	0.279	0.279	0.279	0.279	0.279	0.279	0.279
	Environmental Flow Requirement	1.153	1.153	1.153	1.153	1.153	1.153	1.153	1.153	1.153	1.153	1.153	1.153
	Monthly Water Availability	Dry Month	Dry month	Dry month	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok
	Unmet demand -2030 (m^3/s)	-0.043	0.080	0.056	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Unmet demand -2030 (m^3/d)	-3678.7	6915.5	4881.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FUTURE YEAR - 2040													
CATCHMENT	Month	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
R. Namatala	Namatala Flows (m^3/s)	1.928	1.750	1.806	2.039	2.640	3.023	2.257	2.236	2.215	2.334	2.701	2.508
	Current Water Demand (m^3/s) - 2023	0.170	0.170	0.170	0.170	0.170	0.170	0.170	0.170	0.170	0.170	0.170	0.170
	Permitted Users	0.378	0.378	0.378	0.378	0.378	0.378	0.378	0.378	0.378	0.378	0.378	0.378
	Environmental Flow Requirement	1.153	1.153	1.153	1.153	1.153	1.153	1.153	1.153	1.153	1.153	1.153	1.153
	Monthly Water Availability	Ok	Dry Month	Dry Month	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok
	Unmet demand -2030 (m^3/s)	0.0	-0.049	-0.106	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Unmet demand -2030 (m^3/d)	0.0	- 4,214	- 9,128	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

4.5.2 Catchment Management Plan Recommendations

MWE, (2018) developed a Mpologoma catchment management plan (CMP) encompasses our study area. The management plan had 13No. Sub catchments lumped into one which is the Mpologoma catchment. The CMP categorized R. Namatala catchment as moderate to High water stressed with deficit occurring between 26 to 59%. The CMP for Mpologoma recommended the following;

Table 4.35: Solutions provided by Mpologoma Catchment Management Plan

SN	Threat	Solution
1.	Flooding	▪ Develop flood warning systems ▪ River protection work ▪ Implement flood risk management activities ▪ Develop drainage network associated with irrigation Schemes; ▪ Implementation of flood control reservoirs.
2.	Landslides	▪ Land use planning, reforestation, land management ▪ Establish siltation monitoring system for future planning ▪ Priorities the structure and design of comprehensive integrated reforestation, rehabilitation and Sustainable Land Management programmes for steep landscapes ▪ Awareness of landslide preparedness
3.	Droughts	▪ Promotion of rainwater harvesting for domestic use and livestock watering ▪ Development of water resources for irrigation and irrigation infrastructure in order to enhance crop production ▪ Training the local community in sustainable agriculture and irrigation management ▪ Develop stock watering dams.
4.	Loss of Biodiversity	▪ Promote and train farmers on agricultural practices that ensure stability of the soils ▪ Establish conservation agriculture - Training of the community and demonstration on soil and water

SN	Threat	Solution
		conservation techniques (construction of ditches/bands ▪ Land use planning ▪ Reforestation and tree planting activity ▪ Field management (contouring, buffer zones for river banks and roads.) ▪ River bank protection; - Road drainage
5.	Dependence in rainfed agriculture/Reliance on rainfall	▪ Develop irrigation schemes ▪ Develop water harvesting ▪ Adapt simple rainwater harvesting technologies like sunken pits, ditches etc. ▪ Implement good agricultural practices to optimize rainfall and soil moisture ▪ Match dams to needs
6.	Use of illegal fishing methods	▪ Enforce control of illegal fishing practices ▪ Awareness creation on the application of illegal fishing methods
7.	Low access to safe water supply	▪ Develop piped water systems, boreholes, rainwater harvesting; shallow wells and springs ▪ Water quality monitoring; guidelines and plans for rainwater harvesting (roof water tanks and large underground tanks); dams (large, small, etc.) ▪ Promote water source protection
8.	Shortage of the order of 150 MW/insufficient energy alternative	▪ Undertake feasibility study for small HPPs. Catchment was proposed to have a 4.2Mm^3 dam of width – 205 m and height 30m. ▪ Obtain license to build and operate small HPPs ▪ Promote alternative sources of energy (solar, biogas).

Table 4.35 provided recommendations that are specific to the R. Namatala catchment. These recommendations were categorized in terms of risk, catchment management, wetlands, agriculture-irrigated and rainfed, aquaculture & fisheries, water supply & sanitation and hydroelectric power. The Mpologoma CMP proposed a 4.2MW dam which was envisaged to store and control of water in the R. Namatala Catchment.

Source Protection Plan for Mbale WSSP mentioned that there is natural woodland in the R. Namatala upstream reaches, but squatters are encroaching on it apparently encouraged by local politicians seeking for happy votes. However, this has detrimental effects on biodiversity, soil stability, and catchment features (NWSC, 2016). The water source protection plan for R. Namatala, Nabijo and Nabuyonga recommended the following;

Table 4.36: Solutions provided by Mbale WSSP Source Protection Plan

SN	Threat	Solution
1.	Flooding	▪ Catchment Restoration ▪ Areas of mulched gardens on sloping land ▪ Areas under agro-forestry and other measures to increase intake opportunity time
2.	Yield: ensure adequate yield to meet water supply demand B. Long term Short fall	▪ Value chains established and reflecting the values of conservation agriculture ▪ Value chains incorporating sustainable forest and wetland exploitation ▪ Number of families using energy saving technologies
	C. Long term Short fall	▪ Number of value chains established and reflecting the values of conservation agriculture ▪ Acreage with terracing and contour bands constructed ▪ Number of value chains incorporating sustainable forest and wetland exploitation ▪ Number families using energy saving technologies ▪ Number of water storage reservoir constructed ▪ Number of hydrological monitoring stations constructed

4.5.1 Catchment Measures to Improve Catchment

The following actions are suggested to guarantee the preservation of ecosystem functioning based on the findings. These include:

1. Flood Control
2. Maintaining flow regimes
3. Water demand Management
4. River bank Restoration
5. Catchment Restoration of Degraded Area

4.6 Discussion of Findings

4.6.1 Objective 1: To determine the current E-flow requirement.

4.6.1.1 Discussions on R. Namatala Flows.

The findings showed that from 1948 to 2021, the flows had a temporal variation in flows with R. Namatala fluctuating in respect to the mean (2.65 m^3/s). This illustrated the seasonal variability of R. Namatala over the years with 1978 chosen as the water year and 1953, 2009, 2012 regarded as the dry years. The findings revealed a seasonal pattern of December to March (4 Months) as the low flow period and two flood periods of April to June (Large Flood) and August to November (Small Flood).

4.6.1.2 Discussions on R. Namatala E-flows.

Hydrological E-flow of 1.072 m^3/s was estimated from the using Tessman's method. Season variability on a temporal scale showed that Hydrological E-flow the month of May required high E-flow requirement as compared to December to February that require low E-flow requirement in respect to the average (1.072 m^3/s). In terms of Hydraulic E-flow, the catchment was estimated as an average E-flow requirement of 1.036 m^3/s with sections varying between 0.79 m^3/s to 1.47 m^3/s. The Holistic approach estimated an E-flow requirement of 1.103 m^3/s incorporating socio-economic requirements, biodiversity, water quality, flora and fauna.

4.6.2 Objective 2: To assess land use change trends in R. Namatala Catchment.

This study revealed that the watershed has six land cover classifications acquired during the past 26-year period (1995-2020). The R. Namatala catchment had a historical annual LULC increase that was dominated by cropland (0.471%), followed by grassland (0.158%). The findings showed that two land cover types were encroached on by anthropogenic activities and these included; Forestland (0.466%) and wetlands (0.176%) in order to access fertile rich soils as well as timber for source of fuel.

Minimum gains in Land cover were experienced in Water (0.01%) and Built up land (0.012%).

Basing on the historical LULC changes, five drivers affected the projected LULC change in line with Vision 2040. The study envisaged annual LULC gains dominated by Forestland (0.263%), followed by Cropland (0.071%). The policies put in place to protect forests and gazetting them as CFRs will help improve the forest coverage. These same policies aimed at protecting the environment are envisaged to reduce the fast-growing cropland from 0.471% (1995 to 2020) to 0.071% (2020 to 2040). Minimum gains in Land cover are envisaged to be in Water (0.001%) and Built up land (0.014%). On the other hand, the projections envisage grassland to reduce at a rate of 0.343% per annum.

4.6.3 Objective 3: To determine the impact of LULC on the environmental Flow requirements of R. Namatala

4.6.3.1 Discussion on Climatic Data

The data showed a temporal variation precipitation under RCP 2.6 and RCP 8.5. Findings showed that RCP 8.5 will have more rains in month of May, July and November in 2030 as compared to RCP 2.6. In 2030, Both RCP 2.6 and RCP 8.5 are envisaged to have a similar seasonal trend over a temporal scale as the historical climatic inclinations with slight deviations a spatial scale. The findings ascertained that by 2030, the catchment shall have similar seasonal variations for RCP 2.6 and RCP 8.5 with Dry season spanning between January to March and August to October while the wet season spans between April to July (High intensity) and Nov to December (Low intensity).

In 2040, Both RCP 2.6 and RCP 8.5 are envisaged to have a more rains as compared to 2030 period. The catchment is envisaged to have a slight deviation in seasonal patterns under RCP 8.5 with January to March maintaining the dry season spell followed by August and October as the other dry months with significant rains received. The wet season will be categorized under two with high intensity short duration rains experienced between April to July and Low intensity rains experienced in months of September, November and December. The pattern for RCP 2.6 is similar to that of RCP 2.6 under 2030.

4.6.3.2 Discussions on Projected Flows.

The findings showed that from 2023 to 2040, the projected flows under RCP 2.6 had a temporal variation with 2039 flourishing with highest flows while 2031 having the lowest flows predicted to be experienced. In terms of seasonal variability, RCP 2.6 two high flow periods are envisaged between April to May as well as September to October and Low flows to be experienced in months of November to February and June to July.

Under RCP 8.5, the findings showed that from 2023 to 2040, the projected flows had a temporal variation with 2031 flourishing with highest flows while 2027 and 2040 having the lowest flows predicted to be experienced. In terms of seasonal variability, RCP 8.5 two high flow periods are envisaged between May to June as well as November to December and Low flows to be experienced in months of January to April and July to September

Based on the projected land use, its envisaged that forestland, Built-up areas and Cropland would grow annually at a rate of 0.263%, 0.014% and 0.071%. This in turn symbolizes that forestland and cropland will increase the amount of water infiltrating the soils as compared to the run-off generated by built-up. With the government policies in place to increase water storage, we envisage a decrease in run off which contributes to R. Namatala’s flow.

4.6.3.3 Discussions on Projected environmental Flow requirements.

Under RCP 2.6, Hydrological e-flow of 0.88 m^3/s was estimated from the projected flows using Tessman’s method. Season variability on a temporal scale showed that Hydrological E-flow the month of April to May will require high E-flow requirement as compared to November to February and June to July that require low E-flow requirement in respect to the average (0.874 m^3/s). This shows are deviation from the current E-flow requirement where the high e-flow requirement was observed in May and August while low requirements observed in December to March. In terms of Hydraulic E-flow, the catchment is envisaged to average E-flow requirement of 1.082 m^3/s with sections varying between 0.86 m^3/s to 1.47 m^3/s. The Holistic approach estimated an E-flow requirement of 1.1591 m^3/s incorporating socio-economic requirements, biodiversity, water quality, flora and fauna.

Under RCP 8.5, Hydrological E-flow of 0.91 m^3/s was estimated from the projected flows using Tessman’s method. Season variability on a temporal scale showed that

Hydrological E-flow the month of May to June will require high E-flow requirement as compared to January to April and July to September that require low E-flow requirement in respect to the average (0.915 m^3/s). This shows are deviation from the current E-flow requirement where the high E-flow requirement was observed in May and August while low requirements observed in December to March. In terms of Hydraulic E-flow, the catchment is envisaged to average E-flow requirement of 1.076 m^3/s with sections varying between 0.86 m^3/s to 1.47 m^3/s. The Holistic approach estimated an E-flow requirement of 1.1523 m^3/s incorporating socio-economic requirements, biodiversity, water quality, flora and fauna.

From the estimation of projected E-flow requirements based on RCP 2.6 and RCP 8.5, there was a small variation of less 1% between the two scenarios. However, RCP 2.6 and RCP 8.5 showed an increment in E-flow requirement by 4.9%, 4.3%respectively from the current E-flow requirement. This was attributed to the increase in socio-economic requirement, aquatic water requirement as well as the hydraulic flow requirements aimed to sustain the river.

CONCLUSIONS AND RECOMMENDATIONS.

5.1 Conclusions of the Study

5.1.1 Conclusions for Objective 1

Based on the findings, the current e-flow for River Namatala was obtained as 1.103 m^3/s. The holistic approach was also found to be the most realistic method for E-flow estimation as it adequately accounts for hydraulic needs, flora, fauna, aquatic life, and socio-economic water use within 100 m of the river corridor.

The study also noted that catchment has not yet been regulated in terms of water demand and environmental flow. currently the catchment faces a lot of unpermitted users that are not well known to the water resources regulators – MWE DWRM. The catchment is currently threatened by poor practices like Overfishing, unsustainable agricultural practices near the Namatala – Doho Wetland.

5.1.2 Conclusions for Objective 2

Land-use and land-cover trends for the R. Namatala catchment were examined over a 26-year period (1995–2020), during which six land-use classes were consistently identified: grassland, forest land, cropland, wetland, built-up areas, and water bodies. Of these, grassland, forest land, and cropland were the dominant land-use types throughout the study period.

There was a consistent increase in cropland, expanding from 63.92 km^2 (1995) to 140.58 km^2 (2020) a net gain of 76.66 km^2 (12.24%), equivalent to an average annual increase of 0.471%. This trend underscores growing agricultural pressure driven by population growth, livelihood demands, and national development programmes (e.g., NDP II and NDP III). Built-up areas also showed a steady increase from 0.79 km^2 to 2.80 km^2 reflecting urban growth supported by road expansion, improved water supply systems, and socioeconomic development. Conversely, wetlands declined dramatically, dropping from 89.95 km^2 in 1995 to 14.09 km^2 in 2020 a loss of 75.85 km^2 and an average reduction rate of 0.466% per annum. This significant degradation is largely attributed to conversion for agriculture and settlement expansion, despite existing wetland protection regulations. Grassland, although remaining the dominant land-cover type, showed a fluctuating but net decreasing trend—falling from 357.92 km^2 (1995) to

383.62 km² (2020) but later dropping again due to conversion into cropland and forest land.

Future projections (2020–2040) indicate that grassland will continue declining, whereas forest cover, cropland, and built-up areas are expected to expand. This shift is strongly influenced by policy interventions, road and water supply infrastructure, slope constraints, and ongoing economic development. Notably, the projections show improved forest recovery rates and a significant slowdown in wetland degradation, suggesting that enforcement of environmental policies will play a critical role in shaping future land-use dynamics. The findings will also be able to describe difficulties such as persistent built-up and farmland expansion experienced in the catchment in relation to other requirements such as water availability and ecosystem needs in order to fulfill their current and future demands. In summary, the R. Namatala catchment has undergone marked land-use transitions over the past decades, driven largely by population growth, agricultural expansion, infrastructure development, and policy interventions.

5.1.3 Conclusions for Objective 3

The study examined the combined impacts of land use/land cover (LULC) change and climate change on the hydrological regime and environmental flow (E-flow) requirements of River Namatala under two climate scenarios RCP 2.6 (most likely) and RCP 8.5 (least likely). Historical rainfall analysis revealed moderate variability across the 1979–2023 period, with notable shifts in seasonality and episodic wet and dry years. Future projections indicated significant alterations in rainfall patterns, including a shift of the main rainy season from March–May to April–July, accompanied by overall reductions in annual rainfall across both RCPs.

Hydrological modelling using the HBV-Light model demonstrated acceptable performance, adequately capturing the catchment's hydrological dynamics despite some underestimation of peak flows. Both climate scenarios showed declining precipitation and simulated river discharge through 2030, with slight recovery or stabilization toward 2040. Projected flows under RCP 2.6 exhibited a mean annual discharge of 2.19 m³/s, while RCP 8.5 resulted in a slightly higher estimate of 2.27 m³/s, reflecting differences in climate forcing assumptions.

The holistic E-flow estimates, incorporating hydraulics, flora, fauna, socio-economic water demand, and aquatic ecosystem needs, yielded requirements of 1.159 m^3/s for RCP 2.6 and 1.153 m^3/s for RCP 8.5. RCP 2.6 and RCP 8.5 E-flow requirements projected were similar with a variation of less than 1%. Both RCP 2.6 and RCP 8.5 deviated 4.9% & 4.3% from the current E-flow requirement hence were in acceptable limits of -/+10%.

5.2 Recommendation of the Study

5.2.1 Community in the Catchment

The study recommends the following to the community in the catchment;

- Promotion of water conservation practices, especially during the critical dry months (December–February) when water shortages are projected to increase.
- Participation in catchment restoration activities, including tree planting and forest conservation, to enhance local water retention and reduce catchment degradation.
- Support sustainable water use by adopting efficient irrigation and domestic water management practices.

5.2.2 Policy Makers

The study recommends the following to the policy makers in the catchment;

- Undertake a detailed socio-economic study tailored to water needs in the catchment to guide long-term water resource planning and equitable water allocation.
- Develop and enforce regulations to reduce water abstractions during dry months (December–February), especially as the catchment approaches 2040 when demand deficits are expected (25,197 m^3/d in 2023 and 9,861 m^3/d in 2040).
- Implement and strengthen policies promoting forest coverage and catchment restoration, ensuring alignment with national environmental and water policies.
- Facilitate inter-basin transfer projects, such as augmenting the catchment with water from river Manafwa, to meet domestic water demands sustainably.

5.2.3 Research and Partners

The study recommends the following to the researchers;

- Conduct a comprehensive socio-economic and hydrological study to refine water demand projections and integrate groundwater assessments within the catchment's water balance.
- Undertake further assessments of environmental flows (E-flows) to include groundwater contributions and ensure ecological sustainability.
- Carry out detailed fish population and aquatic ecosystem studies across water systems beyond River Namatala to determine aquatic water needs.
- Advance research on climate change scenarios, focusing on Shared Socioeconomic Pathways (SSPs) relevant to the project area to inform adaptive management strategies.

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APPENDIX

Appendix A: Population Projection

Appendix A-1: Population Projection

Catchment	District	Sub County	Parish	Village	District Area (km²)	District Area in Catchment (km²)	Left Out aea District Area (km²)	% of Habitable District Area in Catchment	Base HHs	Base Population
RIVER NAMATALA CATCHMENT	MBALE DISTRICT	BUBYANGU	BUKIKOSO	BUNAKOFA	519	317	202	51%	115	575
			BUNABUGIBO	MADILU					80	400
			KILAYI	BUMUDULI 'A'					126	630
				BUMUDULI 'B'					110	550
				BUMUTEKA 'A'					109	545
				KILAYI 'A'					123	615
				KILAYI 'B'					100	500
				MT ELGON FOREST RESERVE					9	45
				WANASWA					100	500
			MADENGE	MT ELGON FOREST RESERVE					9	45
		BUFUMBO	BUKOBE	BUKOBE UPPER					71	355
				KYAPE					68	340
			BUMUSILI	KIBEMBE					62	310
				NAMATALE FR					9	45
			JEWA	BUKABALYENDA					38	190
			KAMA	KAMA LOWER					56	280
				KIKONYORO					75	375
		BUKASAKYA	DOKO	MOSQUE					100	500
				NKWANGA					93	465
			TSABANYANYA	KIBINIKO					100	500
		BUKONDE	NANYUNZA	LUSAALA					117	585
				NAKITOKOLO					78	390
				SAGIYA					107	535
				TUGUTU					109	545
		BUNGOKHO	BUSHIKORI	KHAMOTO					62	310
			KHAMOTO	KHAMOTO					100	500
				SHIBINIKO					66	330
		NAKALOKE	DOKO	DOKO					109	545
				KIBUMBIRE					105	525
				NAMABASA III					115	575
			KASANJA	DOKO KASANJA I					107	535
				DOKO KASANJA II					71	355
			NAMABASA	NAMABASA IV LOWER					58	290
		NAKALOKE TC	AFYA	BUSAJJABWANKUBA A					105	525
		NAMANYONYI	AISA	NANGOLO					56	280
				NAMABWA					90	450
				NANKUSI					73	365
			NAMAGUMBA	NAMAKOLE					122	610
			NKOMA	KINYOLI A					120	600
				KINYOLI B					121	605
				NAMANYONYI CENTRE B					102	510
				NKOMA CENTRE A					121	605
				NKOMA CENTRE B					115	575
		INDUSTRIAL DIVISION	NAMATALA	BUBIRABI					78	390
				DOKO					72	360
				SISYE					18	90
				WANDAWA					1	5
		NORTHERN	IUIU	NORTHERN					1	5
				SHERATON					101	505
			NABUYONGA	KISENYI					72	360
			NKOMA	BUSANJA					48	240
				HYGIENE					117	585
	PALLISA	KABWANGASI	NASENYI	BWIBERE	1,095	14	1,081	2%	126	630
				BUNYEKERO					45	225
	SIRONKO	BUWALASI	BUSAMAGA	KAMA B	446	51	395	8%	64	320
				BUKIDIYA					57	285
				KAMA A					74	370
				MUSOLA(BUSAMAGA)					53	265
				MABUYE					15	75
				MAGULU B					40	200
				LUSISI(BUSAMAGA)					70	350
				MAGULU A					62	310
		BUNYAFA	BUKIITI	MAKKU					64	320
				BUNADUNGA					46	230
			BUGAMBI	MANJJENGA					70	350
				BUMUNGASWE					75	375
				MWIRI					79	395
		BUTEZA	BUMUKONE	DULUMBA					82	410
		ZESUI	NABWEYA	KYESHA A					1	5
			NABWEYA	MT ELGON NP(NABWEYA)					76	380
		BUTEZA	BUGWIMBI	BUBBALINGANGA B					45	225
				BUKOBE					99	495
				BUBBALINGANGA A					52	260
				BUNABIDOKO					46	230
			BUMUKONE	KIWULUKO					78	390
				NAMADOGODA B					110	550
	BUDAKA	NABOA	NANGEYE	NANGEYE II	410	163	247	26%	89	445
				NAMWAMBA					49	245
				BWIKOMBA					80	400
		KAMONKOLI	JAMI	JAMI B					40	200
				JAMI A					101	505
				JAMI B					60	300
			BUNYOLO	BUNYOLO A					125	625
			KAMONKOLI	NYANZA					80	400
		MUGITI	NYANZA	NAMAMBA					75	375
				NYANZA SOUTH					86	430
		LYAMA	TADEMERI	KAZINGA					95	475
		NABOA	NABOA	NAMAJJA II					100	500
		KAMONKOLI	BUNYOLO	BUNYOLO B					60	300
				BUNYOLO A					75	375
		NABOA	NANGEYE	KAKOLI					123	615
		MUGITI	NYANZA	BWIKOMBA II					105	525
		BUDAKA	CHALI	IZIBANGABO					88	440
			NAMPANGALA	BULUMBI					9	45
	BUDUDA	BUSHIKA	BUBUNGI	MT ELGON NATIONAL PARK	251	4	246	1%	9	45
		NAKATSI	BUNUSENYI	NAKATSI FOREST RESERVE					21	105
		BUSHIKA	BUNABUTITI	LUKHOLI					50	250
	BUTALEJA	NAWEYO	NASINYI	NASINYI B	653	77	576	12%	68	340
			KAITI	NAMATALA					68	340
				NAHAMYA A					80	400
				KAITI CENTRAL					61	305
		KACHONGA	NAMUNASA	MUHULA KAGONDO					68	340
			CHADONGO	NANTALO					55	275
				NSAMBYA					63	315
				MUWANGA					61	305
			NAMAWA	NAMAWA A					45	225
				MUKWANO					97	485
				NAMATALA					187	935
		NAWEYO	NASINYI	NASINYI A					70	350
		KACHONGA	NAMUNASA	NAHIGOGOLA					62	310
		Total			3,373	626	2,747	100%	8,324	41,620

Appendix A-2: Irrigation Acreage

No.	District	2022	2023	2028	2030	2038	2040
1	Mbale	287.32	287.46	288.18	288.47	289.62	289.91
2	Butebo	0.44	0.44	0.44	0.44	0.45	0.45
3	Sironko	7.07	7.07	7.09	7.10	7.13	7.13
4	Budaka	74.67	74.71	74.90	74.97	75.27	75.35
5	Bududa	0.11	0.11	0.11	0.11	0.11	0.11
6	Butaleja	15.91	15.91	15.95	15.97	16.03	16.05
	Total	**385.52**	**385.71**	**386.68**	**387.07**	**388.62**	**389.01**

Appendix A-3: Livestock Population

Catchment	District	% of Habitable District Area in Sub-Catchment	2008 Livestock in Catchment				
			Cattle	Goats	Sheep	Pigs	Poultry
RIVER NAMATALA CATCHMENT	Mbale	51.0%	24,414.98	36,956	1,955	8,916	175,900
	Butebo	2.0%	2,318.63	2,536	349	431	7,489
	Sironko	8.0%	6,301.48	5,388	668	2,228	26,628
	Budaka	26.0%	8,326.00	10,750	826	1,043	35,728
	Bududa	1.0%	460.85	235	36	46	1,866
	Butaleja	12.0%	7,888.77	7,313	994	460	25,729
	Total	100%	49,711	63,177	4,827	13,123	273,340

Appendix B: Water Demand Projections

Appendix B-1: Summary of Livestock Population

Catchment	District	Cattle	Goats	Sheep	Pigs	Poultry
RIVER NAMATALA CATCHMENT	Mbale	24,414.98	36,956	1,955	8,916	175,900
	Butebo	2,318.63	2,536	349	431	7,489
	Sironko	6,301.48	5,388	668	2,228	26,628
	Budaka	8,326.00	10,750	826	1,043	35,728
	Bududa	460.85	235	36	46	1,866
	Butaleja	7,888.77	7,313	994	460	25,729
Livestock Count - 2008	**Total**	**49,711**	**63,177**	**4,827**	**13,123**	**273,340**
RIVER NAMATALA CATCHMENT	Mbale	24,422	36,729	1,941	8,998	278,065
	Butebo	2,319	2,520	346	435	11,839
	Sironko	6,303	5,355	663	2,249	42,094
	Budaka	8,328	10,684	820	1,053	56,478
	Bududa	461	233	36	46	2,949
	Butaleja	7,891	7,268	986	464	2,949
Livestock Count - 2023	**Total**	**49,726**	**62,790**	**4,792**	**13,244**	**394,376**
RIVER NAMATALA CATCHMENT	Mbale	24,425	36,654	1,936	9,025	295,572
	Butebo	2,320	2,515	345	436	12,585
	Sironko	6,304	5,344	661	2,256	44,744
	Budaka	8,329	10,662	818	1,056	60,034
	Bududa	461	233	36	46	3,135
	Butaleja	7,892	7,253	984	465	3,135
Livestock Count - 2028	**Total**	**49,731**	**62,661**	**4,781**	**13,284**	**419,206**
RIVER NAMATALA CATCHMENT	Mbale	24,426	36,624	1,934	9,036	377,340
	Butebo	2,320	2,513	345	436	13,377
	Sironko	6,304	5,340	661	2,258	47,561
	Budaka	8,330	10,653	817	1,057	63,814
	Bududa	461	233	36	46	3,332
	Butaleja	7,892	7,247	983	466	3,332
Livestock Count - 2030	**Total**	**49,733**	**62,610**	**4,776**	**13,301**	**508,758**
RIVER NAMATALA CATCHMENT	Mbale	24,430	36,504	1,927	9,048	401,098
	Butebo	2,320	2,505	344	439	17,078
	Sironko	6,305	5,322	658	2,269	60,719
	Budaka	8,331	10,618	814	1,062	81,468
	Bududa	461	232	36	47	4,254
	Butaleja	7,894	7,223	979	468	4,254
Livestock Count - 2038	**Total**	**49,741**	**62,405**	**4,758**	**13,332**	**568,871**
RIVER NAMATALA CATCHMENT	Mbale	24,431	36,474	1,925	9,092	512,059
	Butebo	2,320	2,503	343	441	21,802
	Sironko	6,306	5,318	658	2,280	77,516
	Budaka	8,331	10,610	813	1,068	104,005
	Bududa	461	232	36	47	5,431
	Butaleja	7,894	7,217	978	470	5,431
Livestock Count - 2040	**Total**	**49,743**	**62,354**	**4,753**	**13,398**	**726,245**

Appendix B-2: Livestock Population

Domestic

Current - 2023 (m^3/s)						
R. Namatala Catchment						
Mbale	Butebo	Sironko	Budaka	Bududa	Butaleja	
0.0076	0.0003	0.0024	0.0027	0.0002	0.0019	0.0
0.0084	0.0003	0.0027	0.0030	0.0027	0.0021	0.0
0.0076	0.0003	0.0024	0.0027	0.0024	0.0019	0.0
0.0079	0.0003	0.0025	0.0028	0.0025	0.0019	0.0
0.0076	0.0003	0.0024	0.0027	0.0024	0.0019	0.0
0.0079	0.0003	0.0025	0.0028	0.0025	0.0019	0.0
0.0076	0.0003	0.0024	0.0027	0.0024	0.0019	0.0
0.0076	0.0003	0.0024	0.0027	0.0024	0.0019	0.0
0.0079	0.0003	0.0025	0.0028	0.0025	0.0019	0.0
0.0076	0.0003	0.0024	0.0027	0.0024	0.0019	0.0
0.0079	0.0003	0.0025	0.0028	0.0025	0.0019	0.0
0.0076	0.0003	0.0024	0.0027	0.0024	0.0019	0.0
0.0078	**0.0003**	**0.0025**	**0.0028**	**0.0023**	**0.0019**	

2028 (m^3/s)						
R. Namatala Catchment						
Mbale	Butebo	Sironko	Budaka	Bududa	Butaleja	
0.0086	0.0003	0.0026	0.0031	0.0002	0.0022	0.0
0.0095	0.0004	0.0029	0.0034	0.0029	0.0024	0.0
0.0086	0.0003	0.0026	0.0031	0.0026	0.0022	0.0
0.0089	0.0003	0.0027	0.0032	0.0027	0.0022	0.0
0.0086	0.0003	0.0026	0.0031	0.0026	0.0022	0.0
0.0089	0.0003	0.0027	0.0032	0.0027	0.0022	0.0
0.0086	0.0003	0.0026	0.0031	0.0026	0.0022	0.0
0.0086	0.0003	0.0026	0.0031	0.0026	0.0022	0.0
0.0089	0.0003	0.0027	0.0032	0.0027	0.0022	0.0
0.0086	0.0003	0.0026	0.0031	0.0026	0.0022	0.0
0.0089	0.0003	0.0027	0.0032	0.0027	0.0022	0.0
0.0086	0.0003	0.0026	0.0031	0.0026	0.0022	0.0
0.0088	**0.0003**	**0.0026**	**0.0031**	**0.0024**	**0.0022**	

Irrigation

	Current - 2023 (m^3/s)					
	R. Namatala Catchment					
	Mbale	Butebo	Sironko	Budaka	Bududa	Butaleja
Jan	0.0537	0.00008	0.0013	0.0139	0.000021	0.0030
Feb	0.0594	0.00009	0.0015	0.0154	0.000023	0.0033
Mar	0.0537	0.00008	0.0013	0.0139	0.000021	0.0030
Apr	0.0555	0.00009	0.0014	0.0144	0.000021	0.0031
May	0.0537	0.00008	0.0013	0.0139	0.000021	0.0030
Jun	0.0555	0.00009	0.0014	0.0144	0.000021	0.0031
Jul	0.0537	0.00008	0.0013	0.0139	0.000021	0.0030
Aug	0.0537	0.00008	0.0013	0.0139	0.000021	0.0030
Sep	0.0555	0.00009	0.0014	0.0144	0.000021	0.0031
Oct	0.0537	0.00008	0.0013	0.0139	0.000021	0.0030
Nov	0.0555	0.00009	0.0014	0.0144	0.000021	0.0031
Dec	0.0537	0.00008	0.0013	0.0139	0.000021	0.0030
Avg	**0.0547**	**0.0001**	**0.0013**	**0.0142**	**0.0000210**	**0.0030**

	2028 (m^3/s)					
	R. Namatala Catchment					
	Mbale	Butebo	Sironko	Budaka	Bududa	Butaleja
Jan	0.0538	0.000083	0.0013	0.0140	0.000021	0.0030
Feb	0.0596	0.000092	0.0015	0.0155	0.000023	0.0033
Mar	0.0538	0.000083	0.0013	0.0140	0.000021	0.0030
Apr	0.0556	0.000085	0.0014	0.0144	0.000021	0.0031
May	0.0538	0.000083	0.0013	0.0140	0.000021	0.0030
Jun	0.0556	0.000085	0.0014	0.0144	0.000021	0.0031
Jul	0.0538	0.000083	0.0013	0.0140	0.000021	0.0030
Aug	0.0538	0.000083	0.0013	0.0140	0.000021	0.0030
Sep	0.0556	0.000085	0.0014	0.0144	0.000021	0.0031
Oct	0.0538	0.000083	0.0013	0.0140	0.000021	0.0030
Nov	0.0556	0.000085	0.0014	0.0144	0.000021	0.0031
Dec	0.0538	0.000083	0.0013	0.0140	0.000021	0.0030
Avg	**0.0549**	**0.00008**	**0.0014**	**0.0143**	**0.0000**	**0.0030**

Livestock

	Current - 2023 (m^3/s)						
	R. Namatala Catchment						
	Mbale	Butebo	Sironko	Budaka	Bududa	Butaleja	
Jan	0.0158	0.0013	0.0036	0.0047	0.0002	0.0040	0.0
Feb	0.0175	0.0014	0.0040	0.0052	0.0002	0.0044	0.0
Mar	0.0158	0.0013	0.0036	0.0047	0.0002	0.0040	0.0
Apr	0.0164	0.0013	0.0038	0.0048	0.0002	0.0041	0.0
May	0.0158	0.0013	0.0036	0.0047	0.0002	0.0040	0.0
Jun	0.0164	0.0013	0.0038	0.0048	0.0002	0.0041	0.0
Jul	0.0158	0.0013	0.0036	0.0047	0.0002	0.0040	0.0
Aug	0.0158	0.0013	0.0036	0.0047	0.0002	0.0040	0.0
Sep	0.0164	0.0013	0.0038	0.0048	0.0002	0.0041	0.0
Oct	0.0158	0.0013	0.0036	0.0047	0.0002	0.0040	0.0
Nov	0.0164	0.0013	0.0038	0.0048	0.0002	0.0041	0.0
Dec	0.0158	0.0013	0.0036	0.0047	0.0002	0.0040	0.0
Avg	**0.0162**	**0.0013**	**0.0037**	**0.0048**	**0.0002**	**0.0040**	

	2028(m^3/s)						
	R. Namatala Catchment						
	Mbale	Butebo	Sironko	Budaka	Bududa	Butaleja	
Jan	0.0159	0.0013	0.0037	0.0047	0.0002	0.0040	0.0
Feb	0.0176	0.0014	0.0040	0.0052	0.0002	0.0044	0.0
Mar	0.0159	0.0013	0.0037	0.0047	0.0002	0.0040	0.0
Apr	0.0164	0.0013	0.0038	0.0049	0.0002	0.0041	0.0
May	0.0159	0.0013	0.0037	0.0047	0.0002	0.0040	0.0
Jun	0.0164	0.0013	0.0038	0.0049	0.0002	0.0041	0.0
Jul	0.0159	0.0013	0.0037	0.0047	0.0002	0.0040	0.0
Aug	0.0159	0.0013	0.0037	0.0047	0.0002	0.0040	0.0
Sep	0.0164	0.0013	0.0038	0.0049	0.0002	0.0041	0.0
Oct	0.0159	0.0013	0.0037	0.0047	0.0002	0.0040	0.0
Nov	0.0164	0.0013	0.0038	0.0049	0.0002	0.0041	0.0
Dec	0.0159	0.0013	0.0037	0.0047	0.0002	0.0040	0.0
Avg	**0.0162**	**0.0013**	**0.0037**	**0.0048**	**0.0002**	**0.0040**	

Industrial

	Current - 2023 (m^3/s)					
	R. Namatala Catchment					
	Mbale	Butebo	Sironko	Budaka	Bududa	Butaleja
Jan	0.0231	0.00002	0.00007	0.00106	0.0000039	0.0005
Feb	0.0256	0.00002	0.00008	0.00118	0.0000044	0.0006
Mar	0.0231	0.00002	0.00007	0.00106	0.0000039	0.0005
Apr	0.0239	0.00002	0.00008	0.00110	0.0000041	0.0005
May	0.0231	0.00002	0.00007	0.00106	0.0000039	0.0005
Jun	0.0239	0.00002	0.00008	0.00110	0.0000041	0.0005
Jul	0.0231	0.00002	0.00007	0.00106	0.0000039	0.0005
Aug	0.0231	0.00002	0.00007	0.00106	0.0000039	0.0005
Sep	0.0239	0.00002	0.00008	0.00110	0.0000041	0.0005
Oct	0.0231	0.00002	0.00007	0.00106	0.0000039	0.0005
Nov	0.0239	0.00002	0.00008	0.00110	0.0000041	0.0005
Dec	0.0231	0.00002	0.00007	0.00106	0.0000039	0.0005
Avg	**0.0236**	**0.0000**	**0.0001**	**0.0011**	**0.0000**	**0.0005**

	2028 (m^3/s)					
	R. Namatala Catchment					
	Mbale	Butebo	Sironko	Budaka	Bududa	Butaleja
Jan	0.0268	0.00002	0.00008	0.0012	0.0000046	0.0006
Feb	0.0297	0.00002	0.00009	0.0014	0.0000050	0.0007
Mar	0.0268	0.00002	0.00008	0.0012	0.0000046	0.0006
Apr	0.0277	0.00002	0.00009	0.0013	0.0000047	0.0006
May	0.0268	0.00002	0.00008	0.0012	0.0000046	0.0006
Jun	0.0277	0.00002	0.00009	0.0013	0.0000047	0.0006
Jul	0.0268	0.00002	0.00008	0.0012	0.0000046	0.0006
Aug	0.0268	0.00002	0.00008	0.0012	0.0000046	0.0006
Sep	0.0277	0.00002	0.00009	0.0013	0.0000047	0.0006
Oct	0.0268	0.00002	0.00008	0.0012	0.0000046	0.0006
Nov	0.0277	0.00002	0.00009	0.0013	0.0000047	0.0006
Dec	0.0268	0.00002	0.00008	0.0012	0.0000046	0.0006
Avg	**0.0273**	**0.00002**	**0.00009**	**0.0013**	**0.00000**	**0.0006**

Domestic

2030 (m^3/s)						
R. Namatala Catchment						
Mbale	Butebo	Sironko	Budaka	Bududa	Butaleja	
0.0090	0.0003	0.0027	0.0032	0.0002	0.0023	0.0
0.0100	0.0004	0.0029	0.0036	0.0002	0.0026	0.0
0.0090	0.0003	0.0027	0.0032	0.0002	0.0023	0.0
0.0093	0.0003	0.0027	0.0033	0.0002	0.0024	0.0
0.0090	0.0003	0.0027	0.0032	0.0002	0.0023	0.0
0.0093	0.0003	0.0027	0.0033	0.0002	0.0024	0.0
0.0090	0.0003	0.0027	0.0032	0.0002	0.0023	0.0
0.0090	0.0003	0.0027	0.0032	0.0002	0.0023	0.0
0.0093	0.0003	0.0027	0.0033	0.0002	0.0024	0.0
0.0090	0.0003	0.0027	0.0032	0.0002	0.0023	0.0
0.0093	0.0003	0.0027	0.0033	0.0002	0.0024	0.0
0.0090	0.0003	0.0027	0.0032	0.0002	0.0023	0.0
0.0092	**0.0003**	**0.0027**	**0.0033**	**0.0002**	**0.0024**	

Irrigation

	2030 (m^3/s)					
	R. Namatala Catchment					
	Mbale	Butebo	Sironko	Budaka	Bududa	Butaleja
Jan	0.0539	0.000083	0.0013	0.0140	0.000021	0.0030
Feb	0.0596	0.000092	0.0015	0.0155	0.000023	0.0033
Mar	0.0539	0.000083	0.0013	0.0140	0.000021	0.0030
Apr	0.0556	0.000086	0.0014	0.0145	0.000021	0.0031
May	0.0539	0.000083	0.0013	0.0140	0.000021	0.0030
Jun	0.0556	0.000086	0.0014	0.0145	0.000021	0.0031
Jul	0.0539	0.000083	0.0013	0.0140	0.000021	0.0030
Aug	0.0539	0.000083	0.0013	0.0140	0.000021	0.0030
Sep	0.0556	0.000086	0.0014	0.0145	0.000021	0.0031
Oct	0.0539	0.000083	0.0013	0.0140	0.000021	0.0030
Nov	0.0556	0.000086	0.0014	0.0145	0.000021	0.0031
Dec	0.0539	0.000083	0.0013	0.0140	0.000021	0.0030
Avg	**0.0549**	**0.000084**	**0.0014**	**0.0143**	**0.000021**	**0.0030**

Livestock

	2030 (m^3/s)					
	R. Namatala Catchment					
	Mbale	Butebo	Sironko	Budaka	Bududa	Butaleja
Jan	0.0161	0.0013	0.0037	0.0047	0.0002	0.0040
Feb	0.0178	0.0014	0.0041	0.0052	0.0003	0.0044
Mar	0.0161	0.0013	0.0037	0.0047	0.0002	0.0040
Apr	0.0167	0.0013	0.0038	0.0049	0.0002	0.0041
May	0.0161	0.0013	0.0037	0.0047	0.0002	0.0040
Jun	0.0167	0.0013	0.0038	0.0049	0.0002	0.0041
Jul	0.0161	0.0013	0.0037	0.0047	0.0002	0.0040
Aug	0.0161	0.0013	0.0037	0.0047	0.0002	0.0040
Sep	0.0167	0.0013	0.0038	0.0049	0.0002	0.0041
Oct	0.0161	0.0013	0.0037	0.0047	0.0002	0.0040
Nov	0.0167	0.0013	0.0038	0.0049	0.0002	0.0041
Dec	0.0161	0.0013	0.0037	0.0047	0.0002	0.0040
Avg	**0.0164**	**0.0013**	**0.0037**	**0.0048**	**0.0002**	**0.0040**

Industrial

		2030 (m^3/s)					
		R. Namatala Catchment					
		Mbale	Butebo	Sironko	Budaka	Bududa	Butaleja
0.0	Jan	0.0284	0.00002	0.00009	0.00131	0.0000048	0.00065
0.0	Feb	0.0314	0.00002	0.00010	0.00145	0.0000053	0.00072
0.0	Mar	0.0284	0.00002	0.00009	0.00131	0.0000048	0.00065
0.0	Apr	0.0294	0.00002	0.00009	0.00135	0.0000050	0.00067
0.0	May	0.0284	0.00002	0.00009	0.00131	0.0000048	0.00065
0.0	Jun	0.0294	0.00002	0.00009	0.00135	0.0000050	0.00067
0.0	Jul	0.0284	0.00002	0.00009	0.00131	0.0000048	0.00065
0.0	Aug	0.0284	0.00002	0.00009	0.00131	0.0000048	0.00065
0.0	Sep	0.0294	0.00002	0.00009	0.00135	0.0000050	0.00067
0.0	Oct	0.0284	0.00002	0.00009	0.00131	0.0000048	0.00065
0.0	Nov	0.0294	0.00002	0.00009	0.00135	0.0000050	0.00067
0.0	Dec	0.0284	0.00002	0.00009	0.00131	0.0000048	0.00065
	Avg	**0.0290**	**0.00002**	**0.00009**	**0.0013**	**0.00000**	**0.0007**

2038 (m^3/s)						
R. Namatala Catchment						
Mbale	Butebo	Sironko	Budaka	Bududa	Butaleja	
0.0102	0.0004	0.0028	0.0037	0.0002	0.0027	0.0
0.0113	0.0004	0.0031	0.0040	0.0002	0.0030	0.0
0.0102	0.0004	0.0028	0.0037	0.0002	0.0027	0.0
0.0106	0.0004	0.0029	0.0038	0.0002	0.0028	0.0
0.0102	0.0004	0.0028	0.0037	0.0002	0.0027	0.0
0.0106	0.0004	0.0029	0.0038	0.0002	0.0028	0.0
0.0102	0.0004	0.0028	0.0037	0.0002	0.0027	0.0
0.0102	0.0004	0.0028	0.0037	0.0002	0.0027	0.0
0.0106	0.0004	0.0029	0.0038	0.0002	0.0028	0.0
0.0102	0.0004	0.0028	0.0037	0.0002	0.0027	0.0
0.0106	0.0004	0.0029	0.0038	0.0002	0.0028	0.0
0.0102	0.0004	0.0028	0.0037	0.0002	0.0027	0.0
0.0104	**0.0004**	**0.0029**	**0.0037**	**0.0002**	**0.0028**	

	2038 (m^3/s)					
	R. Namatala Catchment					
	Mbale	Butebo	Sironko	Budaka	Bududa	Butaleja
Jan	0.054	0.000083	0.00133	0.0141	0.00002	0.0030
Feb	0.060	0.000092	0.00147	0.0156	0.00002	0.0033
Mar	0.054	0.000083	0.00133	0.0141	0.00002	0.0030
Apr	0.056	0.000086	0.00137	0.0145	0.00002	0.0031
May	0.054	0.000083	0.00133	0.0141	0.00002	0.0030
Jun	0.056	0.000086	0.00137	0.0145	0.00002	0.0031
Jul	0.054	0.000083	0.00133	0.0141	0.00002	0.0030
Aug	0.054	0.000083	0.00133	0.0141	0.00002	0.0030
Sep	0.056	0.000086	0.00137	0.0145	0.00002	0.0031
Oct	0.054	0.000083	0.00133	0.0141	0.00002	0.0030
Nov	0.056	0.000086	0.00137	0.0145	0.00002	0.0031
Dec	0.054	0.000083	0.00133	0.0141	0.00002	0.0030
Avg	**0.0552**	**0.00008**	**0.0014**	**0.0143**	**0.00002**	**0.0031**

	2038 (m^3/s)					
	R. Namatala Catchment					
	Mbale	Butebo	Sironko	Budaka	Bududa	Butaleja
Jan	0.0162	0.0013	0.0037	0.0048	0.0002	0.0040
Feb	0.0179	0.0015	0.0041	0.0053	0.0003	0.0044
Mar	0.0162	0.0013	0.0037	0.0048	0.0002	0.0040
Apr	0.0167	0.0014	0.0038	0.0049	0.0002	0.0041
May	0.0162	0.0013	0.0037	0.0048	0.0002	0.0040
Jun	0.0167	0.0014	0.0038	0.0049	0.0002	0.0041
Jul	0.0162	0.0013	0.0037	0.0048	0.0002	0.0040
Aug	0.0162	0.0013	0.0037	0.0048	0.0002	0.0040
Sep	0.0167	0.0014	0.0038	0.0049	0.0002	0.0041
Oct	0.0162	0.0013	0.0037	0.0048	0.0002	0.0040
Nov	0.0167	0.0014	0.0038	0.0049	0.0002	0.0041
Dec	0.0162	0.0013	0.0037	0.0048	0.0002	0.0040
Avg	**0.0165**	**0.0013**	**0.0038**	**0.0049**	**0.0002**	**0.0040**

		2038 (m^3/s)					
		R. Namatala Catchment					
		Mbale	Butebo	Sironko	Budaka	Bududa	Butaleja
0.0	Jan	0.0329	0.00002	0.00010	0.00151	0.000006	0.00076
0.0	Feb	0.0364	0.00003	0.00012	0.00168	0.000006	0.00084
0.0	Mar	0.0329	0.00002	0.00010	0.00151	0.000006	0.00076
0.0	Apr	0.0340	0.00002	0.00011	0.00157	0.000006	0.00078
0.0	May	0.0329	0.00002	0.00010	0.00151	0.000006	0.00076
0.0	Jun	0.0340	0.00002	0.00011	0.00157	0.000006	0.00078
0.0	Jul	0.0329	0.00002	0.00010	0.00151	0.000006	0.00076
0.0	Aug	0.0329	0.00002	0.00010	0.00151	0.000006	0.00076
0.0	Sep	0.0340	0.00002	0.00011	0.00157	0.000006	0.00078
0.0	Oct	0.0329	0.00002	0.00010	0.00151	0.000006	0.00076
0.0	Nov	0.0340	0.00002	0.00011	0.00157	0.000006	0.00078
0.0	Dec	0.0329	0.00002	0.00010	0.00151	0.000006	0.00076
	Avg	**0.0336**	**0.00002**	**0.00011**	**0.0015**	**0.00001**	**0.0008**

Domestic

2040 (m^3/s)						
R. Namatala Catchment						
Mbale	Butebo	Sironko	Budaka	Bududa	Butaleja	
0.0116	0.0004	0.0030	0.0041	0.0003	0.0032	0.0
0.0128	0.0004	0.0034	0.0046	0.0003	0.0035	0.0
0.0116	0.0004	0.0030	0.0041	0.0003	0.0032	0.0
0.0120	0.0004	0.0032	0.0043	0.0003	0.0033	0.0
0.0116	0.0004	0.0030	0.0041	0.0003	0.0032	0.0
0.0120	0.0004	0.0032	0.0043	0.0003	0.0033	0.0
0.0116	0.0004	0.0030	0.0041	0.0003	0.0032	0.0
0.0116	0.0004	0.0030	0.0041	0.0003	0.0032	0.0
0.0120	0.0004	0.0032	0.0043	0.0003	0.0033	0.0
0.0116	0.0004	0.0030	0.0041	0.0003	0.0032	0.0
0.0120	0.0004	0.0032	0.0043	0.0003	0.0033	0.0
0.0116	0.0004	0.0030	0.0041	0.0003	0.0032	0.0
0.0118	**0.0004**	**0.0031**	**0.0042**	**0.0003**	**0.0032**	

Irrigation

	2040 (m^3/s)					
	R. Namatala Catchment					
	Mbale	Butebo	Sironko	Budaka	Bududa	Butaleja
Jan	0.0541	0.00008	0.00133	0.01407	0.00002	0.00300
Feb	0.0599	0.00009	0.00147	0.01557	0.00002	0.00332
Mar	0.0541	0.00008	0.00133	0.01407	0.00002	0.00300
Apr	0.0559	0.00009	0.00138	0.01453	0.00002	0.00310
May	0.0541	0.00008	0.00133	0.01407	0.00002	0.00300
Jun	0.0559	0.00009	0.00138	0.01453	0.00002	0.00310
Jul	0.0541	0.00008	0.00133	0.01407	0.00002	0.00300
Aug	0.0541	0.00008	0.00133	0.01407	0.00002	0.00300
Sep	0.0559	0.00009	0.00138	0.01453	0.00002	0.00310
Oct	0.0541	0.00008	0.00133	0.01407	0.00002	0.00300
Nov	0.0559	0.00009	0.00138	0.01453	0.00002	0.00310
Dec	0.0541	0.00008	0.00133	0.01407	0.00002	0.00300
Avg	**0.0552**	**0.00008**	**0.0014**	**0.0143**	**0.00002**	**0.0031**

Livestock

	2040 (m^3/s)					
	R. Namatala Catchment					
	Mbale	Butebo	Sironko	Budaka	Bududa	Butaleja
Jan	0.0165	0.0013	0.0038	0.0048	0.0002	0.0040
Feb	0.0183	0.0015	0.0042	0.0053	0.0003	0.0044
Mar	0.0165	0.0013	0.0038	0.0048	0.0002	0.0040
Apr	0.0170	0.0014	0.0039	0.0050	0.0002	0.0041
May	0.0165	0.0013	0.0038	0.0048	0.0002	0.0040
Jun	0.0170	0.0014	0.0039	0.0050	0.0002	0.0041
Jul	0.0165	0.0013	0.0038	0.0048	0.0002	0.0040
Aug	0.0165	0.0013	0.0038	0.0048	0.0002	0.0040
Sep	0.0170	0.0014	0.0039	0.0050	0.0002	0.0041
Oct	0.0165	0.0013	0.0038	0.0048	0.0002	0.0040
Nov	0.0170	0.0014	0.0039	0.0050	0.0002	0.0041
Dec	0.0165	0.0013	0.0038	0.0048	0.0002	0.0040
Avg	**0.0168**	**0.0014**	**0.0038**	**0.0049**	**0.0002**	**0.0040**

Industrial

		2040 (m^3/s)					
		R. Namatala Catchment					
		Mbale	Butebo	Sironko	Budaka	Bududa	Butaleja
0.0	Jan	0.0381	0.00003	0.00012	0.00175	0.0000065	0.00087
0.0	Feb	0.0422	0.00003	0.00013	0.00194	0.0000072	0.00097
0.0	Mar	0.0381	0.00003	0.00012	0.00175	0.0000065	0.00087
0.0	Apr	0.0394	0.00003	0.00012	0.00181	0.0000067	0.00090
0.0	May	0.0381	0.00003	0.00012	0.00175	0.0000065	0.00087
0.0	Jun	0.0394	0.00003	0.00012	0.00181	0.0000067	0.00090
0.0	Jul	0.0381	0.00003	0.00012	0.00175	0.0000065	0.00087
0.0	Aug	0.0381	0.00003	0.00012	0.00175	0.0000065	0.00087
0.0	Sep	0.0394	0.00003	0.00012	0.00181	0.0000067	0.00090
0.0	Oct	0.0381	0.00003	0.00012	0.00175	0.0000065	0.00087
0.0	Nov	0.0394	0.00003	0.00012	0.00181	0.0000067	0.00090
0.0	Dec	0.0381	0.00003	0.00012	0.00175	0.0000065	0.00087
	Avg	**0.0389**	**0.00003**	**0.00012**	**0.0018**	**0.00001**	**0.0009**

Appendix C: Land Use classification for Google Earth Engine

(a) Eucalyptus Forested land (36N 641798.19 124068.17 1381.42 m.a.s.l)

(b) Eucalyptus Forested land (36N 640786.41 125042.79 1364.89 m.a.s.l)

(c) Cabbage farmland (36N 641405.18 120610.61 1511.18 m.a.s.l)

(d) Beans farmland (36N 639394.83 125512.67 1350 m.a.s.l)

(e) Doho WWTP (36N 627991.07 118705.44 1104.35 m.a.s.l)

(f) R. Namatala Downstream (36N 636830.06 124110.88 1179.65 m.a.s.l)

(g) Grassland (36N 609100.09 113544.11 1107.86 m.a.s.l)

(h) Built up area (36N 646782.25 122351.48 1474.6 m.a.s.l)

Appendix D: Land Use Code

```
var sJuldate = '2010-01-01'
var eJuldate = '2010-12-31'
// importing lansat collection and uganda bounday
var landsatcollection = ee.ImageCollection("LANDSAT/LE07/C02/T1_L2")
var MurchisionBay = ee.FeatureCollection('users/ceasarkisa/Namatala_Catchment');
Map.setCenter(34.207630, 1.015423, 12)
var cloudMaskL457 = function(image) {
  var qa = image.select('pixel_qa');
  // If the cloud bit (5) is set and the cloud confidence (7) is high
  // or the cloud shadow bit is set (3), then it's a bad pixel.
  var cloud = qa.bitwiseAnd(1 << 5)
                .and(qa.bitwiseAnd(1 << 7))
                .or(qa.bitwiseAnd(1 << 3));
  // Remove edge pixels that don't occur in all bands
  var mask2 = image.mask().reduce(ee.Reducer.min());
  return image.updateMask(cloud.not()).updateMask(mask2);
};
var Dataset2010 = ee.ImageCollection('LANDSAT/LE07/C01/T1_SR')
                .filterDate('2010-01-01', '2010-12-31')
                .map(cloudMaskL457);
// displaying ground truth data
// Map.addLayer(agric, {min:0, max:0.3},'GTagric');
// Map.addLayer(bare, {min:0, max:0.3}, 'GTbare');
// Map.addLayer(built, {min:0, max:0.3}, 'GTbuilt');
// Map.addLayer(forest, {min:0, max:0.3}, 'GTforest');
// Map.addLayer(swamp, {min:0, max:0.3}, 'GTswamp');
// // preparing training samples
var Samples = ee.FeatureCollection(BuiltUpLand
                          .merge(WaterBody)
                          .merge(AgriculturalLand)
                          .merge(WetLand)
                          .merge(ForestLand)
                          .merge(Grassland));

// print('marged samples' , Samples);
// variables/features (bands).
var variables = ['B2', 'B3', 'B4', 'B6', 'B7'];
```

```
// prepare data to train classifier
var InputSamples = Dataset2010.median().select(variables).sampleRegions({collection: Samples,
                                properties: ['class'],
                                scale: 30 });
//Split sample data for training and validation
var trainingSamples = InputSamples.randomColumn();
print("sample", trainingSamples.limit(100))

var split = 0.7;  // Roughly 70% training, 30% testing.
var trainingdata = trainingSamples.filter(ee.Filter.lt('random', split));
var validationdata = trainingSamples.filter(ee.Filter.gte('random', split));
print("validationdata", validationdata.limit(100))
//###########################################################################################################//
                                // Random Forest //
//###########################################################################################################//
var RandomForestclassifier = ee.Classifier.smileRandomForest(10).train({
  features: trainingdata,
  classProperty: 'class',
  inputProperties: variables
});
print("RandomForestclassifier", RandomForestclassifier);
// Confusion matrix representing resubstitution accuracy.
var trainAccuracy_RandomForest = RandomForestclassifier.confusionMatrix();
print('Resubstitution error matrix_RandomForest: ', trainAccuracy_RandomForest);
print('Training overall accuracy_RandomForest: ', trainAccuracy_RandomForest.accuracy());
// Classify the validation data.
var validated_RandomForest = validationdata.classify( RandomForestclassifier);
print('vaidation_RandomForest', validated_RandomForest.limit(100) );
// Get a confusion matrix representing expected accuracy.
var testAccuracy_RandomForest = validated_RandomForest.errorMatrix('class', 'classification');
print('Validation error matrix_RandomForest: ', testAccuracy_RandomForest);
print('Validation overall accuracy_RandomForest: ', testAccuracy_RandomForest.accuracy());
print('Training kappa_RandomForest: ', testAccuracy_RandomForest.kappa());
//*********************************************************************//
//                    2020                              //
//*********************************************************************//
var Dataset2020 = ee.ImageCollection('LANDSAT/LE07/C01/T1_SR')
                .filterDate('2020-01-01', '2020-12-31')
                .map(cloudMaskL457);
var visParams = {
  bands: ['B3', 'B2', 'B1'],
  min: 0,
  max: 3000,
  gamma: 1.4,
};
Map.setCenter(34.207630, 1.015423, 12);
Map.addLayer(Dataset2020.median().clip(MurchisionBay), visParams, '2020');
// var GTBclassified =MarNamatala.select(variables).classify(GTBclassifier,'GTBresults');
var RFclassified2020 = Dataset2020.median().select(variables).classify(RandomForestclassifier,'RFresults 2020');
// var SVMclassified = MarNamatala.select(variables).classify(SVMclassifier,'SVMresults');
// // Display results
```

```
var palette = ['#eae803', '#438b40', '#e052df', 'ffc82d',  '#ff0931'];
Map.addLayer(RFclassified2020.clip(MurchisionBay),   {min: 1, max: 11, palette: palette}, "RFclassified results 2020");
// Map.addLayer(SVMclassified,  {min: 1, max: 11, palette: palette}, "SVMclassified results");
// Map.addLayer(GTBclassified,  {min: 1, max: 11, palette: palette}, "GTBclassified results");
// Exporting classified map of 2020
Export.image.toDrive({
  image: RFclassified2020,
  description: 'RFclassified2020',
  scale:20,
  maxPixels:1e9,
  region:MurchisionBay
})
//*********************************************************************//
//                    2014                             //
//*********************************************************************//
var Dataset2014 = ee.ImageCollection('LANDSAT/LE07/C01/T1_SR')
                .filterDate('2014-01-01', '2014-12-31')
                .map(cloudMaskL457);
var visParams = {
  bands: ['B3', 'B2', 'B1'],
  min: 0,
  max: 3000,
  gamma: 1.4,
};
Map.setCenter(34.207630, 1.015423, 12);
Map.addLayer(Dataset2014.median().clip(MurchisionBay), visParams, '2014');
// var GTBclassified =MarNamatala.select(variables).classify(GTBclassifier,'GTBresults');
var RFclassified2014 = Dataset2014.median().select(variables).classify(RandomForestclassifier,'RFresults 2014');
// var SVMclassified = MarNamatala.select(variables).classify(SVMclassifier,'SVMresults');
// // Display results
var palette = ['#eae803', '#438b40', '#e052df', 'ffc82d',  '#ff0931'];
Map.addLayer(RFclassified2014.clip(MurchisionBay),   {min: 1, max: 11, palette: palette}, "RFclassified results 2014");
// Map.addLayer(SVMclassified,  {min: 1, max: 11, palette: palette}, "SVMclassified results");
// Map.addLayer(GTBclassified,  {min: 1, max: 11, palette: palette}, "GTBclassified results");
// Exporting classified map of 2014
Export.image.toDrive({
  image: RFclassified2014,
  description: 'RFclassified2014',
  scale:20,
  maxPixels:1e9,
  region:MurchisionBay
})
//*********************************************************************//
//                    2010                             //
//*********************************************************************//
var visParams = {
  bands: ['B3', 'B2', 'B1'],
  min: 0,
  max: 3000,
  gamma: 1.4,
};
Map.setCenter(34.207630, 1.015423, 12);
Map.addLayer(Dataset2010.median().clip(MurchisionBay), visParams, '2010');
```

```
// var GTBclassified =MarNamatala.select(variables).classify(GTBclassifier,'GTBresults');
var                                  RFclassified2010                                  =
Dataset2010.median().select(variables).classify(RandomForestclassifier,'RFresults 2010');
// var SVMclassified = MarNamatala.select(variables).classify(SVMclassifier,'SVMresults');
// // Display results
var palette = ['#eae803', '#438b40', '#e052df', 'ffc82d',  '#ff0931'];
Map.addLayer(RFclassified2010.clip(MurchisionBay),   {min: 1, max: 11, palette: palette},
"RFclassified results 2010");
// Map.addLayer(SVMclassified,  {min: 1, max: 11, palette: palette}, "SVMclassified results");
// Map.addLayer(GTBclassified,  {min: 1, max: 11, palette: palette}, "GTBclassified results");
// Exporting classified map of 2010
Export.image.toDrive({
  image: RFclassified2010,
  description: 'RFclassified2010',
  scale:20,
  maxPixels:1e9,
  region:MurchisionBay
})
//
//*********************************************************************//
// //                    2007                              //
// //*********************************************************************//
var Dataset2007 = ee.ImageCollection('LANDSAT/LE07/C01/T1_SR')
                .filterDate('2007-01-01', '2007-12-31')
                .map(cloudMaskL457);
var visParams = {
  bands: ['B3', 'B2', 'B1'],
  min: 0,
  max: 3000,
  gamma: 1.4,
};
Map.setCenter(34.207630, 1.015423, 12);
Map.addLayer(Dataset2007.median().clip(MurchisionBay), visParams, '2007');
// var GTBclassified =MarNamatala.select(variables).classify(GTBclassifier,'GTBresults');
var                                  RFclassified2007                                  =
Dataset2007.median().select(variables).classify(RandomForestclassifier,'RFresults2007');
// var SVMclassified = MarNamatala.select(variables).classify(SVMclassifier,'SVMresults');
// // Display results
var palette = ['#d63000', '#438b40', '#0b24ff', 'ffc82d',  '#ff0931'];
Map.addLayer(RFclassified2007.clip(MurchisionBay),   {min: 1, max: 11, palette: palette},
"RFclassified results 2007");
// Map.addLayer(SVMclassified,  {min: 1, max: 11, palette: palette}, "SVMclassified results");
// Map.addLayer(GTBclassified,  {min: 1, max: 11, palette: palette}, "GTBclassified results");
// Exporting classified map of 2007
Export.image.toDrive({
  image: RFclassified2007,
  description: 'RFclassified2007',
  scale:20,
  maxPixels:1e9,
  region:MurchisionBay
})
//
//*********************************************************************//
// //                    1999                              //
// //*********************************************************************//
var Dataset1999 = ee.ImageCollection('LANDSAT/LE07/C01/T1_SR')
```

```
.filterDate('1999-01-01', '1999-12-31')
.map(cloudMaskL457);
var visParams = {
 bands: ['B3', 'B2', 'B1'],
 min: 0,
 max: 3000,
 gamma: 1.4,
};
Map.setCenter(34.207630, 1.015423, 12);
Map.addLayer(Dataset1999.median().clip(MurchisionBay), visParams, '1999');
// var GTBclassified =MarNamatala.select(variables).classify(GTBclassifier,'GTBresults');
var RFclassified1999 =
Dataset1999.median().select(variables).classify(RandomForestclassifier,'RFresults 1999');
// var SVMclassified = MarNamatala.select(variables).classify(SVMclassifier,'SVMresults');
// // Display results
var palette = ['#d63000', '#438b40', '#0b24ff', 'ffc82d', '#ff0931'];
Map.addLayer(RFclassified1999.clip(MurchisionBay), {min: 1, max: 11, palette: palette},
"RFclassified results 1999");
// Map.addLayer(SVMclassified, {min: 1, max: 11, palette: palette}, "SVMclassified results");
// Map.addLayer(GTBclassified, {min: 1, max: 11, palette: palette}, "GTBclassified results");
// // Exporting classified map of 1999
Export.image.toDrive({
 image: RFclassified1999,
 description: 'RFclassified1999',
 scale:20,
 maxPixels:1e9,
 region:MurchisionBay
})
//
//**********************************************************************//
// //                    1995                    //
// //**********************************************************************//
var Dataset1995 = ee.ImageCollection("LANDSAT/LT05/C01/T1_SR")
.filterDate('1995-01-01', '1995-12-31')
.map(cloudMaskL457);
var visParams = {
 bands: ['B3', 'B2', 'B1'],
 min: 0,
 max: 3000,
 gamma: 1.4,
};
Map.setCenter(34.207630, 1.015423, 12);
Map.addLayer(Dataset1995.median().clip(MurchisionBay), visParams, '1995');
// var GTBclassified =MarNamatala.select(variables).classify(GTBclassifier,'GTBresults');
var RFclassified1995 =
Dataset1995.median().select(variables).classify(RandomForestclassifier,'RFresults 1995');
// var SVMclassified = MarNamatala.select(variables).classify(SVMclassifier,'SVMresults');
// // Display results
var palette = ['#d63000', '#438b40', '#0b24ff', 'ffc82d', '#ff0931'];
Map.addLayer(RFclassified1995.clip(MurchisionBay), {min: 1, max: 11, palette: palette},
"RFclassified results 1995");
// Map.addLayer(SVMclassified, {min: 1, max: 11, palette: palette}, "SVMclassified results");
// Map.addLayer(GTBclassified, {min: 1, max: 11, palette: palette}, "GTBclassified results");
// // Exporting classified map of 1995
Export.image.toDrive({
 image: RFclassified1995,
```

```
  description: 'RFclassified1995',
  scale:20,
  maxPixels:1e9,
  region:MurchisionBay
})
//
//**********************************************************************//
// //                    1991                              //
// //**********************************************************************//
var Dataset1991 = ee.ImageCollection("LANDSAT/LT05/C01/T1_SR")
              .filterDate('1991-01-01', '1991-12-31')
              .map(cloudMaskL457);
var visParams = {
  bands: ['B3', 'B2', 'B1'],
  min: 0,
  max: 3000,
  gamma: 1.4,
};
Map.setCenter(34.207630, 1.015423, 12);
Map.addLayer(Dataset1991.median().clip(MurchisionBay), visParams, '1991');
// var GTBclassified =MarNamatala.select(variables).classify(GTBclassifier,'GTBresults');
var                                RFclassified1991                                =
Dataset1991.median().select(variables).classify(RandomForestclassifier,'RFresults 1991');
// var SVMclassified = MarNamatala.select(variables).classify(SVMclassifier,'SVMresults');
// // Display results
var palette = ['#d63000', '#438b40', '#0b24ff', 'ffc82d',  '#ff0931'];
Map.addLayer(RFclassified1991.clip(MurchisionBay),   {min: 1, max: 11, palette: palette},
"RFclassified results 1991");
// Map.addLayer(SVMclassified,  {min: 1, max: 11, palette: palette}, "SVMclassified results");
// Map.addLayer(GTBclassified,  {min: 1, max: 11, palette: palette}, "GTBclassified results");
// // Exporting classified map of 1991
Export.image.toDrive({
  image: RFclassified1991,
  description: 'RFclassified1991',
  scale:20,
  maxPixels:1e9,
  region:MurchisionBay
})
//
//**********************************************************************//
// //                    1984                              //
// //**********************************************************************//
var Dataset1984 = ee.ImageCollection("LANDSAT/LT05/C01/T1_SR")
              .filterDate('1984-01-01', '1984-12-31')
              .map(cloudMaskL457);
var visParams = {
  bands: ['B3', 'B2', 'B1'],
  min: 0,
  max: 3000,
  gamma: 1.4,
};
Map.setCenter(34.207630, 1.015423, 12);
Map.addLayer(Dataset1984.median().clip(MurchisionBay), visParams, '1984');
// var GTBclassified =MarNamatala.select(variables).classify(GTBclassifier,'GTBresults');
var                                RFclassified1984                                =
Dataset1984.median().select(variables).classify(RandomForestclassifier,'RFresults 1984');
```

```
// var SVMclassified = MarNamatala.select(variables).classify(SVMclassifier,'SVMresults');
// // Display results
var palette = ['#d63000', '#438b40', '#0b24ff', 'ffc82d',  '#ff0931'];
Map.addLayer(RFclassified1984.clip(MurchisionBay),   {min: 1, max: 11, palette: palette},
"RFclassified results 1984");
// Map.addLayer(SVMclassified,  {min: 1, max: 11, palette: palette}, "SVMclassified results");
// Map.addLayer(GTBclassified,  {min: 1, max: 11, palette: palette}, "GTBclassified results");
// // Exporting classified map of 1984
Export.image.toDrive({
  image: RFclassified1984,
  description: 'RFclassified1984',
  scale:20,
  maxPixels:1e9,
  region:MurchisionBay
})
```

Appendix E: Google Earth Engine Code for CHIRPS Data

```
var chirps = ee.ImageCollection('UCSB-CHG/CHIRPS/DAILY');
var year = 2009;
var startDate = ee.Date.fromYMD(year, 1, 1);
var endDate = startDate.advance(4, 'year');
var dateFilter = ee.Filter.date(startDate, endDate);
var yearFiltered = chirps.filter(dateFilter);
print(yearFiltered.size())
// Convert the collection to a stacked image
// This converts each image to a band
var stackedImage = yearFiltered.toBands();
print(stackedImage)
// Select a region
// If you want your own region, upload a shapefile
// and use the resulting asset instead
var admin2 = ee.FeatureCollection('users/ceasarkisa/Kafu');
// var lis = ee.List(['BBAALE']);
// var selected = admin2.filter(ee.Filter.inList('Name', lis))
var selected = admin2.filter(ee.Filter.eq('OBJECTID', 1))
var geometry = selected.geometry();
Map.addLayer(geometry, {color: 'blue'}, 'Extracted Time-Series');
// We want to extract a time-series at each pixel
// Add a band with latlon values
var imageWithLonLat = stackedImage.addBands(ee.Image.pixelArea())
// Use sample() to extract values at each pixel
// Use native projection and resolution of CHIRPS
var projection = ee.Image(chirps.first()).projection();
var scale = projection.nominalScale();
var extracted = imageWithLonLat.sample({
  region: geometry,
  scale: scale,
```

```
  projection: projection,
  geometries: true});
Map.centerObject(geometry)
Map.addLayer(extracted, {color: 'red'}, 'Extracted Time-Series');
// Export the results as CSV
Export.table.toDrive({
  collection: extracted,
  description: 'Precipitation_Time_Series_Export',
  folder: 'earthengine',
  fileNamePrefix: 'time_series',
  fileFormat: 'CSV'})
```

Appendix F: Water Quality

Appendix F-1: Water Quality Report

Generally, for all sampled locations, in situ water quality was substantially good. R. Namatala had an average pH of 6.6 with Point 7 which is located immediately after Mbale city exhibited high pH of 7.25 while point 2 & 3 exhibited low pH 6.09 and 6.24 respectively. In terms of Temperature, R. Namatala had an average temperature of 20.4^{0}c with Upstream temperature (Point 1, 2, 3, 4) ranging between 18.67 to 19.91^{0}c while downstream temperature (Point 8,9,10) ranging between 21.97 to 20.89^{0}c. In terms of Dissolved Oxygen (DO), R. Namatala had an average DO of 2.447 mg/l with Upstream temperature (Point 1, 2, 3, 4) ranging between 2.56 to 1.49 mg/l while downstream temperature (Point 8,9,10) ranging between 20.5 to 3.86 mg/l.

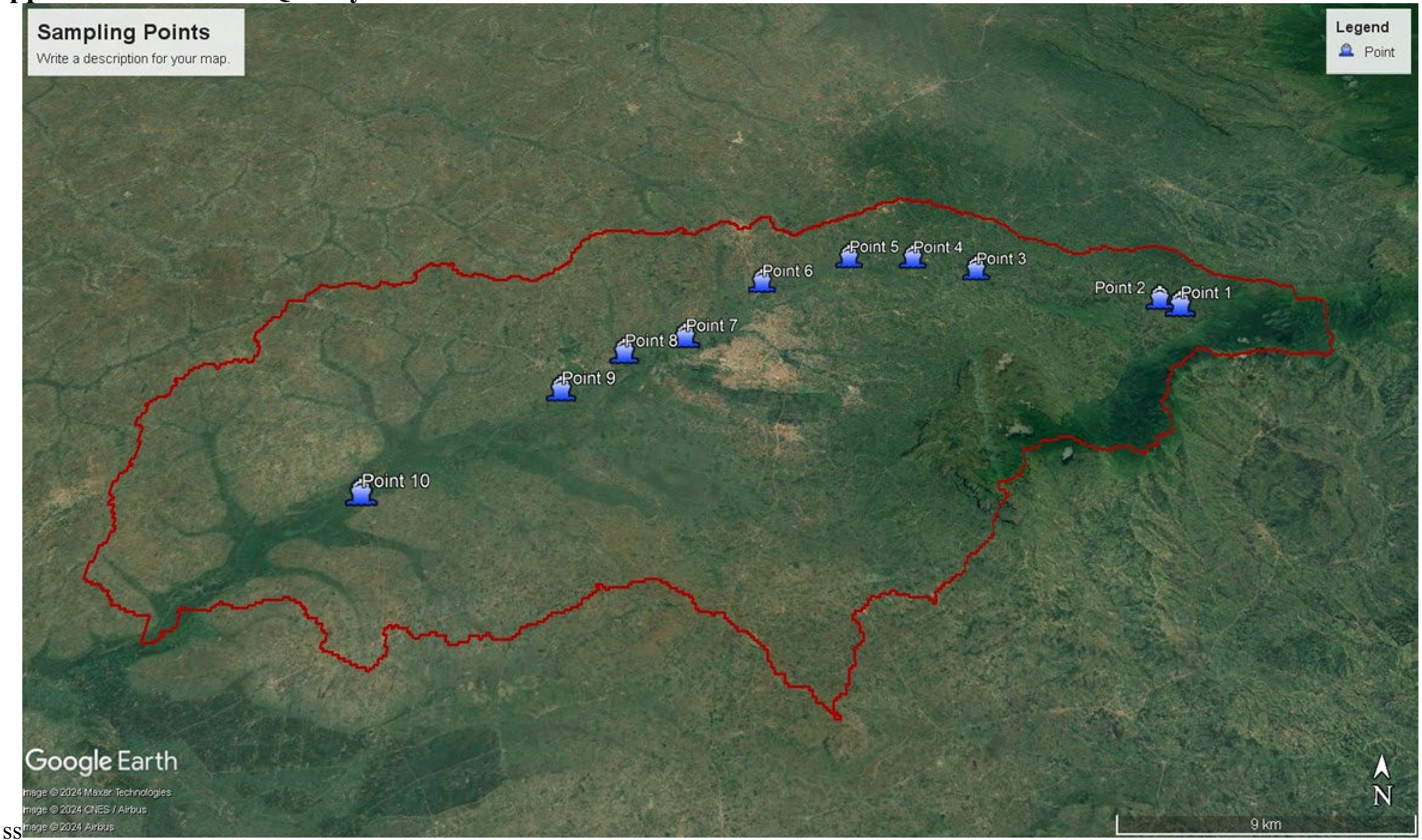
Table 7.1: In situ water quality results. Numbers are average ± stdev on triplicate measurements.

LOCATION	DO%	DO (mg/L)	pH	Temp (ºC)	Atmospheric pressure (mbar)	EC (µS/cm)	TDS (ppm)	Salinity	ORP
Point 1	34.83	2.56	6.62	18.67	901.83	43	4.33	0.02	-16.83
Point 2	35.17	2.63	6.09	19.25	906	42	8.6	0.02	-10.53
Point 3	21.03	1.62	6.24	19.7	910.8	50.33	6.4	0.02	-1.33
Point 4	19.6	1.49	6.71	19.91	900.67	41	10.33	0.02	-4.63
Point 5	13.17	0.96	6.76	20.8	910.57	77.33	19	0.03	-15.1
Point 6	28.23	2.32	6.71	19.95	904.73	169.67	18.2	0.08	-36.1
Point 7	59.53	3.28	7.25	21.36	906.97	278	39	0.13	-44.2

LOCATION	DO%	DO (mg/L)	pH	Temp (ºC)	Atmospheric pressure (mbar)	EC (µS/cm)	TDS (ppm)	Salinity	ORP
Point 8	30.47	2.05	6.27	21.97	908.17	87.67	43.67	0.04	-47.47
Point 9	64.6	3.7	6.6	21.52	903.67	85	42.67	0.04	-49.6
Point 10	49.4	3.86	6.75	20.89	891.27	16.67	48.67	0.06	-81.93

*Dissolved Oxygen; EC- Electrical Conductivity; TDS – Total Dissolved Oxygen; ORP – Oxidation Reduction Potential *The national potable water quality standards for pH is 5.5-9.5, EC- 2500 µS/cm, and TDS – 1500 ppm*

Appendix F-2: Water Quality Pictorial



ss

Figure 7.1: Sampled Points along the River

(a) Water Sampling at Point 3

(b) Water Sampling at Point 5

(c) In situ Sampling at Tributary

(d) Water Sampling at Point 1

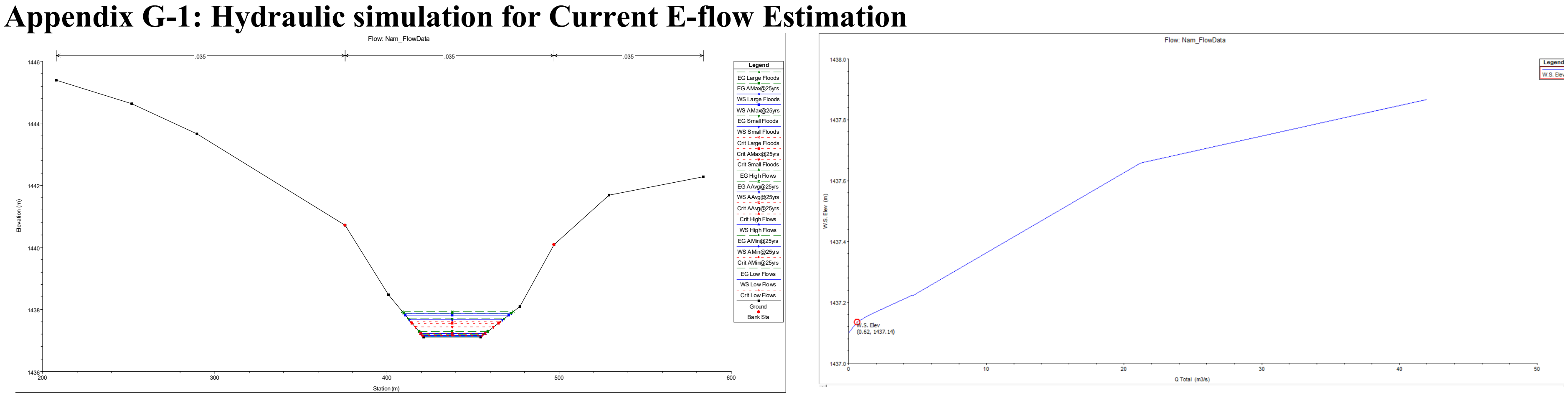
(e) Water Sampling at a tributary

(f) Water Sampling at Point 2

Figure 7.2: Water Sampling in the catchment

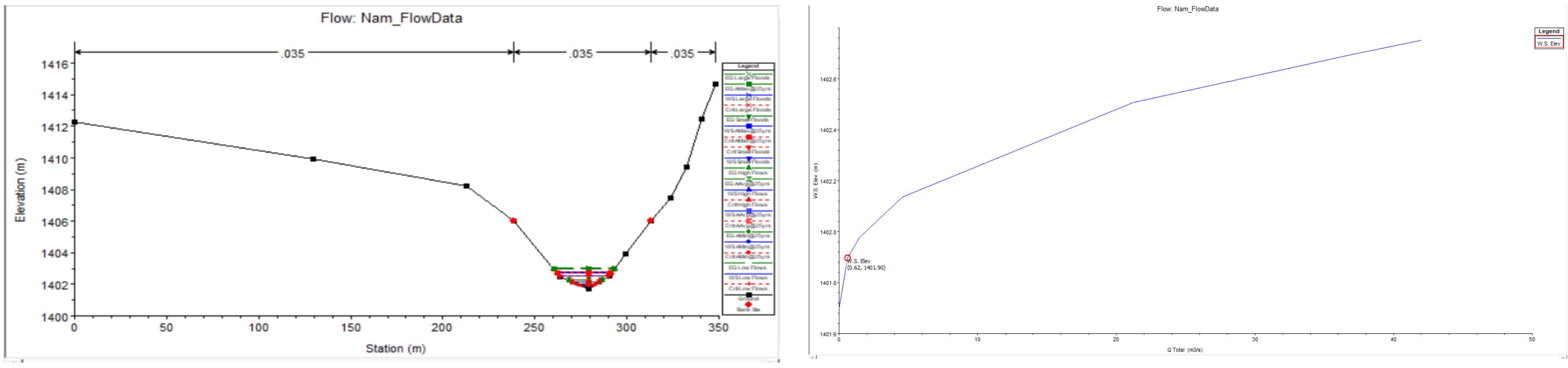
Appendix G: Hydraulic E-flow Simulation

Appendix G-1: Hydraulic simulation for Current E-flow Estimation



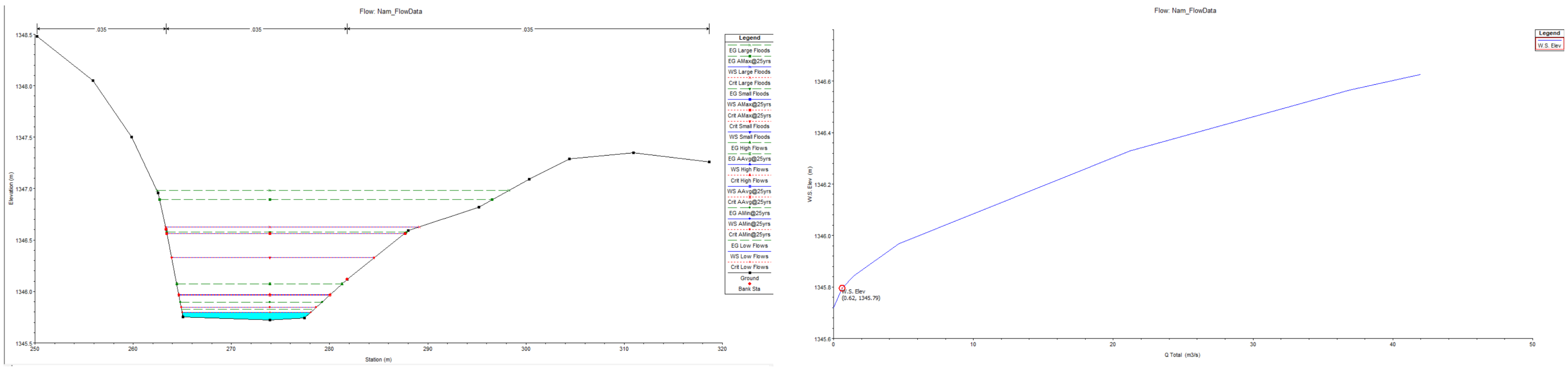
0.
m

(a) Station ID – 51452 (36N 647458 E, 121369N)



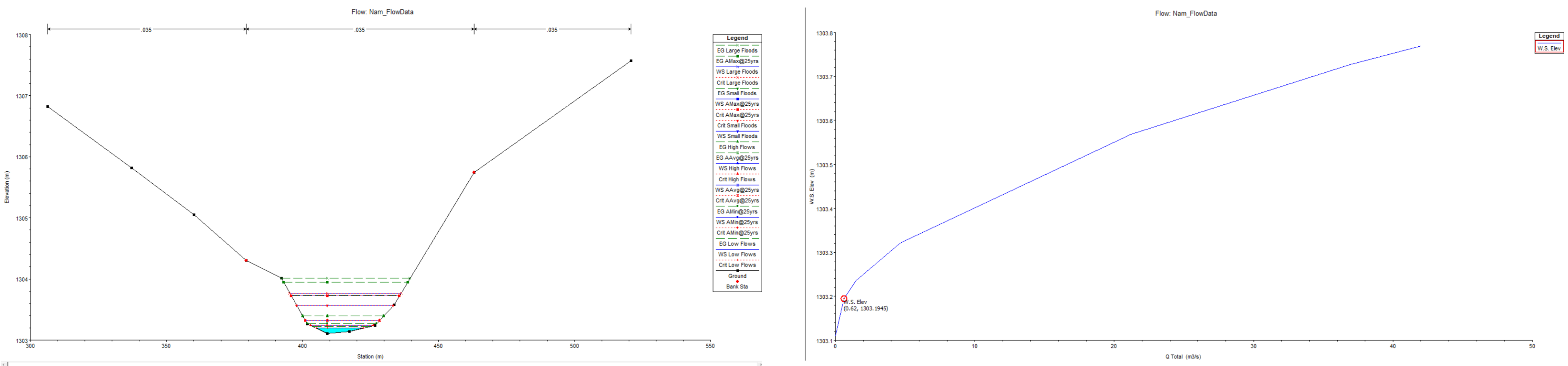
0.
m

(b) Station ID – 45623 (36N 642816.31 E, 121914.04 N)



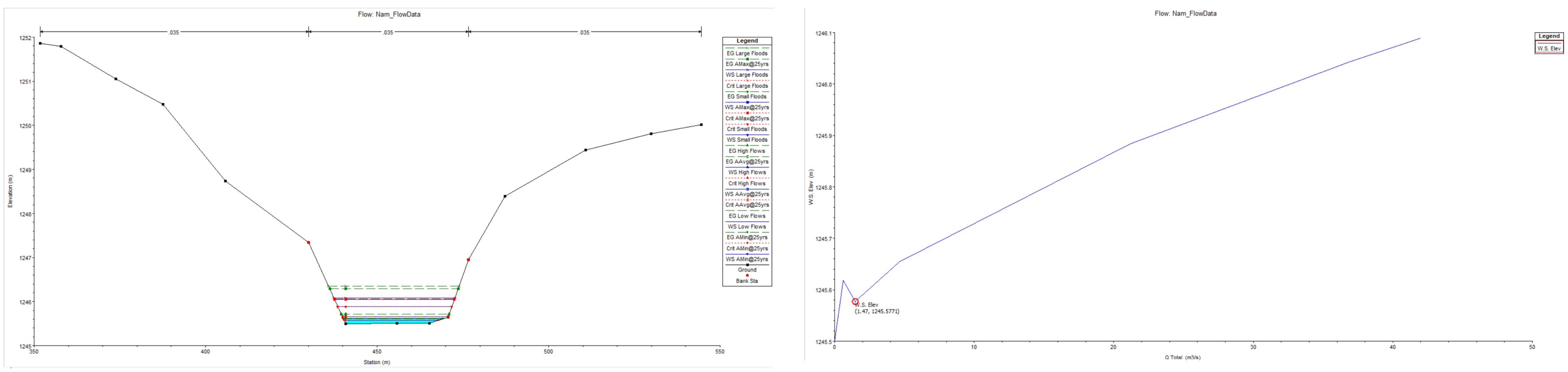
0.
m

(c) Station ID – 43264 (36N 640461.96 E, 122862.08 N)



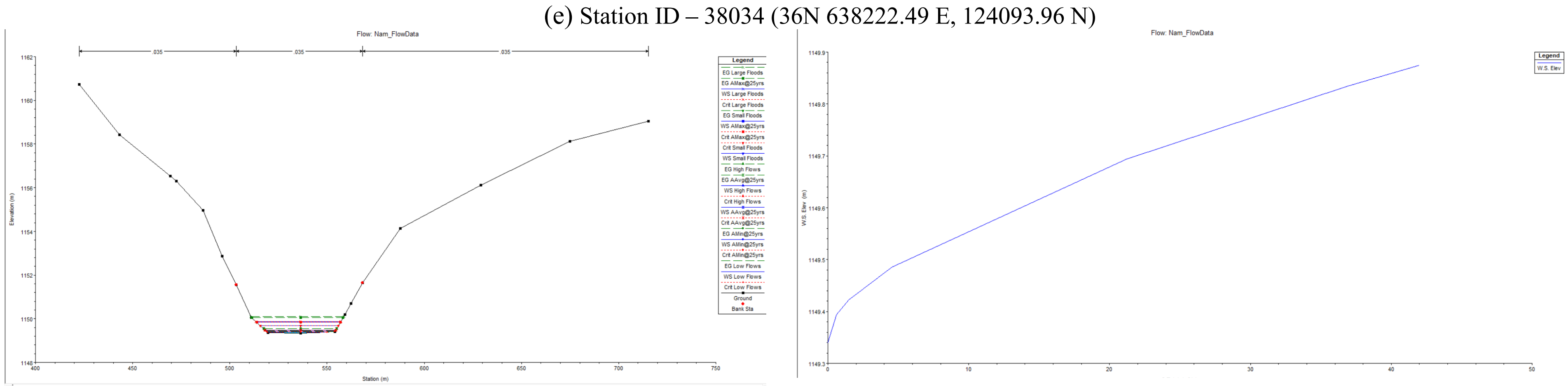
0.
m

(d) Station ID – 40542 (36N 639337.54 E, 123415.79 N)

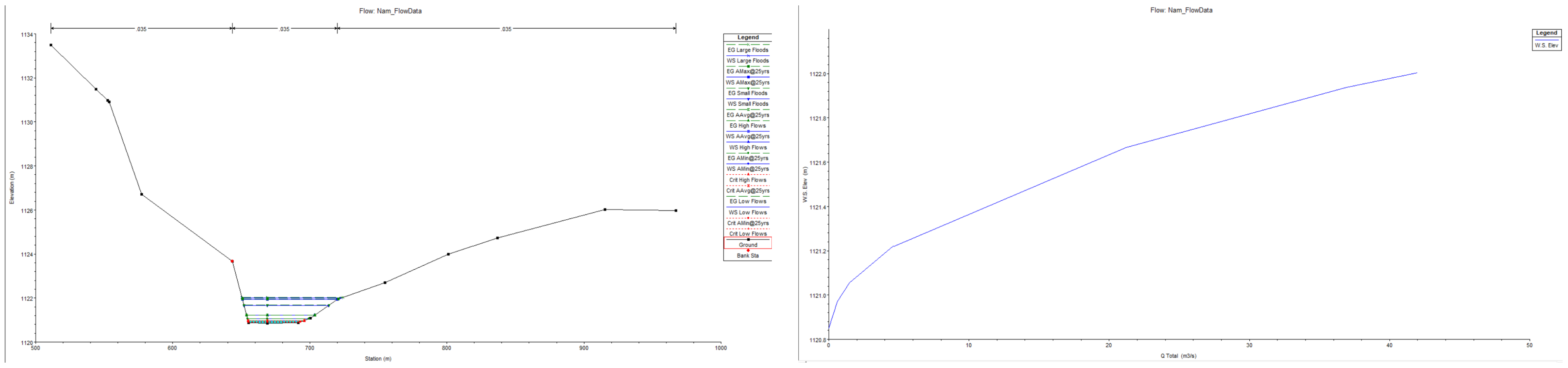


0.
m

(e) Station ID – 38034 (36N 638222.49 E, 124093.96 N)



(f) Station ID – 34275 (36N 636876.04 E, 124088.31 N)



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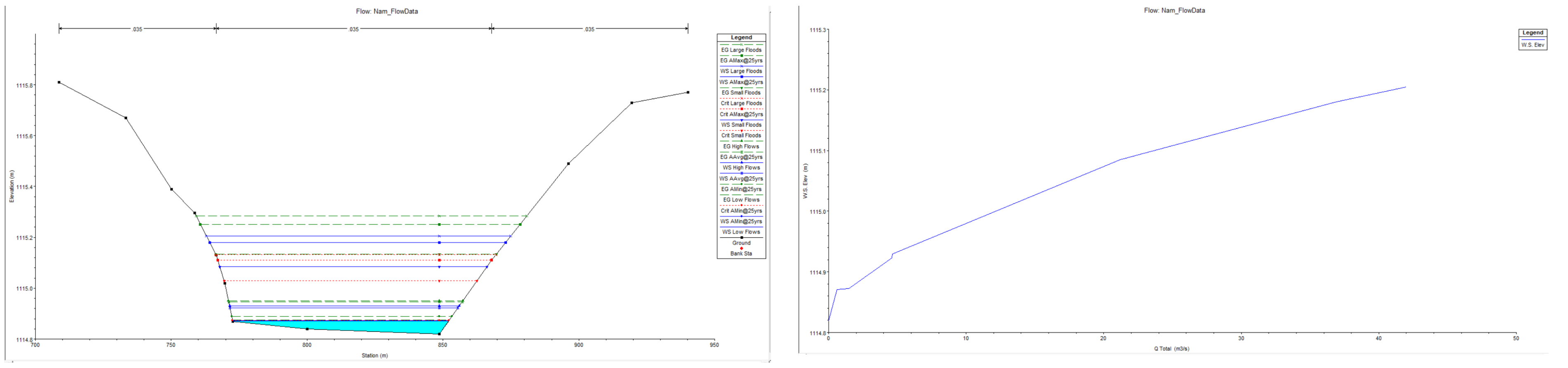
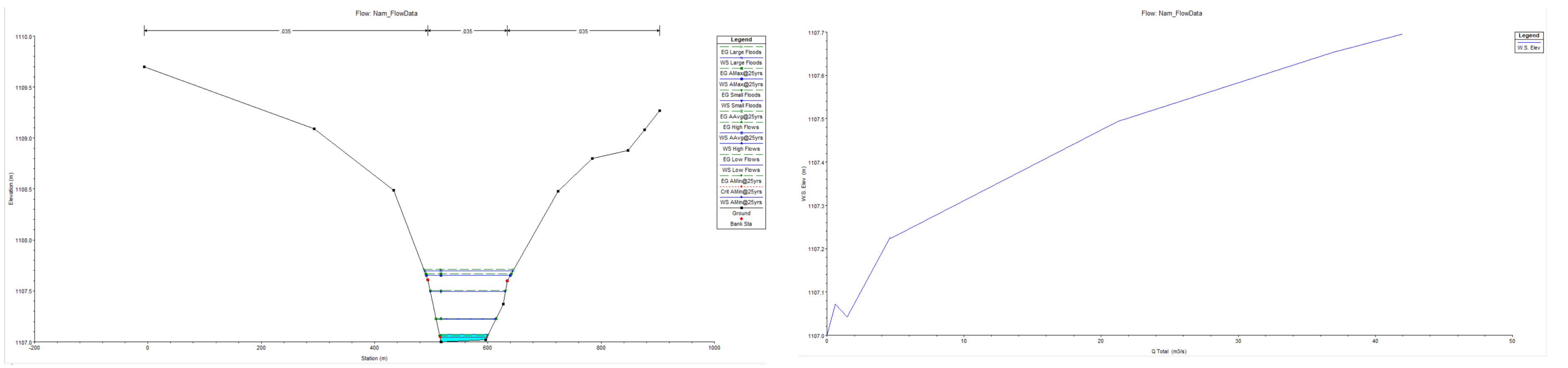
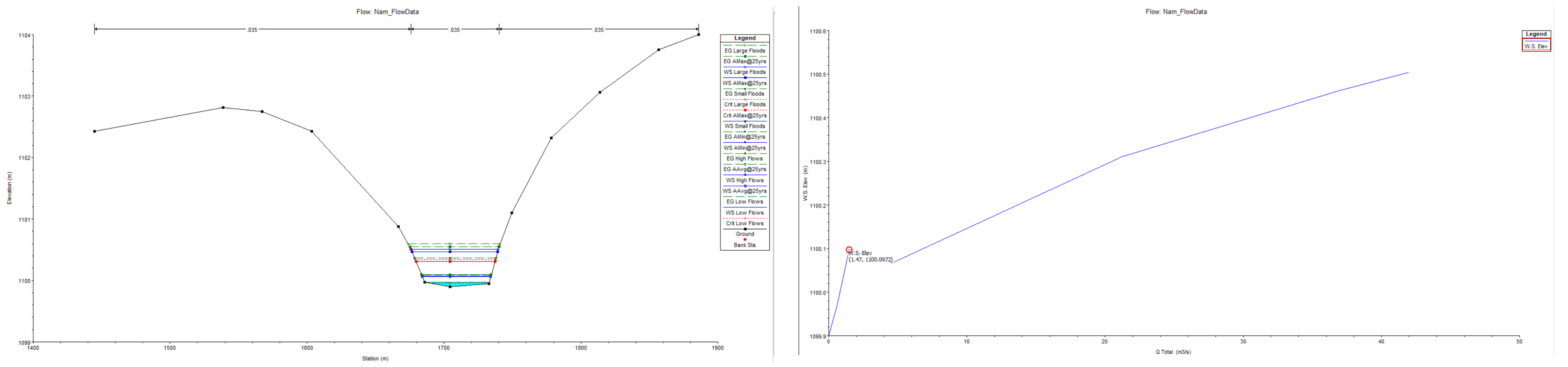


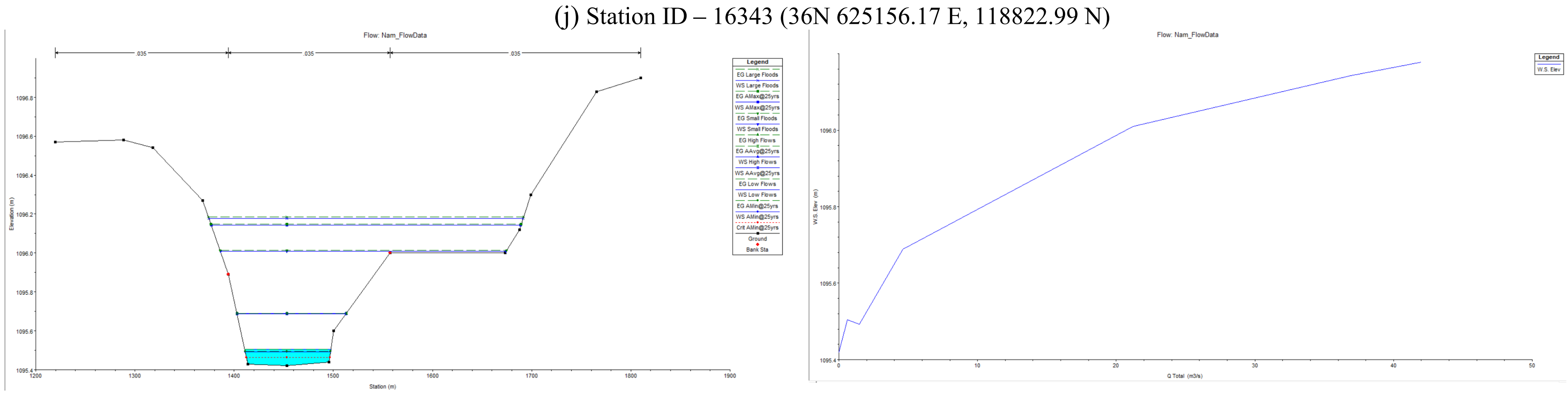
(h) Station ID – 25455 (36N 632026.48 E, 123136.75 N)



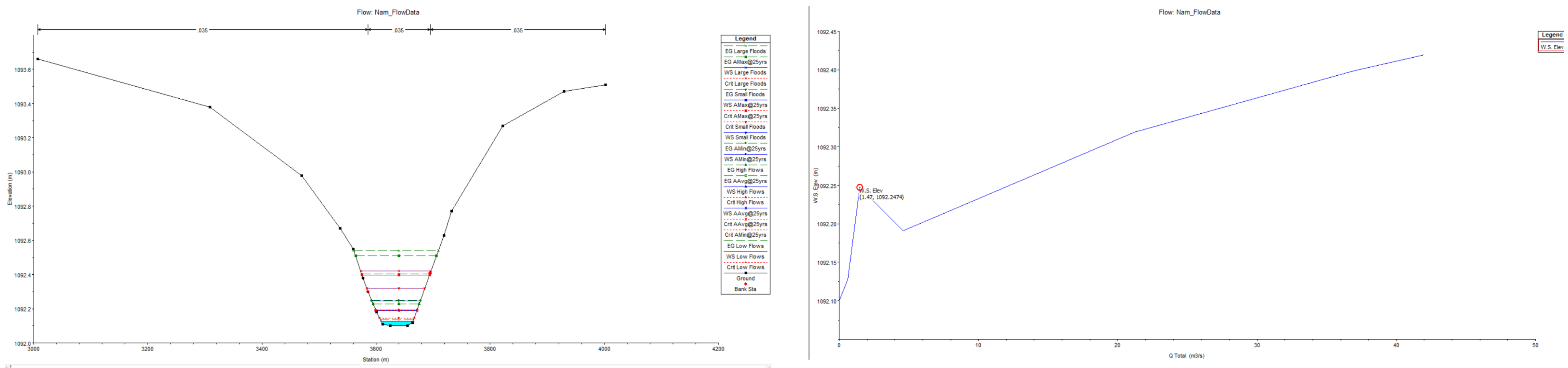
(i) Station ID – 20978 (36N 630561.03 E, 122667.26 N)



(j) Station ID – 16343 (36N 625156.17 E, 118822.99 N)



(k) Station ID – 11743 (36N 624797.28 E, 117727.75 N)



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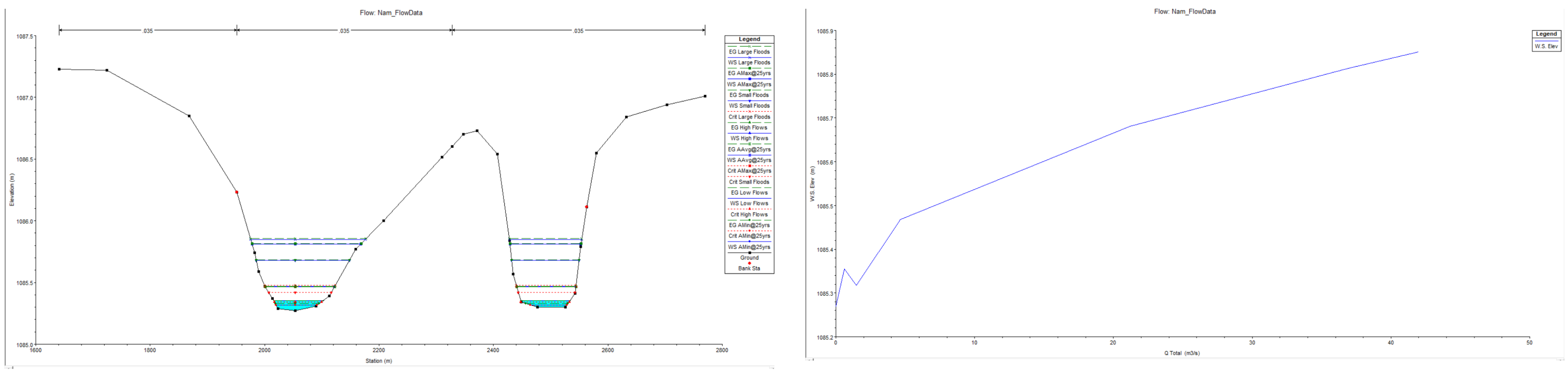
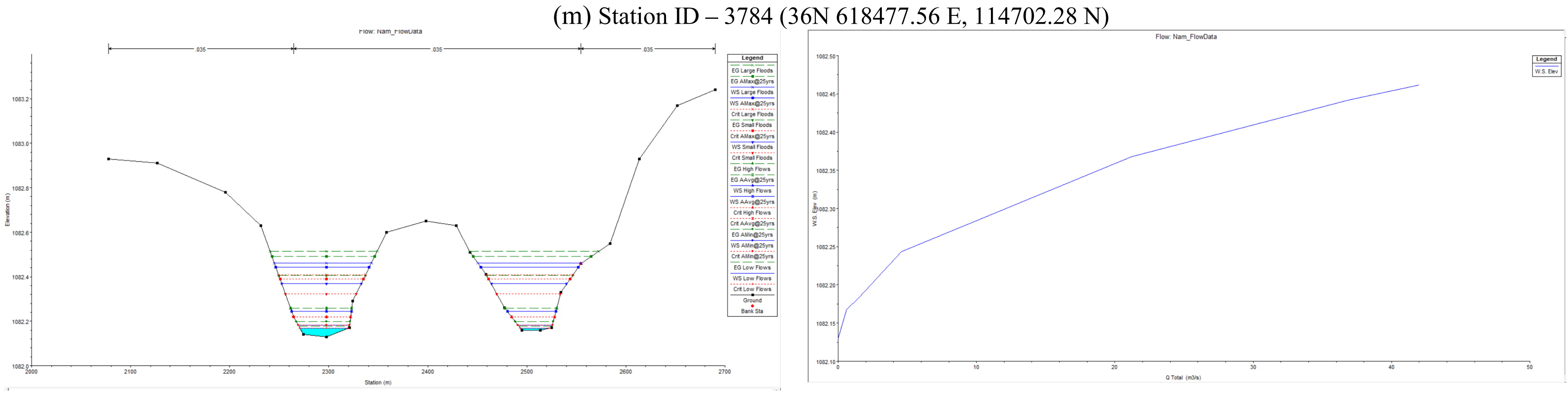


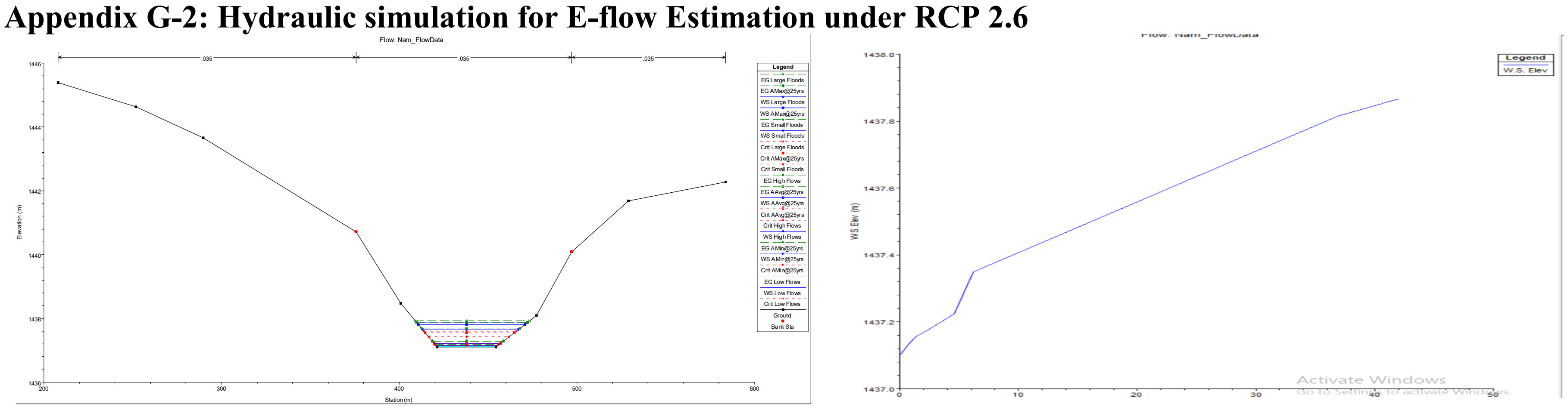
(m) Station ID – 3784 (36N 618477.56 E, 114702.28 N)



(n) Station ID – 491

Figure 7.3: Wetted perimeter Analysis for Selected sections on the river.

Appendix G-2: Hydraulic simulation for E-flow Estimation under RCP 2.6



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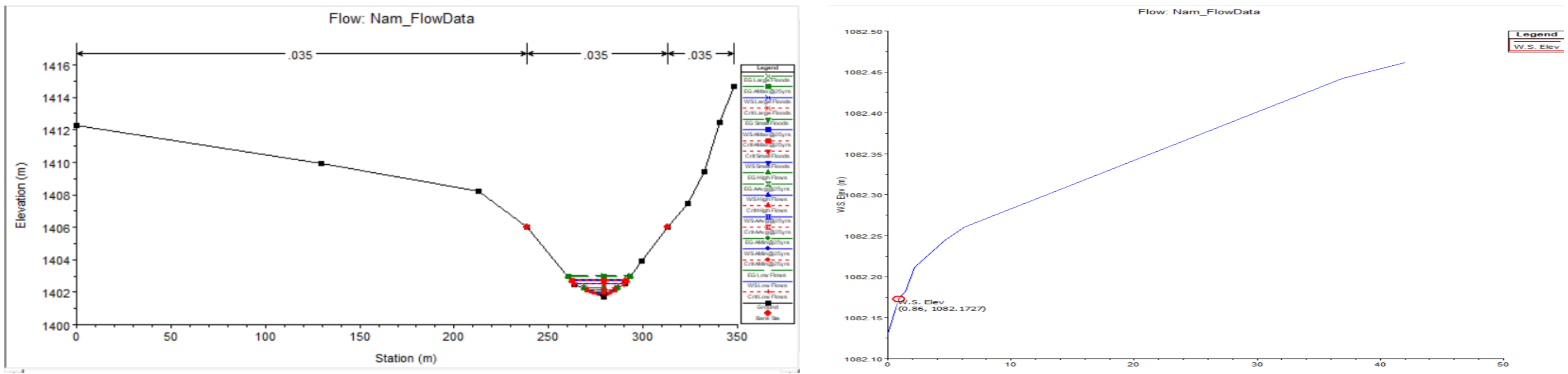
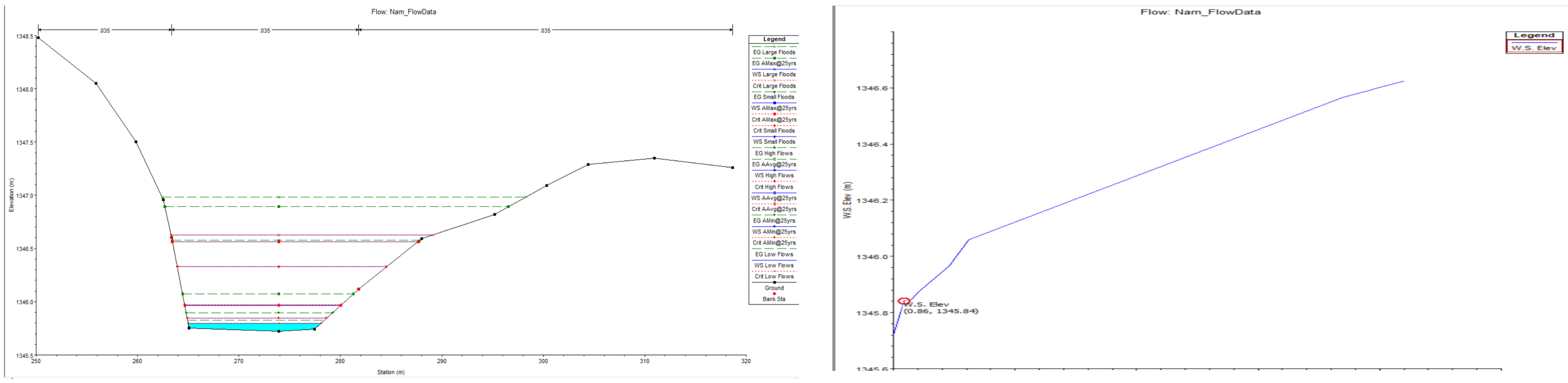
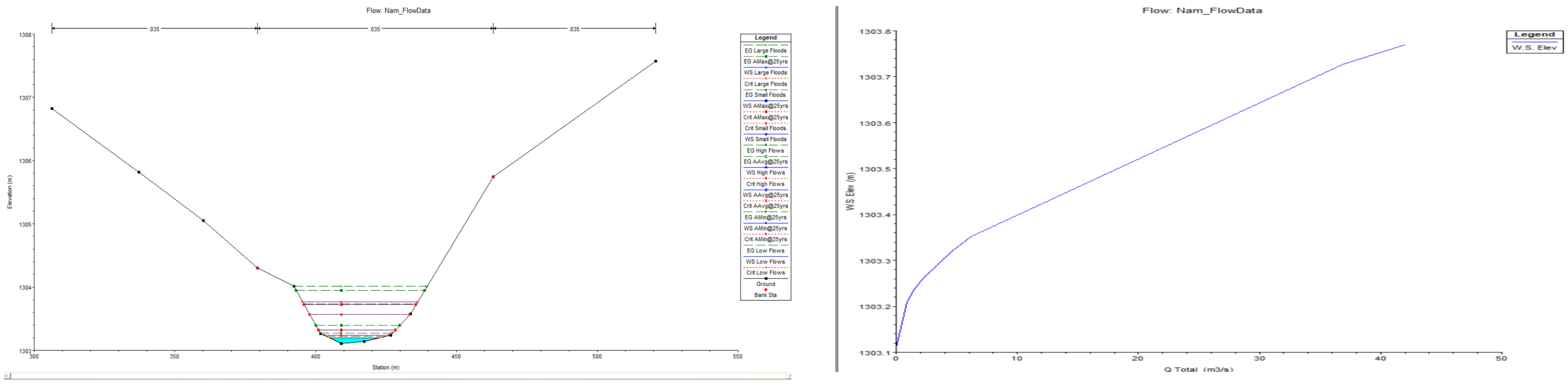


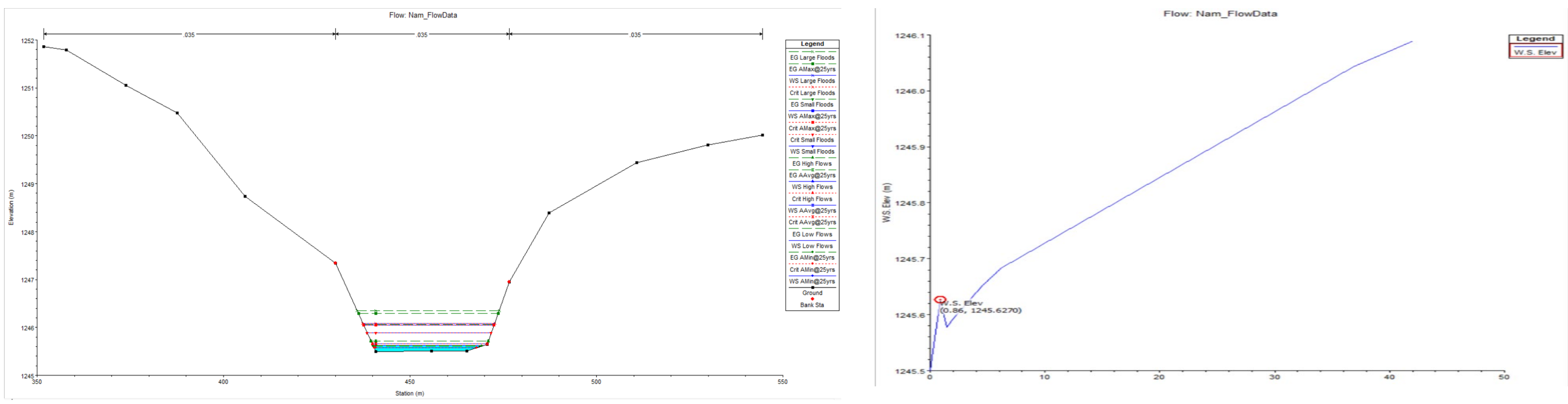
(b) RCP 2.6 Station ID – 45623 (36N 642816.31 E, 121914.04 N)



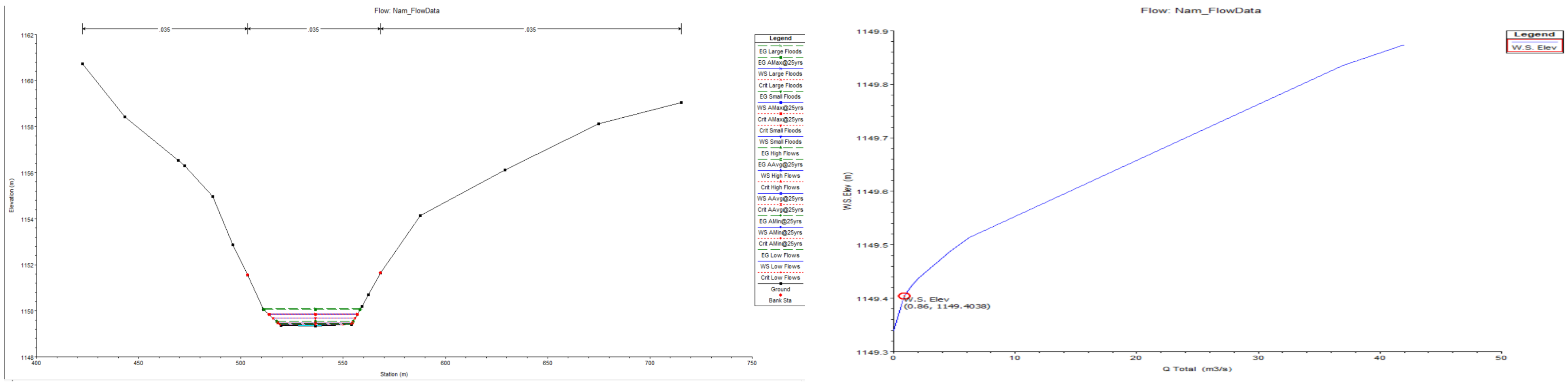
(c) RCP 2.6 Station ID – 43264 (36N 640461.96 E, 122862.08 N)



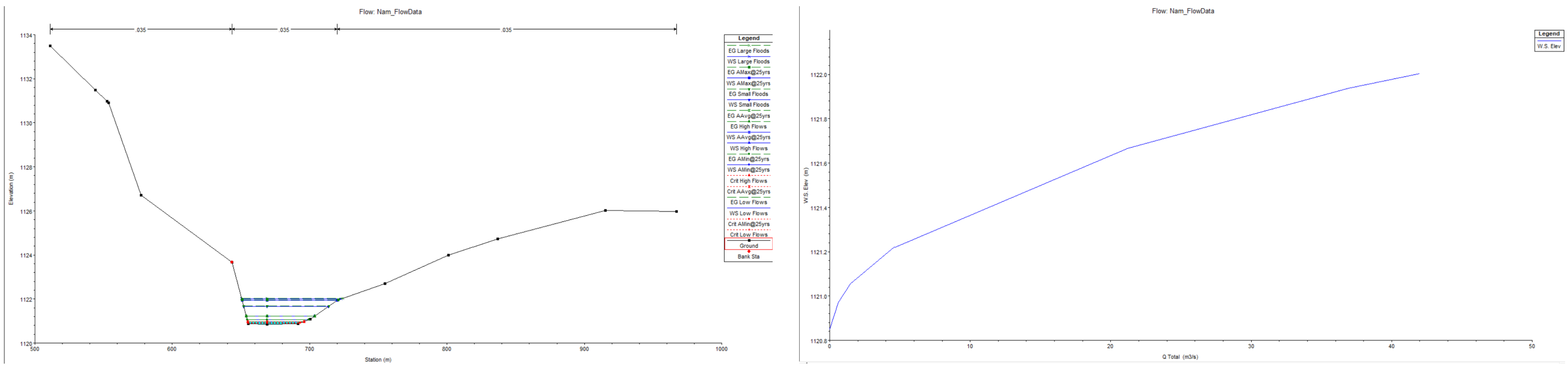
(d) RCP 2.6 Station ID – 40542 (36N 639337.54 E, 123415.79 N)



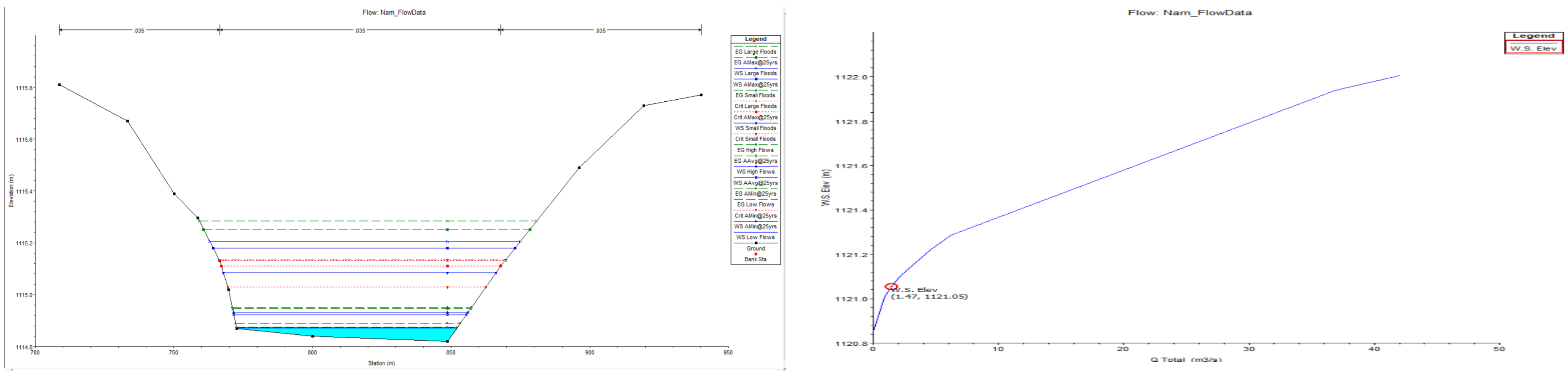
(e) RCP 2.6 Station ID – 38034 (36N 638222.49 E, 124093.96 N)



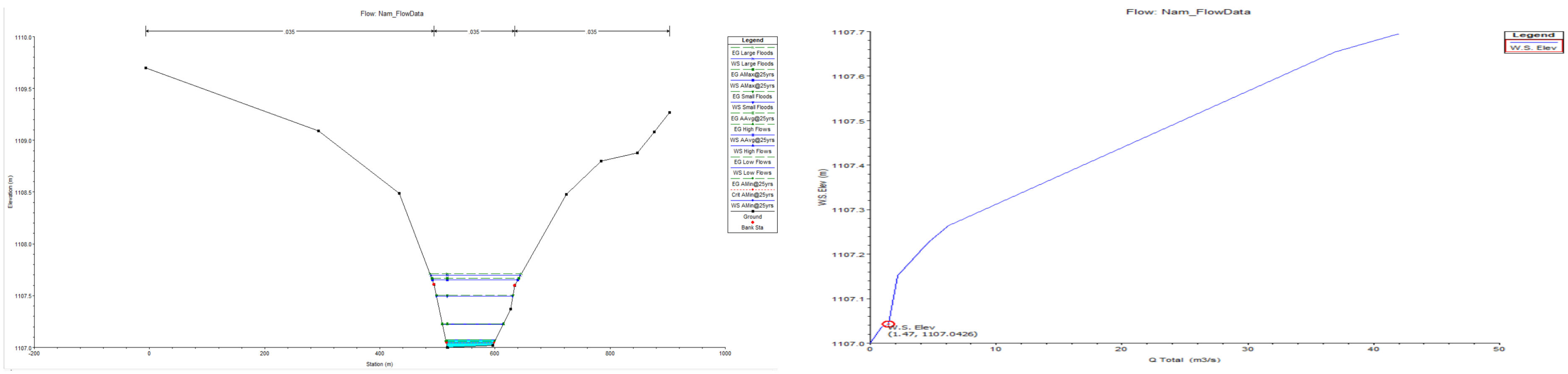
(f) RCP 2.6 Station ID – 34275 (36N 636876.04 E, 124088.31 N)



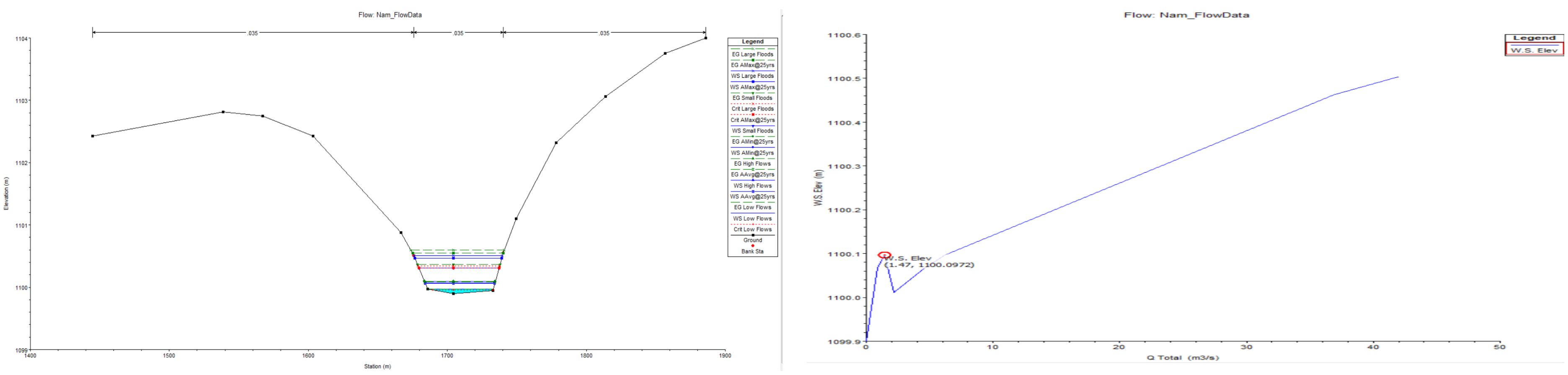
(g) RCP 2.6 Station ID – 29835 (36N 634234.92 E, 124021.39 N)



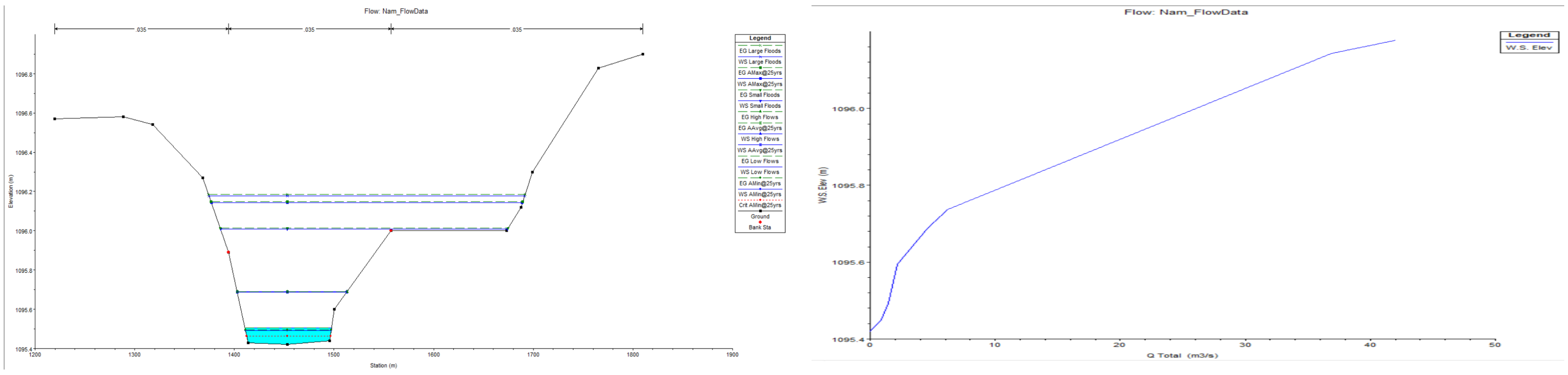
(h) RCP 2.6 Station ID – 25455 (36N 632026.48 E, 123136.75 N)



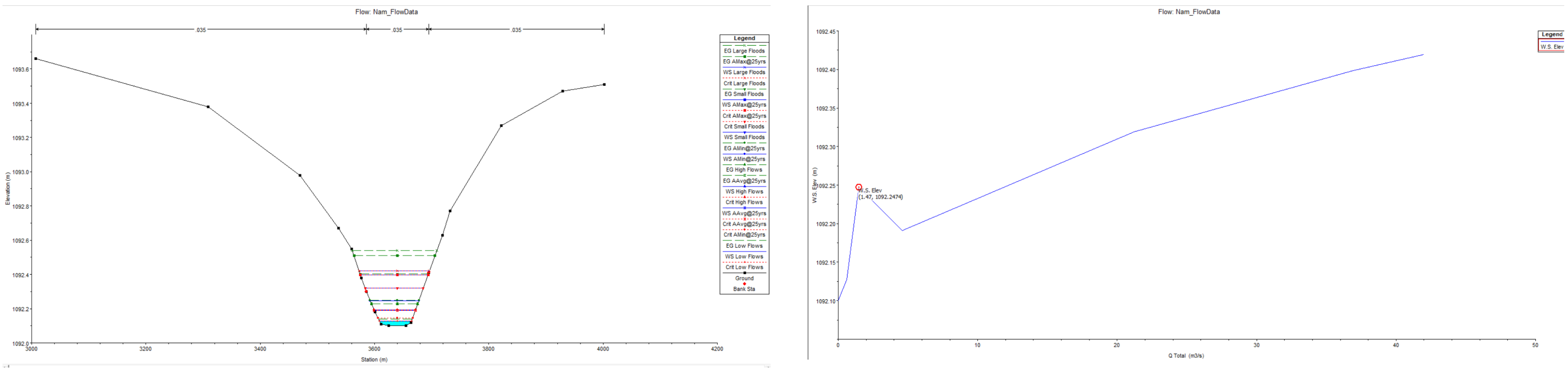
(i) RCP 2.6 Station ID – 20978 (36N 630561.03 E, 122667.26 N)



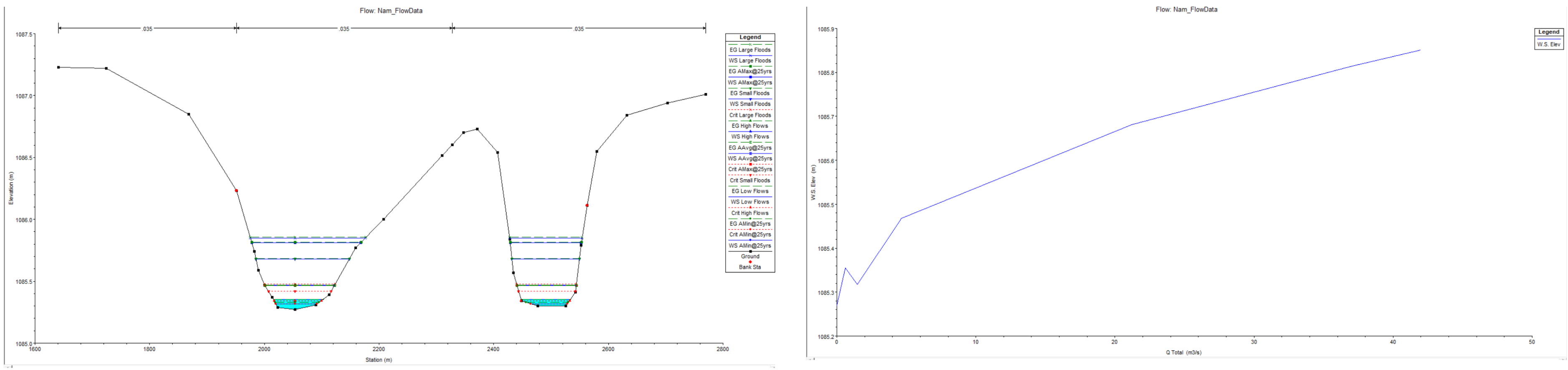
(j) RCP 2.6 Station ID – 16343 (36N 625156.17 E, 118822.99 N)



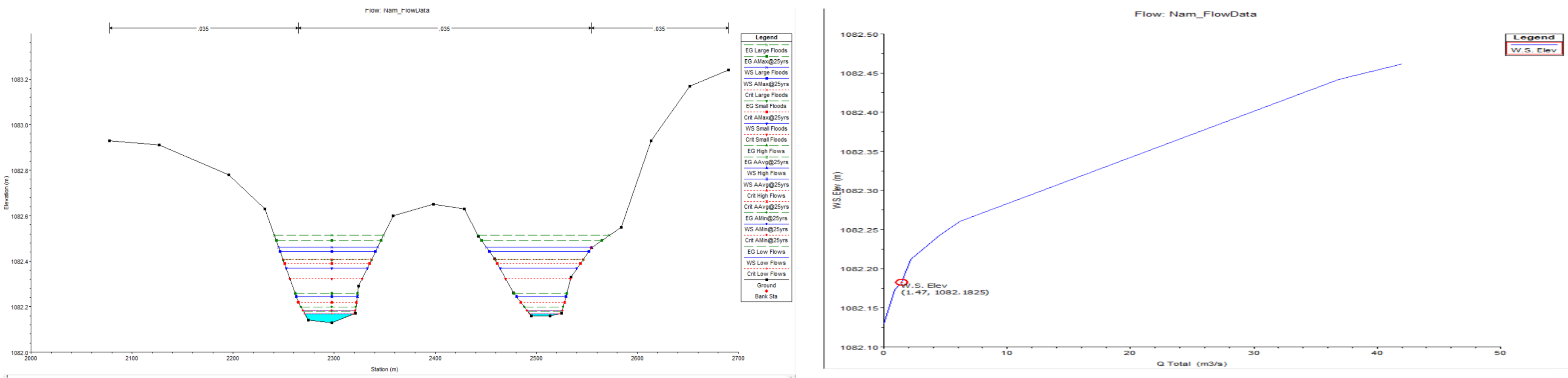
(k) RCP 2.6 Station ID – 11743 (36N 624797.28 E, 117727.75 N)



(l) RCP 2.6 Station ID – 8625 (36N 620322.57 E, 115118.97 N)



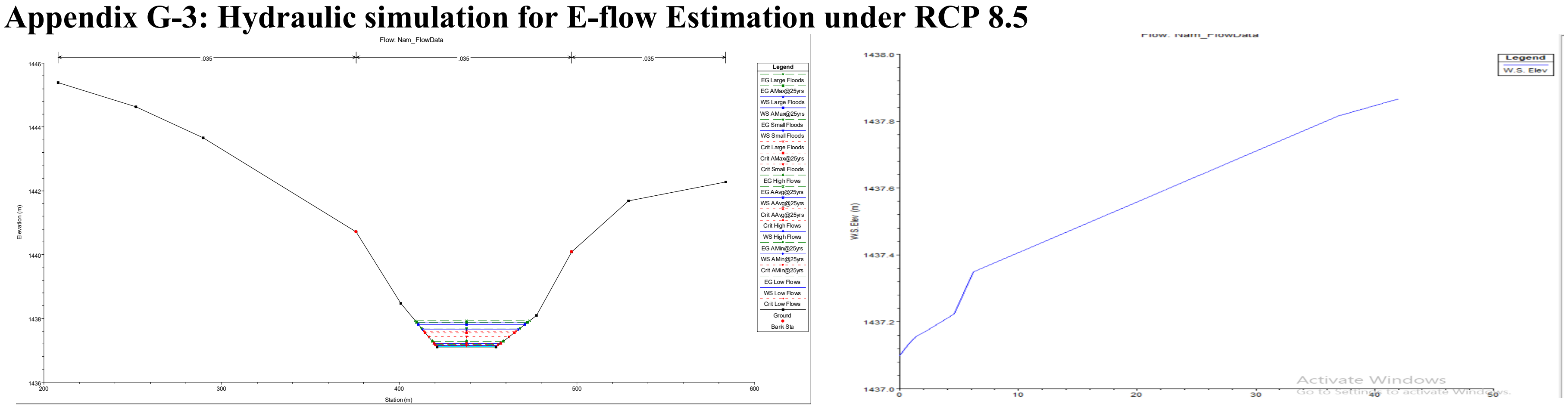
(m) RCP 2.6 Station ID – 3784 (36N 618477.56 E, 114702.28 N)



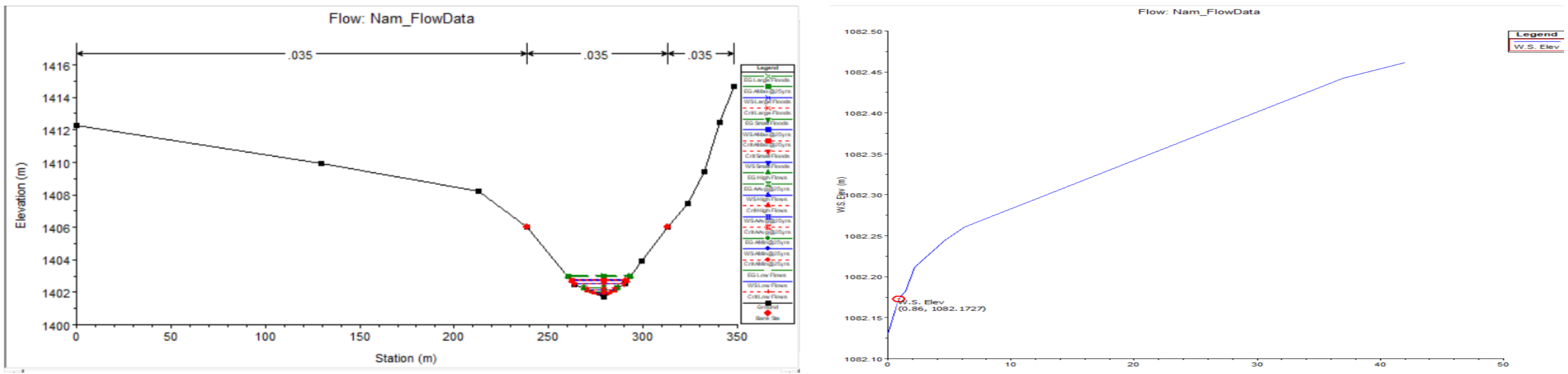
(n) RCP 2.6 Station ID – 491

Figure 7.4: Wetted perimeter Analysis for Selected sections on the river under RCP 2.6

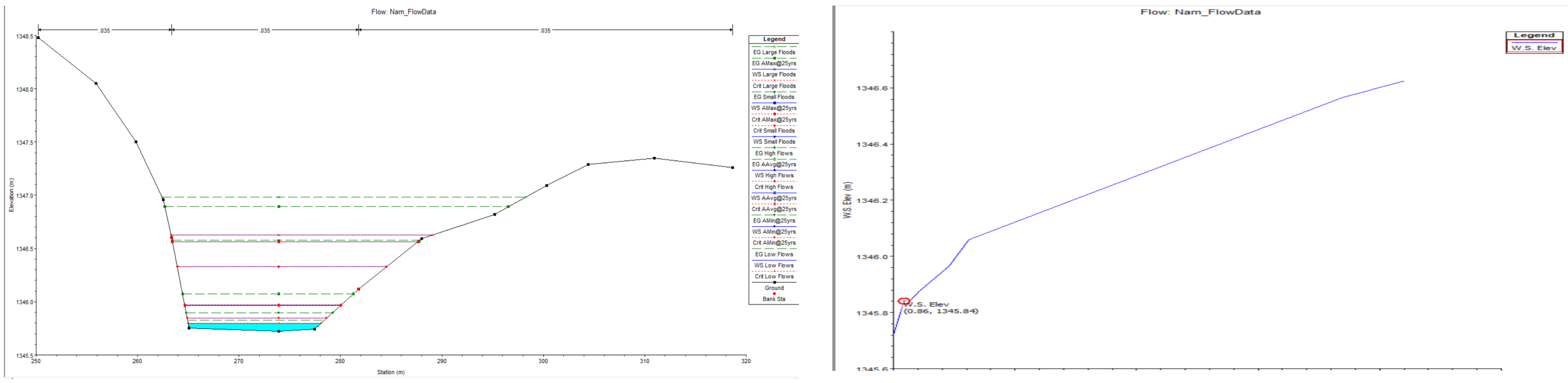
Appendix G-3: Hydraulic simulation for E-flow Estimation under RCP 8.5



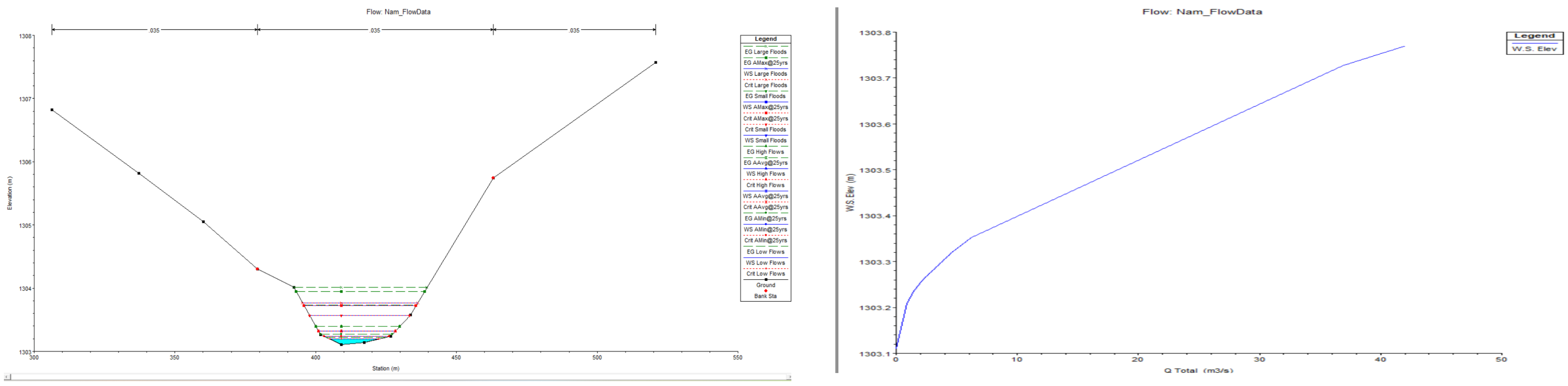
(a) RCP 8.5 Station ID – 51452 (36N 647458 E, 121369N)



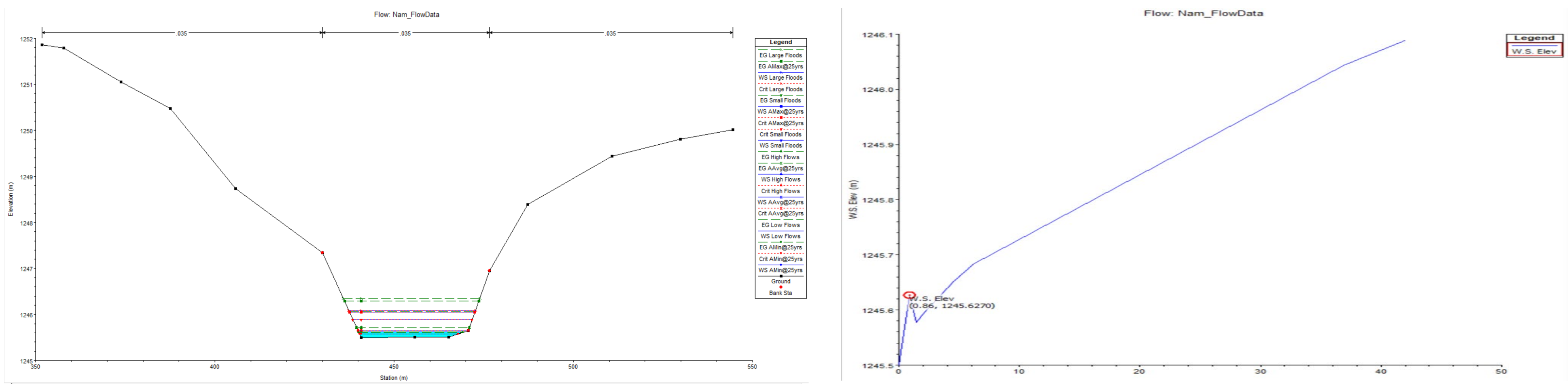
(b) RCP 8.5 Station ID – 45623 (36N 642816.31 E, 121914.04 N)



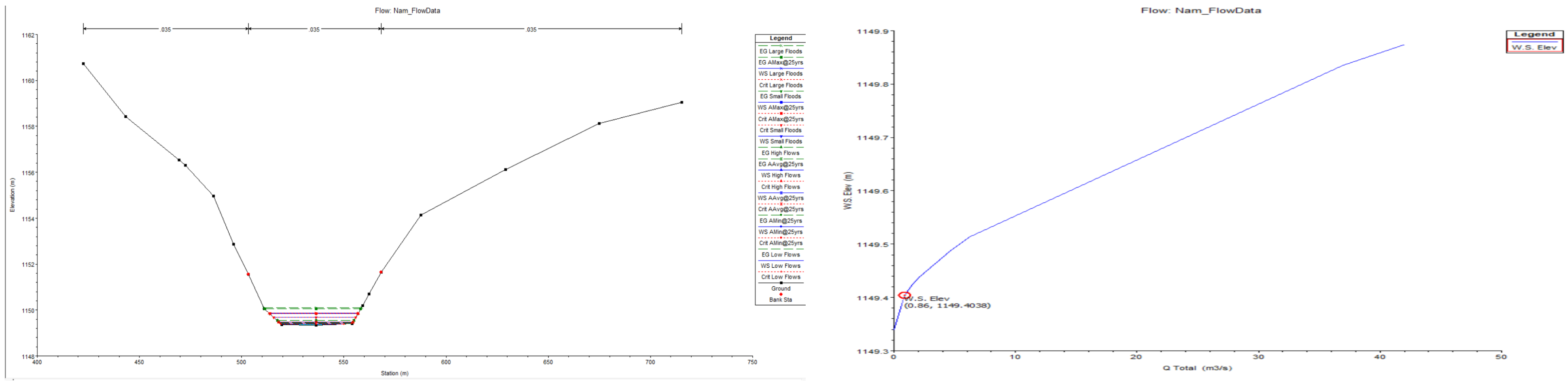
(c) RCP 8.5 Station ID – 43264 (36N 640461.96 E, 122862.08 N)



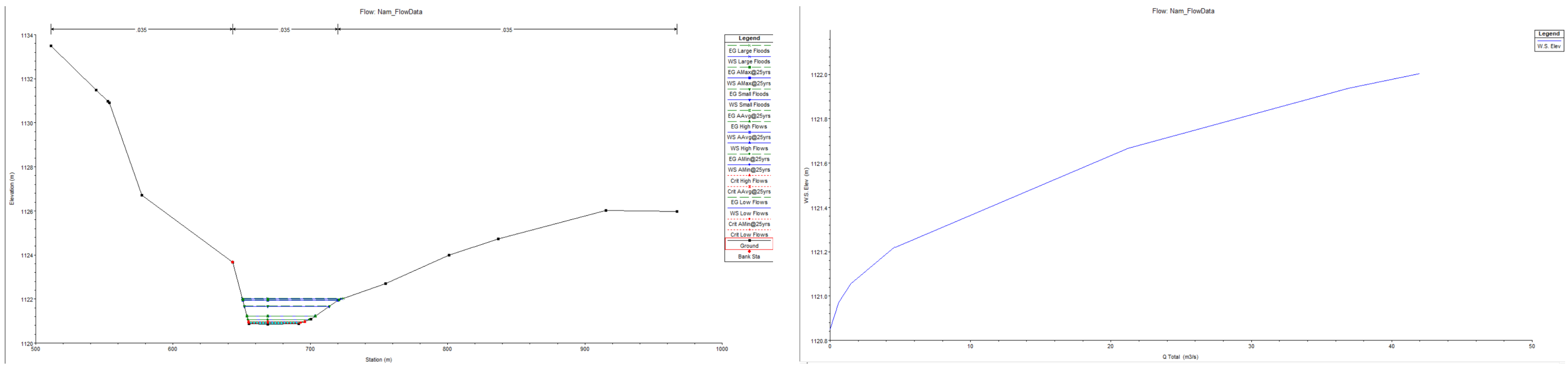
(d) RCP 8.5 Station ID – 40542 (36N 639337.54 E, 123415.79 N)



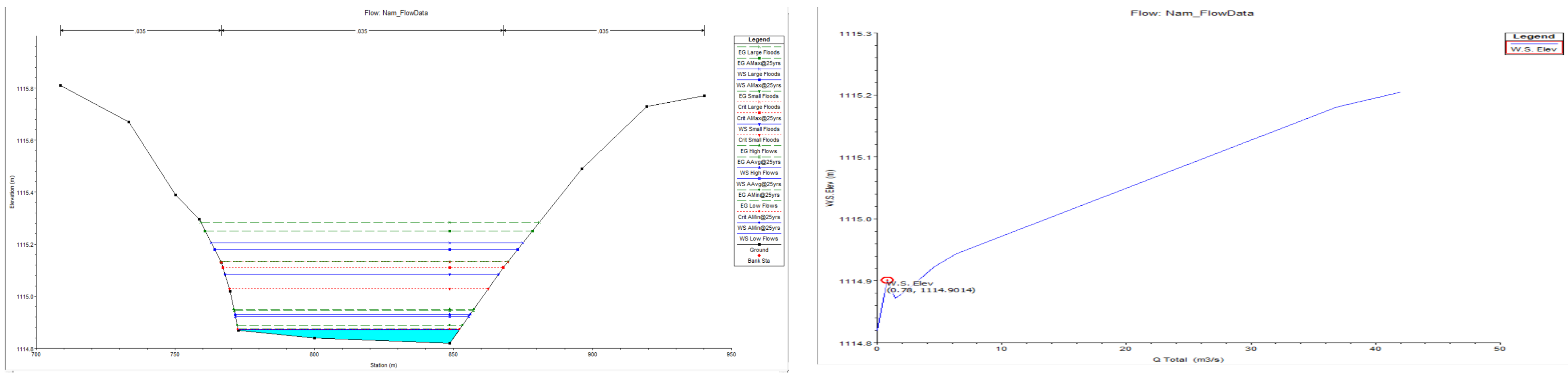
(e) RCP 8.5 Station ID – 38034 (36N 638222.49 E, 124093.96 N)



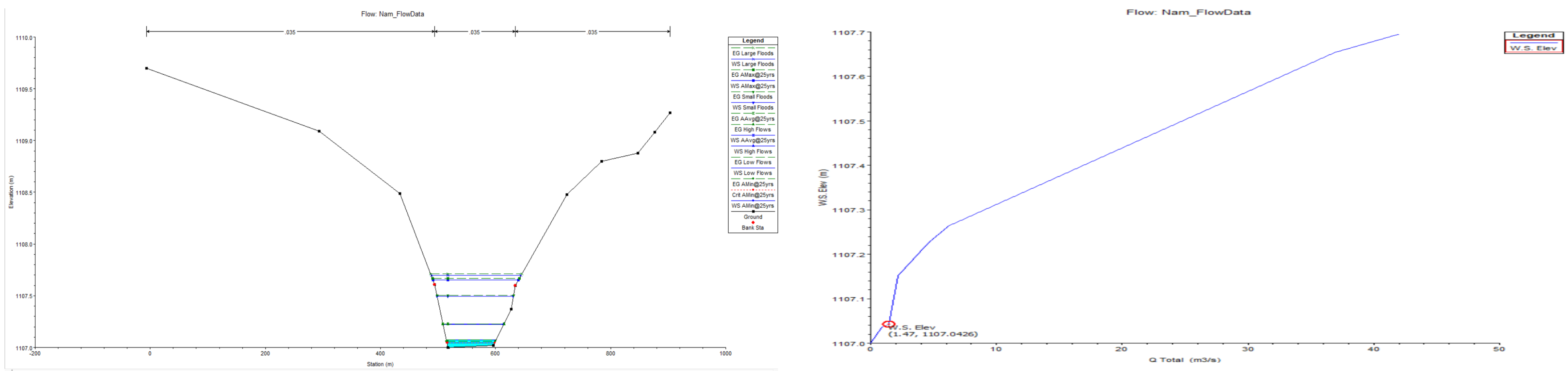
(f) RCP 8.5 Station ID – 34275 (36N 636876.04 E, 124088.31 N)



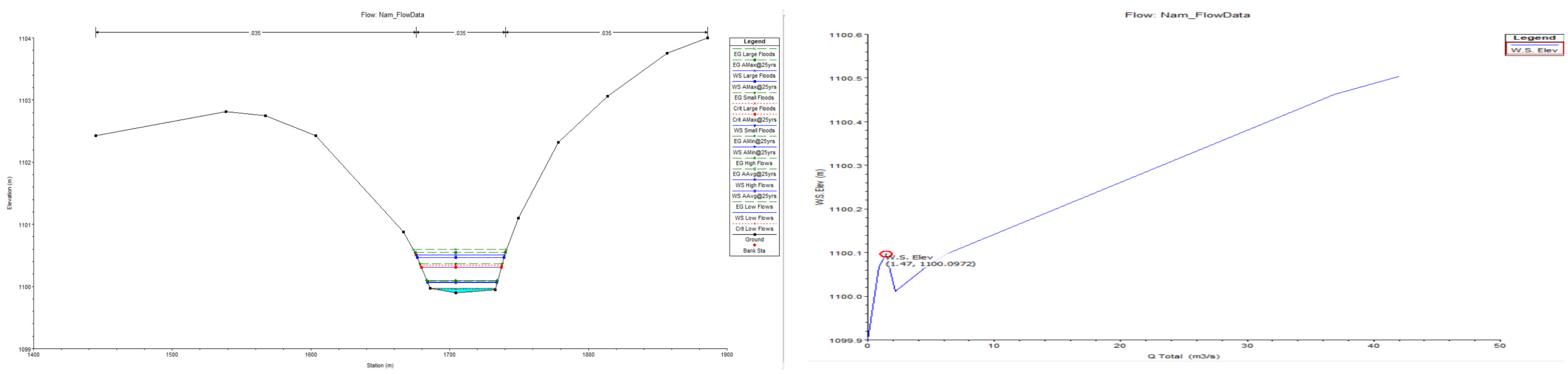
(g) RCP 8.5 Station ID – 29835 (36N 634234.92 E, 124021.39 N)



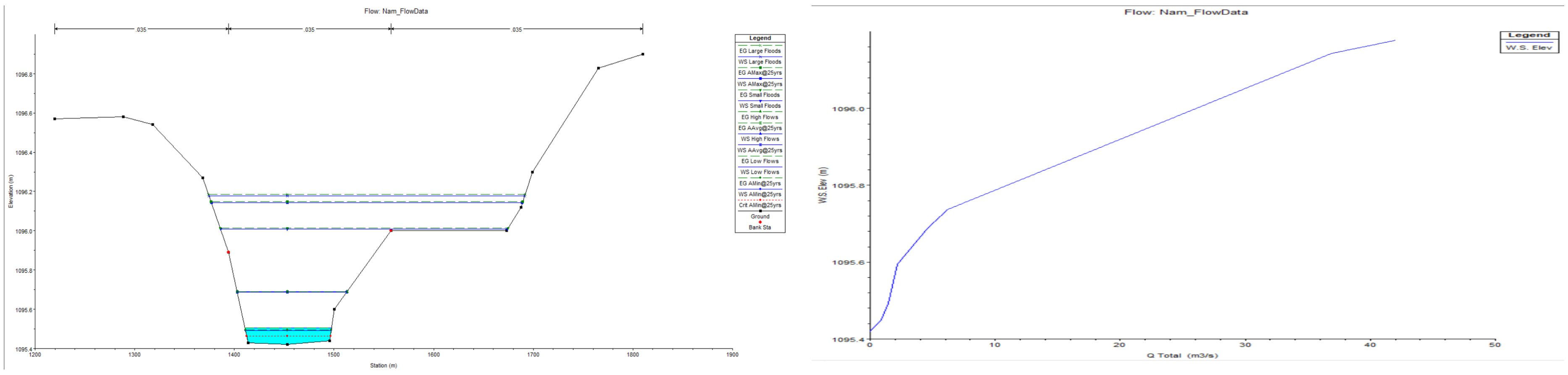
(h) RCP 8.5 Station ID – 25455 (36N 632026.48 E, 123136.75 N)



(i) RCP 8.5 Station ID – 20978 (36N 630561.03 E, 122667.26 N)



(j) RCP 8.5 Station ID – 16343 (36N 625156.17 E, 118822.99 N)



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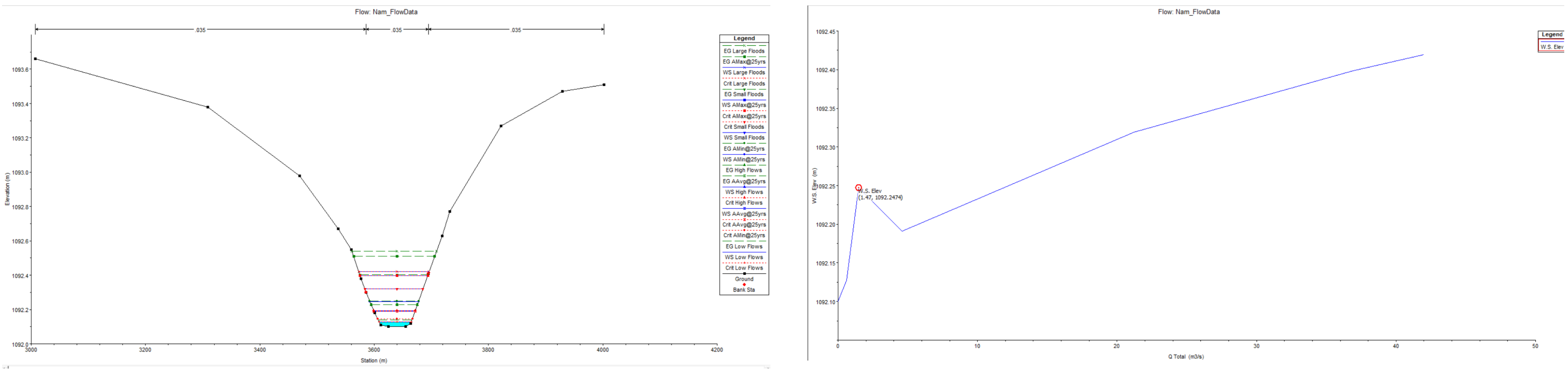
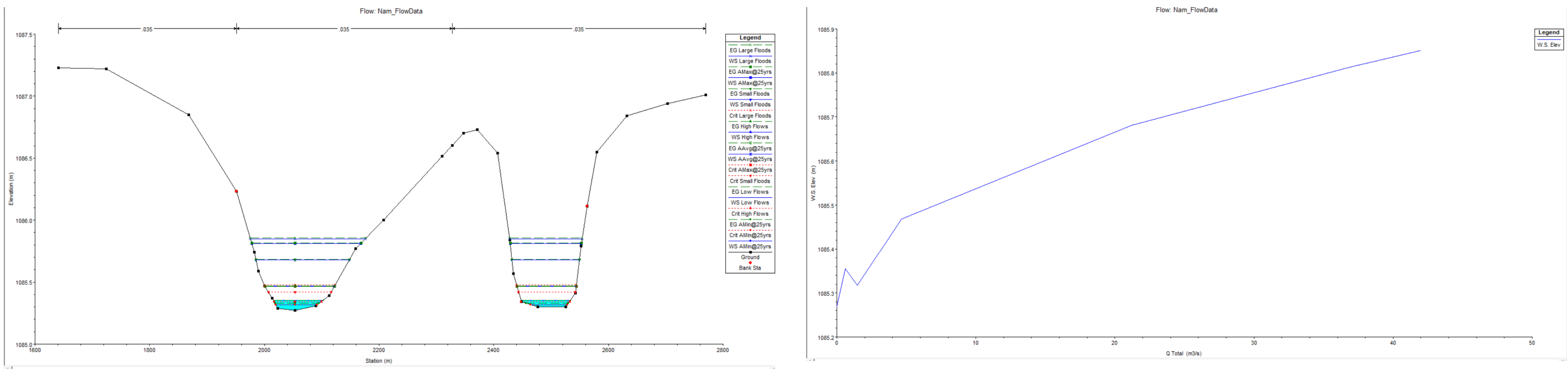


(l) RCP 8.5 Station ID – 8625 (36N 620322.57 E, 115118.97 N)



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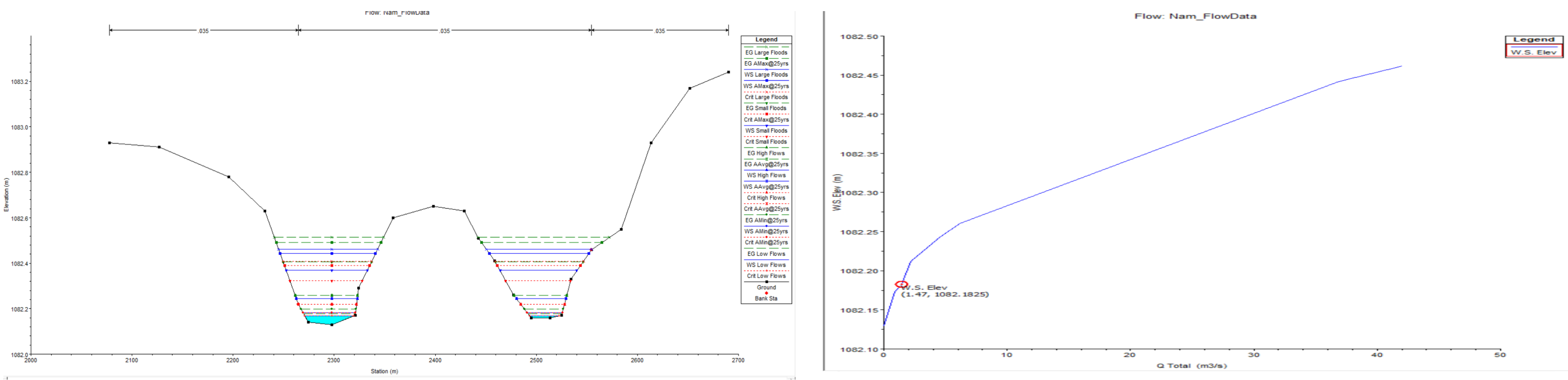

(n) RCP 8.5 Station ID – 491

Figure 7.5: Wetted perimeter Analysis for Selected sections on the river under RCP 8.5

Appendix H: Ecological Study

Appendix H-1: Vegetation and Flora of R. Namatala

The study area traversed in the upstream areas of the catchment from Sironko to Butaleja downstream. Built up areas, cropland (including maize, banana, coffee, Ground nuts, and sugarcane gardens), woodlots (including Eucalyptus spp, Pinus spp, and Grevilia robusta), and mixed woodlots of Eucalyptus, Pinus, Tectonia, Maesopsis eminii, Albizia spp, Milicia excelsa & Azadirachta indica) and patches of post-cultivated light bushland and grassland with scattered trees.

Table below gives a description of the vegetation type and major/dominant flora from all the three pipelines.

Table 7.2: Vegetation types and dominant species at the catchment

Catchment	Vegetation description	Dominant species
R. Namatala Catchment	✓ Subsistence farmland ✓ Post cultivated grassland with scattered trees ✓ Post cultivated light bushl and ✓ Woodlots	- Zea mays - Coffea spp - Musa sp - Albizia coriaria - Mangifera indica - Thevetia peruviana - Synedrella nodiflora - Saccharum officinarum - Psidium guajava - Persea amaricana - Maesopsis eminii - Manihot escelenta - Markhamia lutea - Cymbopogon nardus - Cynodon dactylon - Artocarpus heterophyllu sEucalyptus grandis - Grevilia robusta

(a) Figure 7.6(n) highlight the fact that except in a few sections covered by species of Cyperus, the natural vegetation cover in general landscape is already very much simplified in some cases into mono-cultures such as rice growing.

Zea mays and ground nuts garden with scattered Albizia-Mangifera (N1.11437, E34.22278)

Post cultivated mixed light bushland in between gardens (N1.09439, E34.20867)

Zea mays garden at geographical (N1.10399, E34.21481)

Eucalyptus woodlot

Cyperus dives in Doho wetland

Eucalyptus woodlots, Musa sp gardens and Zea mays gardens

Eucalyptus-Grevilia woodlot, Banana plantation with scattered tress of Milicia excelsa, Ficus natalensis; Zea mays and Ground nuts gardens (N1.06215, E34.21148)

Open grassland with scattered trees of Mangifera indica

Cyperus papyrus swamp along Namatala - Doho Wetland.

Oryza sativa at Doho irrigation scheme

Oryza sativa, zea mays gardens and Eucalyptus woodlot

Banana plantation

Mixed Casuarina- pinus woodlot

Figure 7.6: Flora in R. Namatala catchment

Species Richness: The surveyed areas yielded a total of 149 plant species in 120 genera and 40 families in the sampled areas altogether of which 44 species were trees and 31 shrubs. Figure 7.7 plots the species richness by growth form and appendix 1 presents the full list of all plants encountered. While shrubs and trees encountered formed the woody biomass in the study area, they are found scattered in extensive crop land.

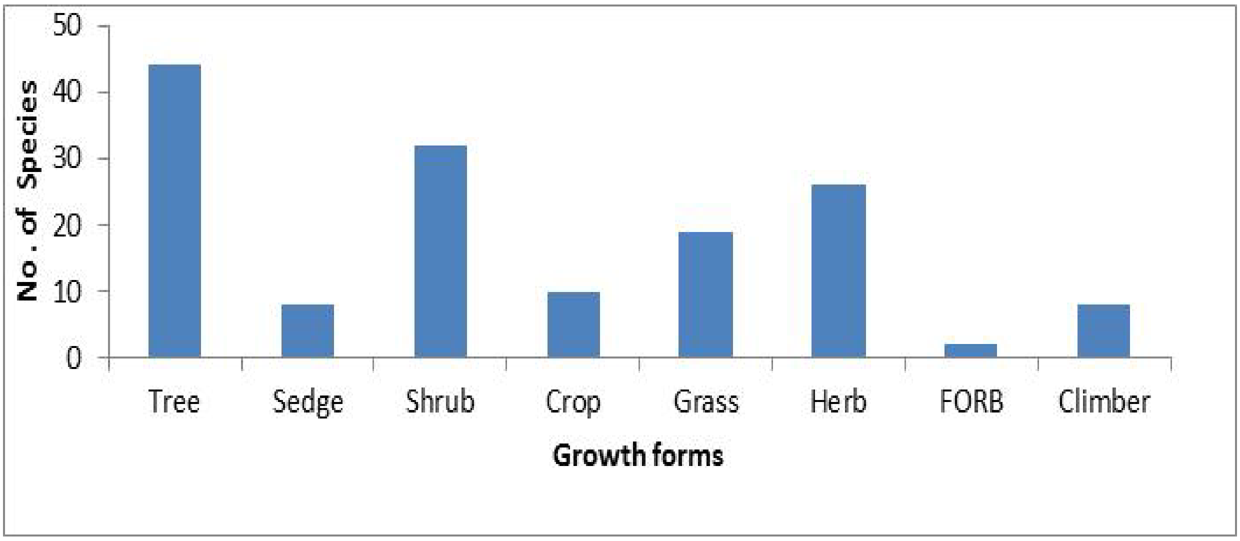

Figure 7.7: Distribution of the recorded plant species in the different growth forms

Based on the findings, vegetation around the catchment obtained water from different sources including; ground water and surface water (as they tend towards water systems). The catchment is well endowered with water resources during the rainy season and lack enough water resources away from the water system. This creates a dependency on the rains in the catchment. The findings concluded that Flora and Fauna growing along the water systems of R. Namatala catchment are dependent of the season and the existing water flows. Where the water is low, they will adapt to these changes by temporarily drying, shedding leaves etc. Therefore, the water requirement for flora in the catchment along the river is dependent on the flows in the rivers either high or low flows.

Appendix H-2: Herpertiles Study along R. Namatala

A number of Herpertiles were observed in the study area from upstream areas to downstream. The catchment traverses through grasslands, forested areas, Wetland system and Built up areas with pertinent biodiversity concerns with signs of thriving life downstream towards the Namatala Doho Wetland system (Figure 7.8).

Figure 7.8: A dead forest water cobra in the catchment

A total of sixteen species of Herpertiles were identified; the majority were recommended for the IUCN Red List of Threatened Species Status as Least Concern. (Table 7.3).

Table 7.3: Amphibians fauna of along R. Namatala

Species	Common Name	IUCN Status
Amientia angolensis	Angola River Frog	Least Concern (LC)
Ptychadena mascareniensis	Mascarean frog	Least Concern (LC)
Phrynobatrachus natalensis	Natal puddle frog	Least Concern (LC)
Xenopus victorianus	Victoria clawed frog	Least Concern (LC)
Hyperolius kivuensis	Kivu reed frog	Least Concern (LC)
Hyperolius viridiflavus	Common reed frog	Least Concern (LC)
Hyperolius nasutus	Sharp nosed reed frog	Least Concern (LC)
Amietophrynus maculatus	Flat backed toad	Least Concern (LC)
Haplobatrachus occipitalis	Common bull-frog	Least Concern (LC)
Amietophrynus regularis	Common toad	Least Concern (LC)
Mabuya striata	Striped Skink	Not Evaluated
Naja melanoleuca	Forest water cobra	Least Concern (LC)
Psammophis mossambicus	Olive sand snake	Least Concern (LC)
Acanthocercus atricolis	Blue headed Agama	Least Concern (LC)
Mabuya maculilabris	Speckled skink	Least Concern (LC)
Hemidactylus brooki	Brook’s gecko	Least Concern (LC)

Appendix H-3: Mammals Study along R. Namatala

In the R. Namatala Catchment, six different species of mammals have been identified (Table 7.4). On the IUCN Red List of Threatened Species, six of the encountered species are classified as Least Concern (LC) (Version 2015.2). Yet, as the animals observed or observed to emerge around the communities are only vagrants from the Wanale Mountain woods, passing through the towns at night, there are no conservation concerns raised by this. As the study's purview does not extend to these creatures' crucial habitats, no impact will result from it.

Table 7.4: Mammal species recorded in the project area and their conservation status

Common Name	Scientific Name	Conservation Status
Side Striped Squirrel	Euxerus erythropus	LC
African Grass Rat	Arvicanthis niloticus	LC
Striped Grass Mouse	Lemniscomys striatus	LC
Savanna-hare	Lepus victoriae	LC
Common Jackal	Canis aureus	LC
Banded Mangoose	Mungos mungo	LC

The mainly wooded area is probably where the wild creatures that have been recorded in the settlements originate from. Another noteworthy habitat feature in the basin is the River Namatala. Figure 7.9 and Figure 7.10 illustrates the kind of plant cover present at certain watershed locations. Natural plant cover has been completely removed to make way for farms or settlements. There aren't many, if any, big to medium-sized animal populations in these types of places. The search regions will still support small animals, but species that are specific about their habitat forest interior and/or intact wetland specialists, for example will also be lost and relocated.

Figure 7.9: Section of the Wanale Mountain

Figure 7.10: Cultivated rice field in Doho

Appendix H-4: Birds Study along R. Namatala

A summary of the bird species richness and habitat preference of the birds recorded from the different survey points is presented in Table 7.5. Over all species that are dependent on availability of some tree stand (f – forest visitors) were the most numerous in most survey areas. There was a near absence of forest specialist species (FF) except for one species. Wetland species were also widely occurring although the numbers of species encountered were generally lower than those of the forest visitors.

The Grey Crowned Crane Balearica regulorum and the Hooded Vulture Necrosyrtes monachus were the two species that were designated as being internationally endangered. The Doho rice program is crucial for the Grey Crowned Crane's ability to reproduce (Gumonye Mafabi, 1989). Nevertheless, there is no information available regarding Hooded Vulture breeding in the nation. The abundance of native trees in the farmed regions, particularly those near Mount Elgon, may be the reason for the high representation of forest species, including one forest generalist. There were many different types of wetlands, particularly in the vicinity of Butaleja and Doho.

Aerial feeders such as, Palm swifts, little swifts and Angola swallows where numerous throughout the study sites. Generally, number of Afro tropical species was higher than that of Palearctic species since the later are expected to return around September. Forest visitors and Grassland specialist where well represented, this could be due to too much rain in the area which impacted on the nature of vegetation and birds too.

Table 7.5:Number of bird species for each transect site in the categories shown

Sites		Downstream of R. Namatala Catchment			Mid-stream of R. Namatala Catchment				Upstream of R. Namatala Catchment		
		Doho	Budaka	Butaleja	Mooni	Bungukho	Kifuluriro	Makhosi	Buwaki	Kama-Lower	Namatale CFR
Habitat Specialist	FF Forest specialist							1			
	F Forest generalist		3	1	4	1	2	1	1	1	2
	f Forest Visitor	7	11	12	16	7	14	12	7	13	15
	W Wetland specialist	18	1	1	13	10		2	2	1	3
	w Wetland associate	9	3	6	13	13	8	2	4	6	8
	G Grassland specialist	4	2	4	3	3	2	1	2	1	3
	Ae Aerial feeder	1	1	2	4	3	1	1	2	3	3
Migrant	P Palearctic	2	1	1	2	1	1	1			
	A Afrotropical	3	1	1	5	4	2	1		1	1
Conservation status	G-EN Globally endangered	1		1							
	R-Vu Regionally Vulnerable	2			1	4					2
	R-NT Regionally Near threatened	4		1	1	1	1	1			2
	R-RR Regional Responsibility	1	2	2	4	2	1	1	2	3	

Appendix H-5: Aquatic Study of R. Namatala

Fish species occurring in River Namatala documented in survey were Oreochromis niloticus, Mormyrus spp, Protopterus annectens and Clarias spp. The fish is especially abundant in the rainy seasons when the river banks flood. None of the fish species identified in the area were identified as rare or endangered. It is however very important to note that the fish diversity of River Namatala is very low with majority of the fish located as the river tends towards the Namatala – Doho Wetland system.

From the local knowledge survey and interaction with the local authorities, they confirmed that fisheries activities are almost non-existent in the downstream project area part of the river. They are faced with over fishing with mormyus ssp fished in its in-fact stages under 6 months of development.

Oreochromis niloticus and Clarias spp

Clarias spp

Protopterus annectens

Figure 7.11: Fish species in the catchment

Tennant, (1976) noted that to cater for aquatic system functioning, a 10% of MAF was considered. Given that the catchment. This was done as a way of low lows of 10% of the average flow left in the river to cater for spawning and upstream movement of fish. However, based on the R. Namatala catchment, there is no fish found upstream and mid-stream of the catchment given the speed of water, low water depth, presence of boulders in flow and the temperature ranging between 18 ^{0}c to 19.5 ^{0}c which factors don't favour fish presence (C. Zhao et al., 2018). On top of these factors, the flows in R. Namatala increase as you tend towards Namatala – Doko Water system. Hence from this, a 5% of Hydraulic E-flow (**0.0518 m^3/s**) was taken to cater for the aquatic water requirement. This requirement shall be added to the hydraulic E-flow in the Holistic approach.