IEc

The Contribution of Water Resources Development and Environmental Management to Uganda's Economy

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ACRONYMS

ASM	Artisanal and Small-scale Mining
CES	Constant Elasticity of Substitution
CGE	Computable General Equilibrium
CPI	Consumer Price Index
DO	Dissolved Oxygen
EAPP	Eastern African Power Pool
FAO	Food and Agriculture Organization of the United
GDP	Gross Domestic Product
GIS	Geographic Information System
IEc	Industrial Economics, Incorporated
IFPRI	the International Food Policy Research Institute
IPSS	Infrastructure Planning and Support System
KWh	Kilowatt-hours
LES	Linear-Expenditure-System
M&I	Municipal and Industrial
MFPED	Ministry of Finance, Planning and Economic
MIT	Massachusetts Institute of Technology
MWE	Ministry of Water and Environment
NBI	Nile Basin Initiative
NDP	National Development Plan
NDP II	National Development Plan II
NWRA	National Water Resources Assessment
NWSC	National Water and Sewerage Corporation
O&M	Operations and Management
RI	Return Interval
SACRED	Systematic Analysis of Climate Resilient
SAM	Social Accounting Matrix
SHP	Small Hydropower Plant
SSIP	Strategic Sector Investment Plan
SUT	Supply Use Table
SWAT	Soil Water Assessment Tool
TLU	Total Livestock Units
TOR	Terms of Reference
USLE	Universal Soil Loss Equation
WIDER	World Institute for Development Economic
WMZ	Water Management Zone

GLOSSARY OF ECONOMIC TERMS

Consumer surplus: A measure of the benefit to the consumer, net of the price or other welfare cost incurred in obtaining a good, from being able to buy a commodity or service at a particular price.

Economic value: The ability of an asset to produce income, including non-market income, in the future.

Ecosystem services: The benefits people obtain from ecosystems, including: provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services, such as nutrient cycling, that maintain the conditions for life on Earth.

Elasticity: A measure of the percentage change in one variable with respect to the percentage change in another variable, e.g. the percent change in quantity due to a percent change in price.

Environmental goods and services: Products that are produced for the purpose of preventing, reducing, and eliminating pollution and any other degradation of the environment and preserving and maintaining the stock of natural resources and hence safeguarding against depletion.

Factors of production: The resources of society used in the process of production. These are usually divided into the three main groups - Land, Labor, and Capital - but may also include Entrepreneurship.

Foreign exchange earnings: Proceeds from the export of goods and services of a country, and the returns from its foreign investments, denominated in convertible currencies.

Hedonic pricing: A pricing model based on the premise that the price of a marketed good is related to its characteristics or services it provides, allowing these characteristics or services to be valued using the price consumers are willing to pay for the associated marketed good.

Impact channel: A pathway by which natural resources are transformed into market goods and services.

Inclusive wealth accounting system: A method that assigns value to natural resources without requiring their extraction.

Intermediate goods: Goods which are used at some point in the production process of other goods, rather than final consumption.

Linear-Expenditure-System demand functions: System in which demand functions are expressed for groups of goods rather than for individual goods. Substitutability within the group is significant but is zero between the groups. The demand functions for the groups may then be added to estimate a total expenditure function.

Macroeconomic equilibrium: A national economic state in which aggregate demand is met by aggregate supply.

Market price: The unique price at which buyers and sellers agree to trade in an open market at a particular time.

National accounts framework: A system for measuring macroeconomic categories of production and purchase in a nation in order to facilitate analysis and/or policymaking.

Non-market value: Economic value placed on a good or service that is not traded in markets and therefore does not have an observable monetary value.

Opportunity cost: The value of alternative actions foregone by choosing a particular action.

Producer surplus: A surplus accruing to the owners of factors of production owing to receiving something which has greater direct or indirect utility than the utility of what is used or given up in the production activity.

Revealed preference method: A technique which infers value based on observed consumer actions and choices.

Shadow prices: An imputed valuation of a commodity or service which has no market price, representing the planned opportunity cost of producing or consuming a commodity which is generally not traded in the economy.

Social Accounting Matrix (SAM): A representation of all transactions and transfers between different production activities, factors of production, and institutions (households, corporate sector, and government) within the economy and with respect to the rest of the world.

Social discount rate: The interest rate used to discount collective or public investments.

Stated preference method: A technique which uses individual respondents' statements about preferences and willingness to pay to estimate economic value.

Travel cost model: A valuation method based on the premise that the time and cost required to visit a site represent the "price" of access to the site and can be used to estimate consumers' willingness to pay to visit the site.

Utility maximization: A consumer's attempt to obtain the greatest value possible from the least expenditure of money.

Water and environment inclusive GDP: A measure of national production that includes additional goods and services usually unaccounted for in GDP calculations, such as resources gathered directly from the source and not traded in market.

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ABSTRACT

Most sectors of the Ugandan economy rely on environmental quality and the stock of natural resources goods and services for enhancing their productivity, providing the necessary raw materials, and reducing the cost of public expenditure for providing the services in those sectors. The objective of this assignment is to assess the economic value of water and environmental goods and services – and the costs of degradation and insufficient action in the sector – to assist the Ministry of Water and Environment (MWE) in establishing and clearly articulating the value of their management services. This assessment seeks to value these goods and services through a series of impact channels which trace raw resources such as arable land, water (as runoff and lakes), and wetlands and forest from their sources, through MWE management, and into the economy. Biophysical models are used to estimate the interaction of natural systems and MWE intervention. The results of these models are then fed into an economy wide model to estimate a variety of economic indicators related to the specified management regime.

A key finding of this analysis is that without proper investment in environmental and water management, projected GDP and employment in Uganda could suffer significantly. The focus of Uganda's national strategy is on achieving structural transformation through increased industrial activity, with a focus on manufacturing, including value-addition in agro-processing. Meeting Uganda's economic 2040 growth targets will require a tripling of reliable water deliveries relative to today's levels, which will require heavy investment in environmental management and water resources. As Uganda seeks to industrialize to meet national development goals, water management will be critical to ensure steady growth of the manufacturing, agricultural, and service sectors.

The study provides ample evidence of the value of MWE investments in water resources development and environmental management. All sectors of the economy benefit substantially from the MWE investments. Overall, GDP gains from MWE interventions are more than eight times investment costs for the incremental change from a business as usual to a full MWE investment scenario. Further, this GDP growth benefits households substantially as incomes and consumption increase over time, which leads to alleviation of poverty.

EXECUTIVE SUMMARY

INTRODUCTION

The importance of water and environmental resources is generally accepted; however the value of that importance in economic terms is not. Uganda's economy is largely dependent on its stock of environmental and natural resources. Most sectors of the economy – including agriculture, which is Uganda's mainstay – rely on environmental and natural resource goods and services to enhance their productivity, provide the necessary raw materials, and reduce the cost of public expenditure for providing the services in those sectors. A rapidly growing population poses an increasing challenge to environmental and natural resources management, calling for greater efforts to ensure that these resources are sustainably managed for present and future generations. To this end, it is important for the Ministry of Water and Environment (MWE) to establish and clearly articulate the contribution of the water and environment sector to economic growth and development. The objective of this assignment is to assess the economic value of water and environmental goods and services – and the costs of degradation and insufficient management action. The assessment will encompass both the value of water and the environment as resources to Uganda's economy, as well as the specific contribution provided by MWE management. This will increase the appreciation for the need to soundly manage and develop these resources for future economic growth, and during budget requests, provide justification for maintaining or increasing investment in the sector to the Ministry of Finance, Planning and Economic Development (MFPED).

OBJECTIVES

The specific objectives of the project are to:

i) determine the economic value of environmental goods and services and the economic costs of environmental degradation in terms of a range of economic indicators (e.g., GDP, employment, livelihoods, foreign exchange earnings), as well as distributional implications using the same indicators;

ii) estimate the economic costs of poor water resources management and development and the potential economic benefits that would arise from improvements in some of the key sectors of the Uganda economy;

iii) determine the economic costs of extreme events (floods and droughts) historically and in the future, considering the impacts of climate change;

iv) provide recommendations of further studies and work needed to fill existing gaps so as to strengthen the case for increased investment in the sector; and

v) build capacity for economic analysis by conducting training sessions with MWE counterpart staff on the tools and techniques employed.

A secondary objective of the study is to broadly outline measures and interventions that may be undertaken to reverse environmental degradation and poor development and management of water resources. However, identifying specific interventions and undertaking detailed project-level economics is beyond the scope of the study.

This report details an assessment answering the valuation objectives outlined above (i, ii, and iii), and provides recommendations for future work (objective iv) based on the findings and limitations of the current study and its available input data. This report also makes substantial progress toward the secondary objective, broadly outlining measures in some key sectors to reverse environmental degradation, such as deforestation and its effects on flood damages as well as forest economics.

SCOPE OF STUDY

In order to address these objectives, it is important to first describe how the terms above are defined for the purposes of this study. In this analysis, the environment is considered land and water, as these are the primary resources affected by MWE management actions. Degradation of these resources includes any waterbody, forest, or wetland degradations that lead to increased sedimentation, reduced water quality, more variable river flows, and a host of other biophysical effects.

Ecosystem services, including water and environmental resources, can be valued in a variety of ways, both as parts of the economy and outside the traditional economy. First, the value of water and environmental goods can be quantified by their direct or indirect contribution to the economy as measured by Gross Domestic Product (GDP) and other macroeconomic measures (e.g., employment), as is done in this assessment. The second approach builds on the first approach by adding the value of goods and services not traded in the market (e.g. fuelwood collected from the forest) and thus not detectable in traditional GDP measures. The third category of value is non-market values, where natural resources are given a value based on their existence, or in terms of a willingness-to-pay (such as to avoid the pain and suffering of poor health), and which would not appear in a GDP account.[1] This assessment focuses primarily on the first approach, as it is the most widely accepted across disciplines, with some incomplete incorporation of the second approach. The second and third approaches are also used in a qualitative manner to provide estimates of the magnitude of benefits outside the national accounts framework.

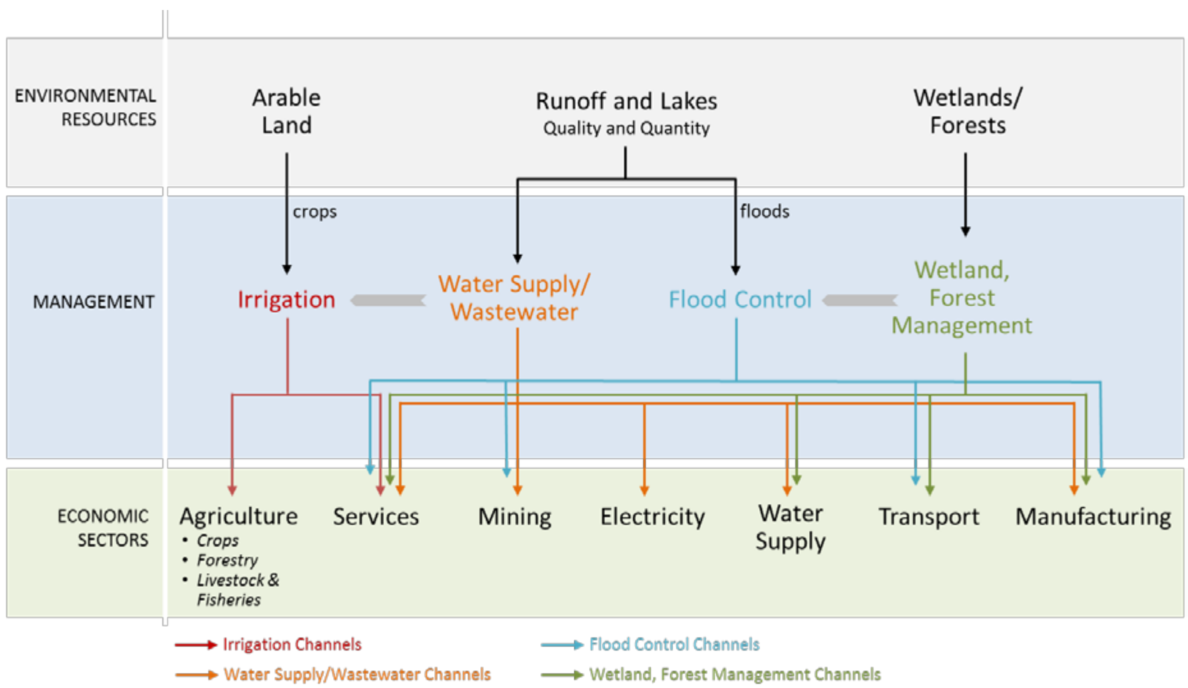
OVERVIEW OF APPROACH

This report addresses the objectives of this study by estimating the contribution of water resources development and environmental management to the economy. The study

[1] A fourth category is the value of a stocks, rather than flows, of goods using an inclusive wealth approach. This approach assigns value to natural resource stocks, effectively allowing valuation without extraction.

employs the framework illustrated in Figure ES-1, which shows the relationship between environmental resources, management actions, and sectors of the economy. Arable land, water (as runoff and lakes), and wetlands and forest are environmental resources that are partly or wholly under the management of MWE. Management actions—primarily investments and regulations—convert these raw environmental resources into intermediate goods, which are then input into the economy for commodity production across a number of sectors. This report refers to these pathways from environment to the economy as channels of impact. In Figure ES-1, simplified versions of these channels as modeled in this analysis are depicted by the arrows linking particular environmental resources to management actions, and then arrows linking management actions to their primary receiving economic sectors. For example, arable land (environmental resource) can be managed through provision of irrigation water (MWE management action), which then improves crop yield and yield reliability, and thus GDP from agriculture (economic sector).

FIGURE ES-1 GENERAL FRAMEWORK FOR MODELING



This assessment follows each of these channels, from environmental resource to economic sector, based on a suite of management actions to value natural resources and sound environmental management in terms of contribution to GDP and other economic indicators. To estimate these economic outcomes, the study analyzes a set of investment scenarios that define stratified sets of management inputs resulting in sets of physical outcomes (as modeled as part of this analysis). These physical outcomes are then transformed to effects on factors of production and used to run an economy wide model of Uganda.

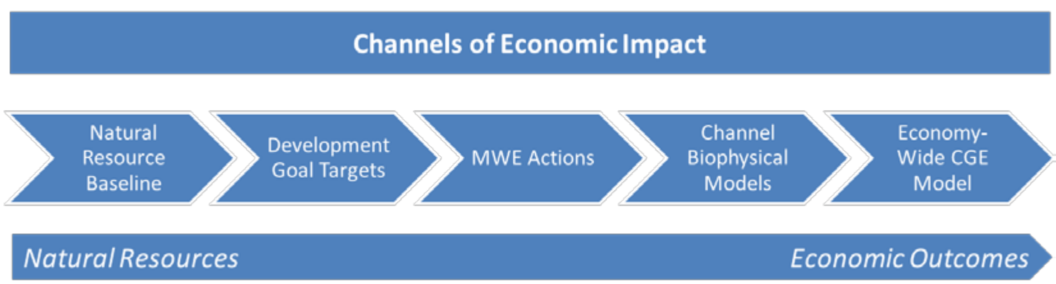
METHODOLOGIES

An economic study of this sort requires comparisons between alternative future states of the world – where economic indicators such as GDP, employment, consumer and producer economic welfare, and net present value of infrastructure benefits are estimated for multiple scenarios that reflect alternative levels of investment and water and environmental management success. The difference between the indicators estimated in each scenario provides one of the key intended outputs of the analysis – the economic value of water and environment management to Uganda's economy. The general methodology employed in this analysis is described below.

ANALYTICAL FRAMEWORK

In order to properly assess both the total economic contribution and the distributional effects of current water and environmental management and potential interventions, this analysis employs a national macro-model, a computable general equilibrium (CGE) model of Uganda's economy. Biophysical models are used to produce impact metrics related to specific management scenarios, which then enter the economic model through their effect on land, labor, and capital productivity. The pathways from natural resources to economic outcomes are referred to as channels of economic impact. For example, a decrease in crop yield due to insufficient irrigation investment would decrease the productivity of land, requiring additional land, labor, or capital to produce the same amount of GDP. Running the general equilibrium modeling framework allows us to report outcomes in terms of GDP, foreign exchange earnings, and other metrics, while also reporting sector level outcomes.

FIGURE ES-2 ANALYTICAL FRAMEWORK



SCENARIOS AND UNCERTAINTIES

When forecasting to the future, modeling of biophysical and economic conditions in the country is critical for successful implementation of the study. In order to capture the broadest possible range of future conditions, it is necessary to consider climate change and other uncertainties that have a potentially pronounced effect on estimation of national and regional economic outcomes, such as land use change, social discount rate, population growth, and economic growth.

By running the models under different management and investment scenarios, the analysis is able to assess the differences in economic indicators between scenarios, and attribute those differences to changes in management. The management scenarios used in this analysis are derived from the National Development Plan II (2015-2020) and Vision 2040 goals. Management and investment scenarios are defined as:

- **Business-as-usual growth (BAU).** Investment across sectors continues to match historical rates out to 2040.
- **Moderate Investment.** Represented by either reaching to 2020 goals by 2040, or reaching 50 percent of 2020 goals by 2020, where investment across sectors continues increasing at the rate necessary to reach 50 percent of 2020 goals by 2020 out to 2040. The specific definition varies by investment depending on the slope of each moderate investment scenario alternative in relation to BAU and high investment.
- **High Investment**: Represented as 100 percent achievement of 2040 goals by 2040. Investment between 2015 and 2020 is consistent with 100 percent to 2020 goals by 2020 investment.

The 2020 and 2040 targets included in the National Development Plan and Vision 2040 reflect goals for an array of indicators including achieving a competitive economy, gaining increased employment and wealth, and improving the level of skilled human capital. Several of the objectives and development indicators are directly or indirectly tied to water and environmental management within Uganda's economy.

BIOPHYSICAL MODELS

The impacts of these investment scenarios on intermediate good production are estimated using biophysical models that translate the data inputs and uncertainties into the physical state of Uganda's water resources and environmental goods and services. Modeling scenarios produce inputs that feed into each of the biophysical modeling components. The runoff, land use, and erosion models are a key component of the modeling system and provide inputs to the flooding and water systems and quality models which relate land management policies to water quality outcomes. The water systems model returns information on water availability and hydropower generation. The crop production and irrigation model generates irrigation water demands that interact with the water resource systems model and information on water availability to estimate irrigated crop yields.

CHANNELS OF ECONOMIC IMPACT

Impact channels are used to describe the pathway from natural resources to market goods (see Thurlow 2008). These pathways show the transition from raw natural products to economic goods, through biophysical and economic modeling under defined management and investment scenarios. The direct effect on economic outcomes is measured through metrics such as GDP and employment. The analysis herein organizes the impacts through ten channels that reflect two broad classes of MWE intervention: water resources development and environmental management. Each channel listed below in Table ES-1 has one or more corresponding interventions that impact the pathway from environmental or water resource to the ultimate economic activity.

TABLE ES-1 CHANNELS OF ECONOMIC IMPACT

WATER RESOURCES DEVELOPMENT CHANNELS	ENVIRONMENTAL MANAGEMENT CHANNELS
CROP PRODUCTION	**FLOOD DAMAGES TO INFRASTRUCTURE**
MWE investments in irrigation infrastructure and reservoirs affect the quantity and reliability of water supply for crop growing. Shocks to irrigated and rainfed crop yields, along with infrastructure costs, are inputs to the CGE.	Sound catchment management practices can mitigate flood risk, thus reducing the average maintenance costs of infrastructure. This affects depreciation rates for roads, bridges, houses, manufacturing, and trade.
LIVESTOCK PRODUCTION	**TIMBER PRODUCTION**
Livestock are more productive when supplied with reliable clean water. This channel examines the impact on livestock production of expanding water supply infrastructure for livestock.	By protecting and expanding forest cover, MWE can promote growth in the timber sector. This analysis estimates the impact of additional hectares available for timber plantations on output in the timber sector.
WATER AVAILABLE FOR INDUSTRY AND SERVICES	**FUELWOOD: HEALTH AND TIME USE**
The industry and service sectors in Uganda require a reliable and adequate water supply. Industrial demands are forecast based on expected GDP growth and entered into the CGE along with any unmet demands predicted due to natural availability or underinvestment. The CGE then allocates available water among the various subsectors of the economy.	To meet national targets for forest cover, MWE needs to enforce forest protection, including encroachment for firewood collection. This analysis models the health, employment, and educational impacts of households switching away from fuelwood as the primary cooking fuel to make reforestation goals possible.
WATER SUPPLY AND SANITATION: HEALTH AND TIME USE	**WATER QUALITY**
A review of previous literature allows us to assign a time series of effects on labor productivity due to changes in health outcomes and educational attainment attributable to access to improved water supply and sanitation. The effects are the result of reduced incidences of diarrheal disease and increased time available for labor outside the home, and education. These labor effects are entered into the CGE along with the costs of urban and rural household water supply.	Fish yields increase under improved lake water quality. Catchment management interventions can reduce pollutant loadings and increase fish yields in Uganda's lakes. The changes in fisheries yields are inputs to the CGE.
HYDROPOWER GENERATION	**ECOSYSTEM PROTECTION**
Mike Hydro, a water resource decision support tool, is used to estimate hydropower production, given available river flow and infrastructure investment. The ability of the plants to meet their full generation potential is dependent on MWE river management. Enhanced hydropower production (a portion of the total production, attributable to water management) is an input to the CGE.	An important component of the Ugandan economy is tourism, and of that component, eco-tourism plays a particularly important part. This channel demonstrates the impact of forest and wetlands management on economic outcomes through the growth of water based recreation and tourism.

ECONOMY-WIDE MODEL

The above channels describe the translation of raw natural goods and services to intermediate goods that affect factors of productivity that drive the CGE model. The Uganda CGE model follows the disaggregation of a Social Accounting Matrix (SAM), and was written as a set of simultaneous equations. The model captures production and consumption behavior through non-linear, first-order optimality conditions of profit and utility maximization. The equations also include a set of "system constraints" that define macroeconomic equilibria (balances for savings-investment, the government, and current-account of the rest of the world) and equilibrium in markets for factors and commodities. Each model solution provides a wide range of economic indicators (e.g., GDP; consumption and incomes for representative households; sectoral production and trade volumes; factor employment; commodity prices; and factor wages).

CHANNEL MODELING RESULTS

Prior to running the economy-wide model, channel models are created to estimate the intermediate outcomes of the investments in the ten channels of impact. The channels modeling represent the intermediate steps necessary to translate biophysical modeling results into inputs for the general equilibrium model, including both impacts on factors of productivity and cost estimates. The ten impact channels reviewed in this chapter are presented in two general groups of management actions: water resources development and environmental management.

INVESTMENT COSTS

Environmental management actions typically involve capital and annual investment costs to effect beneficial changes to water resource quantity and quality, and to environmental quality. Investment costs in this analysis are derived from MWE SSIP (MWE 2009) and other similar sources. The split in costs between water resources development and environmental management is fairly even (roughly $4.3 billion for water development, and $4 billion for environmental management for the high scenario over the full 26 year period). Costs between the moderate and high investment scenario vary in both magnitude and timing, as many investments in the high scenario occur in the first ten years.

In a traditional benefit-cost framework, costs could be compared reliably to quantified and monetized benefits to assess whether the investments are worthwhile. For several reasons, such a comparison is not appropriate here:

- The costs outlined here have multiple benefits.
- There are significant non-linearities in the nature of benefits.
- The main focus of this work is establishing a defensible linkage between MWE management and economic productivity. For some categories of benefits, monetization is only done through aggregated analysis of GDP and other measures in the CGE.

For these reasons, comparison of investment costs to investment returns (measured as changes in GDP) is done only at the aggregated, full national economy level.

WATER RESOURCES DEVELOPMENT BENEFITS

Estimated benefits of MWE water management and investment are outlined below.

- **Crop Production:** The main direct crop-related benefit of MWE investments in irrigation infrastructure is an expansion in irrigated crop area. Irrigated crops have higher yields and lower variability than rainfed crops. While increased irrigated area is important, the benefits of irrigation may be limited by the availability of water for irrigation. Unmet water demands in the irrigation sector, as estimated in the biophysical models therefore may depress yields relative to the potential yield.
- **Livestock Production:** Compared to BAU investment, production increases by 1.5 percent under moderate investment and 5 percent under high investment due to expanded water supply for livestock.
- **Water Available for Industry and Services:** The amount of water available for production increases about 4.4-fold in the BAU scenario from 2015 to 2040, and 4.6- and 5.1-fold increase for the moderate and high investment scenarios respectively due to difference in investment in MWE supply.
- **Water Supply and Sanitation—Health and Time Use:** The total cumulative health care cost savings across the 25 year period, under the moderate and high investment scenarios are $870 million and $1.0 billion over BAU, respectively.
- **Hydropower Generation:** Hydropower generation sees an annual increase of over 1000 GWh per year by 2040 in both the moderate and high investment scenarios due to enhanced management.

ENVIRONMENTAL MANAGEMENT BENEFITS

Estimated benefits of MWE's environmental management and investment are outlined below.

- **Flood Damages to Infrastructure:** In this analysis, damages are measured in terms of depreciation rates, where higher rates signify higher capital stock replacement costs. From an assumed base depreciation rate of 5 percent, by 2030-2040, housing sees the biggest impacts with rates increasing up to 8.5 percent under BAU and dropping to 3 percent in the high investment scenario.
- **Timber Production:** Under the BAU, timber production increases by 10 percent by 2040 relative to 2015 (assuming some growth in the timber sector despite general deforestation trends), but moderate investment yields an increase of 32 percent, and the high investment scenario shows an increase of 72 percent
- **Fuelwood—Health and Time Use:** The total health cost savings by reducing dependence on fuelwood is about $8 billion in total. Additional benefits to labor productivity will lead to increased productivity throughout the economy.
- **Water Quality:** Under BAU, fish production declines due to poor water quality. Relative to BAU, production in 2035 to 2040 is about 30 percent higher under moderate investment and about 50 percent higher on average under high investment.

- **Ecosystem Protection:** The impacts of land management on water based recreation are especially significant in the later years of the analysis although the impacts can also be seen in the first five years. The multiplier on the tourism industry is 18 percent higher 2035-2040 under high investment than BAU due to improved land management.

NON-MARKET WATER RESOURCES AND ENVIRONMENTAL MANAGEMENT BENEFITS

Two previous studies (Karanja et al. (2001) and Woodward and Wui (2001)) of the non-market value of wetlands in Uganda are used to estimate value of wetlands that, while not able to enter the CGE, is still an important consideration. Using the valuation estimates from both of the two sources mentioned above, the total ecosystem service value of all wetland services in 2020 are approximately $970 million to $1.11 billion annually in the moderate investment scenario (when 10% of Uganda's land is assumed to be wetlands), and $1.26 to $1.44 billion annually in the high investment case (13% wetlands). These estimates imply a marginal value of the high investment case, relative to the moderate investment case, of approximately $300 million annually. A broader literature, addressing non-market values globally, suggests that these values are reasonable and may in fact be conservative for some Ugandan contexts.

ECONOMY-WIDE MODELING RESULTS

The overarching conclusion from this work is that effective water and environmental management are critical to achieve Uganda's short- and long-term development goals. First, the importance of water as an input to the economy is presented, followed by a discussion of the economy-wide effects of investments in the ten channels of impact.

All sectors of the economy rely on water, whether as a direct or indirect input, or as energy generated through hydropower. Based on the results of a general case run of the CGE, the following key results emerge on the importance of water to the Ugandan economy:

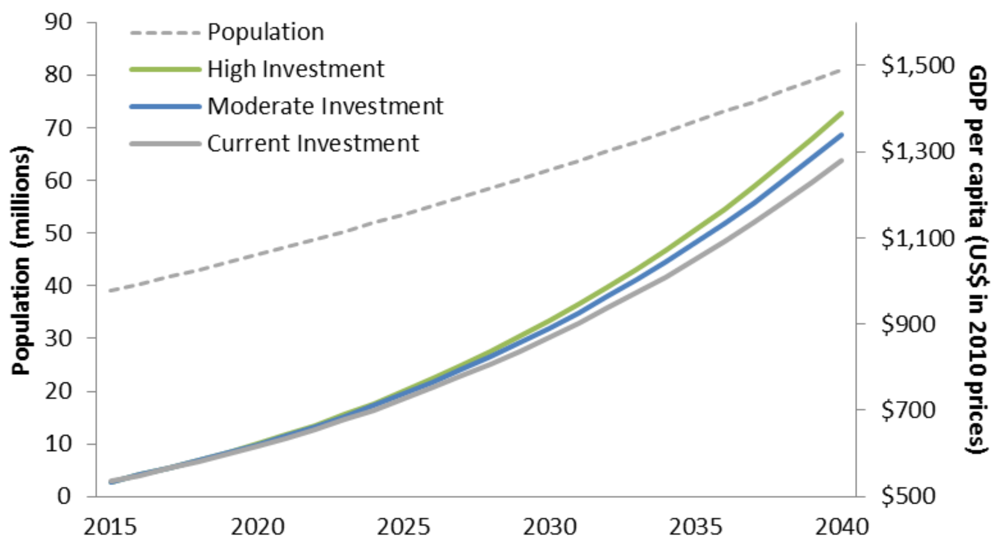
- The agriculture sector is, as expected, the main *direct* user of non-energy related water in the economy, while the most water intensive products are from manufacturing. As Uganda seeks to industrialize, water management will be critical to ensure steady growth of industrial sectors
- Manufacturing depends on electricity inputs more than any other sector of the economy, and electricity is produced primarily through hydropower generation.
- Achieving the social goals of improved education and public health also rely heavily on water-dependent electricity production.
- Meeting 2040 economic growth targets will require dramatic increases in the delivery of managed water.
- Without proper investments in water management and distribution, GDP could suffer significantly.

- Insufficient investment in water management will have much larger effects on specific water-dependent activities in the agricultural, manufacturing, and services sector

The main application of the CGE is to estimate the value of MWE management in terms of enhanced economic outcomes stemming from management decisions related to the ten channels of impact. This analysis yielded the following key results:

- MWE's proposed investments in water and environment yield significant economy wide impacts – by 2040, the beneficial effects of these investments result in a 8.7 percent difference between BAU and high investment scenarios, equivalent to $111 per capita annually, as illustrated in Figure ES-3.

FIGURE ES-3 GDP PER CAPITA GROWTH (2015-2040)



- These investments are very efficient, with benefits greatly exceeding investment costs. For both the moderate and high investment scenarios, the GDP returns alone are roughly 8 to 9 times the investment cost in undiscounted terms, and at least 3 to 4.5 times investment costs when benefits and costs are discounted at 10 percent. The results clearly show that the investments provide direct GDP benefits well in excess of their costs.
- The water development and environmental management components of the MWE investment plans are comparable in magnitude of both costs and impact on the economy, with the water supply and sanitation component of the water development investments having the greatest GDP impact, and the forestry and firewood replacement investments of the environmental management component having the greatest GDP impact among investments in that category. The Water Supply, Sanitation, and Hygiene (WASH) investments alone account for roughly 40 percent of the total economic benefits of MWE investments, as illustrated in Figure ES-4.

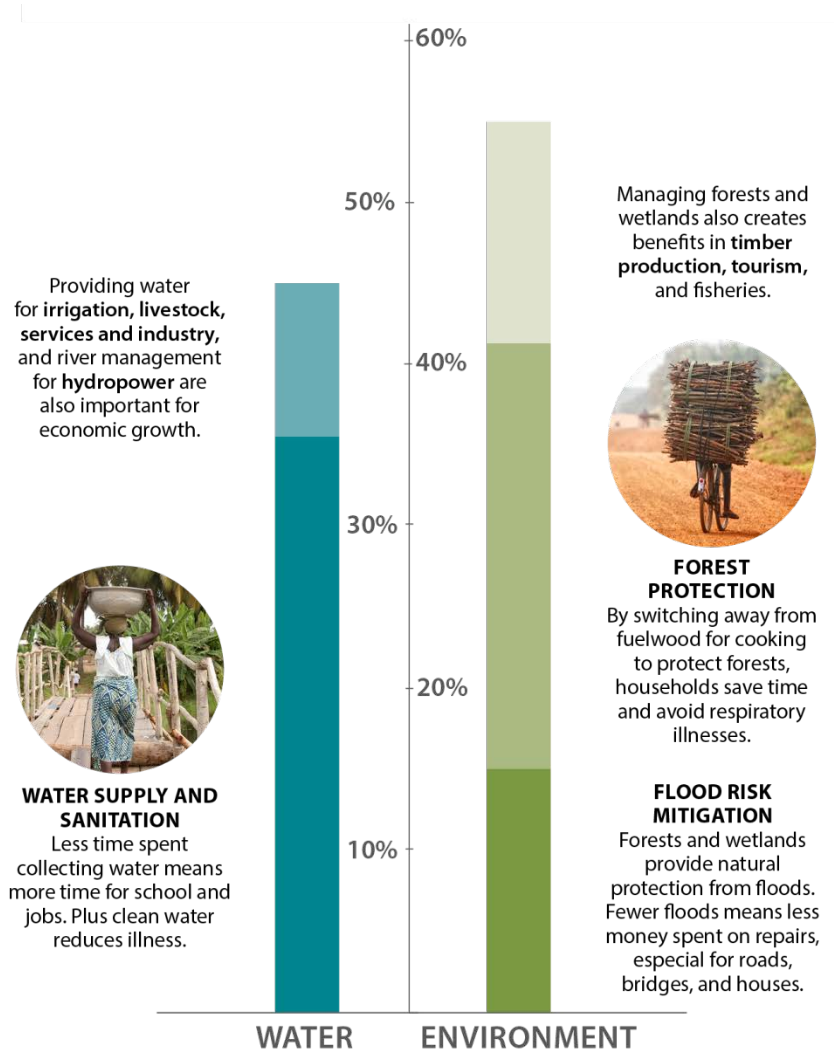
- GDP benefits include direct facilitation of economic activity through such actions as water provision and timber replanting, as well as indirect effects on capital protection through reduced flooding and on fishing through water filtration services of wetlands protection. Nonetheless, a very large component of the benefits is realized through enhanced health (and reduction in the need for government support of health care costs for waterborne or airborne exposures to pollutants), and for the "gathering time" savings that water and non-timber fuelwood provision provides for adults to participate more fully in the growing labor market, and children to enhance labor market skills through education. All of these factors are critically important to support the type of development and economic growth envisioned for Uganda in the Vision 2040 initiatives.
- Benefits measured by private consumption, instead of GDP, show that some of the investment channels (most notably, the water quality channel which improves fishing productivity) have a much higher impact on consumption as compared to the impact on GDP, suggesting that these would benefit low-income households to a greater degree than channels than investments in other channels. .

RECOMMENDATIONS

The analysis described in this report represents a major step forward for MWE as they seek to enable growth and development of Uganda's key industries – agriculture, forestry, and a new wave of manufacturing – while also playing a critical role in the development of human resources and long-term human capital by providing clean water and sanitation services. A key underpinning of the approach the analytic results is that the quality of the physical environment – embodied in water and land – represents a critical piece of the overall development strategy for Uganda. While the report provides a significant milestone, more work needs to be done to ensure that MWE fully capitalizes on its role as an economic growth facilitator in Uganda:

1. ***Update and revise MWE's Strategic Sector Investment Plan***. This study provides a new perspective on both the GDP and sector growth returns on MWE investments, and on the complementarity of investments across the economy, which ought to be considered in future SSIP updates.
2. ***Consider more carefully the specific regional allocation of investments***. The next SSIP should consider more specifically the optimal regional allocation of investment effort, while taking into account the comparative natural resource advantages of each region.
3. ***Fully reconcile MWE's investment plans with the plans of other Ministries***. Coordination with the Ministries of Finance, Energy, Agriculture, Trade and Industry, Disaster Preparedness, Transport, and Health is necessary to enhance the credibility and effectiveness of MWE's investment scenarios.

FIGURE ES-4 DISTRIBUTION OF GDP GAINS FROM MWE INVESTMENTS BY CHANNEL



4. ***Continue a series of active discussions with the Ministry of Finance*** regarding tools, data, and assumptions to characterize the economic performance of MWE-led investments.

5. ***Deliver on realizing the full potential of MWE's investments***. Most importantly, begin efforts to deliver on the planned investments, in cooperation with relevant private sector and government stakeholders, to enhance the likelihood of obtaining the substantial returns to sector and overall GDP growth that this study has confirmed.

CHAPTER 1 | INTRODUCTION

The importance of water and environmental resources is generally accepted; however the value of that importance in economic terms is not. Uganda's economy is largely dependent on its stock of environmental and natural resources. Most sectors of the economy – including agriculture, which is Uganda's mainstay – rely on environmental and natural resource goods and services to enhance their productivity, provide the necessary raw materials, and reduce the cost of public expenditure for providing the services in those sectors. Uganda faces continuing and increasing challenges to environmental and natural resources management, calling for greater efforts to ensure that these resources are sustainably managed for present and future generations. To do this, it is important for the Ministry of Water and Environment (MWE) to establish and clearly articulate the contribution of the water and environment sector to economic growth and development. The objective of this assignment is to assess the economic value of water and environmental goods and services – and the costs of degradation and insufficient management action. The assessment encompasses both the value of water and the environment as resources to Uganda's economy, as well as the specific contribution provided by MWE management. This will increase the appreciation for the need to soundly manage and develop these resources for future economic growth.

OBJECTIVES

The specific objectives of the project are to: i) determine the economic value of environmental goods and services and the economic costs of environmental degradation in terms of a range of economic indicators (e.g., GDP, employment, livelihoods, foreign exchange earnings), as well as distributional implications using the same indicators; ii) for key Ugandan sectors, estimate the economic costs of poor water management and development and the potential economic benefits from improvements; iii) determine the economic costs of extreme events (floods and droughts) historically and in the future, considering the impacts of climate change; iv) provide recommendations of further studies and work needed to fill existing gaps so as to strengthen the case for increased investment in the sector; and v) build capacity for economic analysis by conducting training sessions with MWE counterpart staff on the tools and techniques employed. This report details an assessment to answer the valuation objectives, provides recommendations for future work, and summarizes capacity building efforts.

STUDY SCOPE

In order for this study to address the objectives listed above, it is necessary to first define several key terms and concepts within those objectives. These include the scope and definitions of environment, degradations, poor water management, extreme events, and economic value.

- **What is the environment?** Includes air, land, and water. This study focuses on land and water, as these are the primary resources affected by MWE management actions. In this context, the environment is also the provider of a number of goods and services valued in various ways, both in the economy and outside traditional economic accounts.
- **What environmental degradations are considered?** Poor management of environmental and natural resources that are under the regulatory authority of MWE. This encompasses forest and wetland degradations that lead to increased sedimentation, reduced water quality, more variable river flows, and a host of other biophysical effects. These in turn have impacts on infrastructure costs, tourism revenues, water treatment costs, and other economic outcomes. Environmental degradation can occur as a result of direct mismanagement of the environment; e.g. through poor land use planning, poorly designed infrastructure, pollution and dumping, and others.
- **What is water management and development?** Activities that have a substantial effect on the storage, conveyance, quality, and provision of water. Examples include reservoirs, irrigation systems, water treatment facilities, land management for water quality protection, and supply and sanitation of water. This category also encompasses hydropower production and development, which depends directly on upstream water management.
- **What extreme events are considered?** Droughts and floods, which are extreme events that can be mitigated through MWE management (e.g., flood control systems, reservoirs) and have a significant effect on Uganda's economy.
- **What is economic value?** One category of value is the impacts on the economy, including GDP and employment rates. Another measurement of value focuses on welfare, or consumer surplus, which is the value the consumer holds for a good or service above what it costs in the market. For many environmental goods and services, there is no market price, so the entirety of what consumers would be willing to pay for the good if there were a market is consumer surplus. Both GDP and welfare are appropriate measures but each requires separate tools for assessment. The values captured in this assessment are discussed below.

Using the definitions outlined above, this report estimates the value of water and environmental goods and services in the Ugandan economy, which can be estimated in several ways outlined in Table 1-1. First, the value of these goods can be quantified by their contribution to the economy as measured by GDP. This is the primary approach undertaken in this analysis, but it only encompasses those goods and services that are already included, directly or indirectly, in GDP estimates. The second category, water- and environment-inclusive GDP, follows the same framework, but includes additional goods and services usually unaccounted for in GDP calculations, such as resources gathered directly from the source and not traded in market. The third category of value is existence, or other non-market values, where natural resources are given a value based on their existence, usually in terms of general welfare. These values would not appear in a GDP accounting framework. This report addresses the second and third measures through a literature review of ecosystem service values. Lastly, value can be measured using an inclusive wealth approach. While the direct impact of water and environmental goods requires the good to be extracted in order for it to be assigned a value, inclusive wealth assigns value to natural resource stocks, effectively allowing for it to be valued without extraction. This method is also useful when thinking about the sustainability of resource use, as declining stocks of resources are explicitly shown as lost value.

Of these values, the first through third approaches measure *ecosystem service* flows through the economy. This study presents quantitative results in the first category through the economy wide model, and qualitatively addresses the third category of existence values through a review of existing literature. By focusing on the first and third approaches, this report balances the need for providing values widely accepted across disciplines and acknowledging the environment has value beyond traditional economic indicators.

TABLE 1-1 CONCEPTUAL FRAMEWORK OF THE VALUE OF ENVIRONMENTAL GOODS AND SERVICES

CATEGORY	DESCRIPTION	ENVIRONMENTAL GOOD (EXAMPLES)	EVALUTION METHODS	HOOK TO CGE
Ecosystem Services Reflected in GDP	Service flows provided by ecosystems with outcomes measured in traditional GDP accounts.	- Flood protection - Reduced sediment loads - Improved water quality	- Cost to replace lost service with infrastructure - Damage of losing service	Impact on productivity of capital, labor, and land
Water and Environment Inclusive GDP	Service flows provided by ecosystems that are not captured in traditional GDP accounts.	- Household farms - Self-supplied water - Biomass collected locally from forests	- Cost to replace lost service with infrastructure - Damage of losing service	Impact on productivity of capital, labor, and land
Existence or other non-market values	Service flows that improve human welfare, but do not directly produce GDP – see also Box 1 below.	- Biodiversity - Cultural value - Aesthetics - Sense of place	Stated and revealed preference methods	None
Inclusive Wealth	An accounting system that considers the value of natural resource and environment stocks as well as their extraction values.	Stocks of forest, groundwater, water quality, soil quality, and other environmental resources	Shadow prices, otherwise market values	None

CATEGORIES OF ECOSYSTEM SERVICES

As described in Table 1-1, water and environmental resources in Uganda provide more goods and services, and generally hold more value than can be measured by traditional economic indicators, although there are some instances where linkages exist. The goods and services provided by the Ugandan environment can be broken down into four categories: provisioning services, regulating services, cultural services, and supporting services. The boxes below, from a 2003 United Nations report on ecosystem services, present specific attributes within each service category. Bolded items are valued in this assessment directly within the economy wide model. Several of the remaining items are valued in through a literature review of existing ecosystem services studies that utilize a variety of methodologies (market pricing; hedonic pricing; travel cost; compensation costs and opportunity costs, etc.) to estimate the value of ecosystem services.

Provisioning Services	**Regulating Services**	**Cultural Services**
Products obtained from ecosystems	*Benefits obtained from regulation of ecosystem processes*	*Nonmaterial benefits obtained from ecosystems*
-Food **-Fresh water** **-Fuelwood** -Fiber -Biochemicals -Genetic resources	-Climate regulation **-Disease regulation** **-Water regulation** **-Water purification** -Pollination	-Spiritual and religious **-Recreation and ecotourism*** -Aesthetic -Inspirational -Educational -Sense of place -Cultural heritage

Supporting Services

Services necessary for the production of all other ecosystem services

-Soil formation -Nutrient cycling **-Primary production**

* Note revenue generated within the recreation and ecotourism sectors are included in the economy wide model, however the welfare or consumer surplus associated with those activities is not.

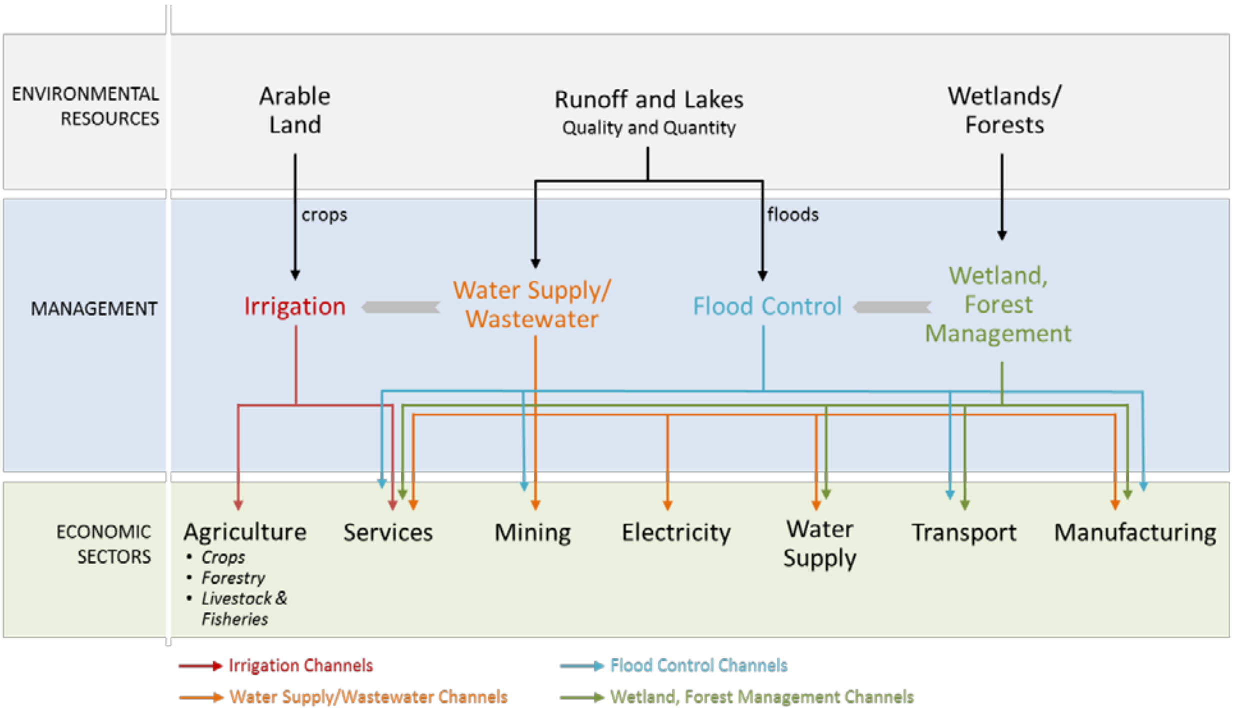
Graphic Source: (WRI 2003), emphasis added

OVERVIEW OF APPROACH

This report addresses the objectives of this study by estimating the contribution of water resources development and environmental management to the economy. The study employs the framework illustrated in Figure 1-1 below, which shows the relationship between environmental resources, management actions, and sectors of the economy. Arable land, water (as runoff and lakes), and wetlands and forests are environmental resources that are partly or wholly under the management of MWE. Management actions—primarily investments and regulations—convert these raw environmental resources into intermediate goods and other factors of production, which are then input into the economy across a number of sectors. This report refers to these pathways from environment to the economy as channels of impact. In Figure 1-1, these channels are depicted by the arrows linking particular environmental resources to management actions, and then arrows linking management actions to economic sectors. For example, arable land (environmental resource) can be managed through provision of irrigation water (MWE management action), which then improves crop yield reliability and thus GDP from agriculture (economic sector).

This assessment follows each of these channels, from environmental resource to economic sector, under a suite of management actions to value natural resources and sound environmental management in terms of contribution to GDP, and other economic indicators. The management action scenarios feed into biophysical models coupled with an economy wide model of Uganda. The approach is detailed in Chapter 2.

FIGURE 1-1 GENERAL STUDY FRAMEWORK



STRUCTURE OF REPORT

The remainder of this report is organized as follows. Chapter 2 describes the methodologies employed for this assessment. Chapter 3 describes sectoral results from biophysical and other intermediate models. Chapter 4 presents the results of the economy-wide modeling activities. Chapter 5 concludes the report with a set of actionable insights. The main body of the report is followed by a series of annexes which provide details on the methodologies presented in this report.

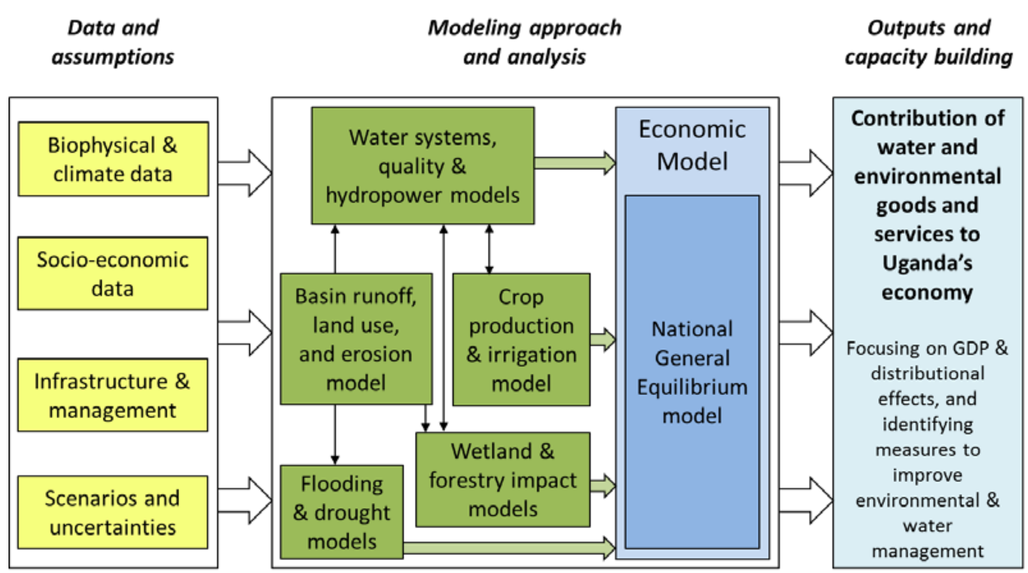
CHAPTER 2 | METHODOLOGIES

This analysis uses an economy wide model to estimate the value of water and environmental goods and services to the Ugandan economy. The model, when coupled with biophysical modeling outputs, tracks how water and environmental resources contribute to economic output. The inputs are adjusted to simulate different management scenarios, for example by changing crop yields or hydropower generation. The sections below first outline the modeling framework used in this assessment, and then discuss the various elements of the framework in more detail, including scenarios and uncertainties, biophysical models, channels of economic impact, and specifics of the CGE model.

MODELING FRAMEWORK

The general approach is illustrated in Figure 2-1 below. Data and assumptions form the beginning of the analytical process. The nature of the project requires that both current and projected biophysical and socioeconomic data be collected, as well as information on existing and planned infrastructure and management. These are coupled with known uncertainties and climate and policy scenarios to be fed through a set of biophysical models, which are then fed into an economy wide model. A variety of economic indicators reflecting the contribution of water and environmental goods and services to Uganda's economy are output from this modeling process.

FIGURE 2-1 MODELING SYSTEM TO ASSESS THE CONTRIBUTION OF WATER AND ENVIRONMENTAL GOODS AND SERVICES TO UGANDA'S ECONOMY



METHODOLOGY OVERVIEW

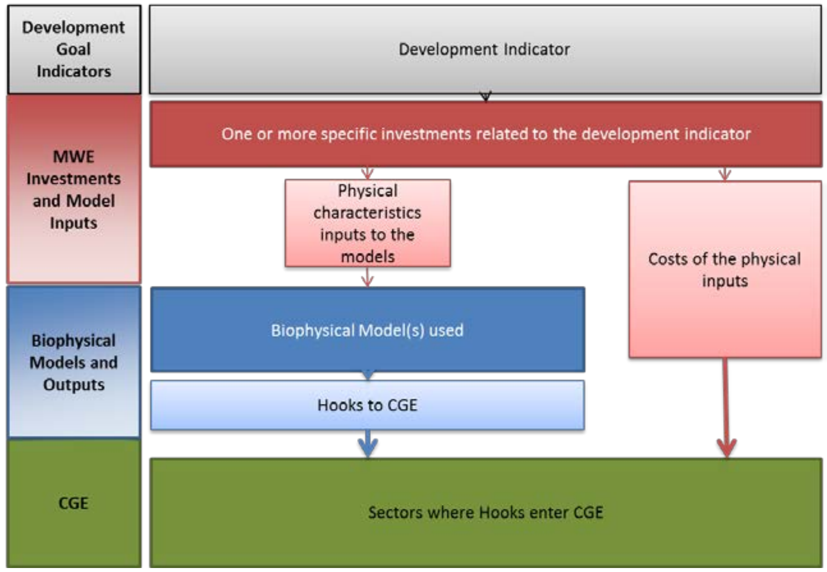
To conceptualize the value of water, environmental goods and services, and the management of these resources to the Ugandan economy, this study uses a series of "impact channels" which each represent a pathway from natural resources to national economic indicators. The ten impact channels used in this study are listed in Table 2-1, grouped by management category: water resources development and environmental management.

TABLE 2-1 IMPACT CHANNELS

IMPACT CHANNEL	SUPPORTING MWE INTERVENTIONS
WATER RESOURCES DEVELOPMENT	
Crop Production	Provision of irrigation water
Livestock Production	Provision of water for livestock
Water Available for Industry and Services	Water supply reliability to manufacturing
	Water supply reliability for service sector
	Water supply reliability to mining
Water Supply and Sanitation: Health and Time Use	Water quality impacts on water supply
	Provision of urban water supply
	Provision of rural water supply
	Reduction in water-borne diseases through sanitation and education
Hydropower Generation	Water management for hydropower efficiency
ENVIRONMENTAL MANAGEMENT	
Flood Damages to Infrastructure	Flood risk mitigation by land management
Timber Production	Forest and plantation management
Fuelwood: Health and Time Use	Enforcement of forest protection
Water Quality	Wetlands and forest management for natural filtration of fisheries
Ecosystem Protection	Ecosystem protection for eco-tourism

The transformation of natural resources to economic outcomes in each channel is affected by MWE management and investment. By running the macroeconomic model (computable general equilibrium, or CGE) under a series of investment scenarios, the value of the resources and appropriate management can be estimated. The flow of this analysis for a generalized channel is provided in Figure 2-2. The pathway from natural resource to economic indicator is first defined by identifying specific investments by MWE which affect the impact channels. Some of these investments relate to physical capital investments, such as supply infrastructure, while others involve educational programming and resource management. A single investment may affect multiple channels. For example, afforestation investments can improve timber harvests, provide flood control, and improve water quality. Development goals from NDPII are used to calibrate investment under each scenario. Flow diagrams depicting the methodology for each channel in this study are presented in Annex 2.

FIGURE 2-2 GENERALIZED CHANNEL METHODOLOGY



Each of the investments is represented in the analysis as a cost and a change in biophysical model inputs, which ultimately enter the CGE as a shock to land, labor, or capital productivity. While investment expenditures have an obvious place in the national product accounts that underlie a CGE, changes in biophysical measures typically have an indirect or unmeasured effect on the macroeconomic inputs and outputs of a CGE. As a result, a method is needed to adequately capture this indirect effect by identifying "hooks" in the CGE, such as changes in land, labor, or capital productivity, that are affected by changes in biophysical effects. This approach is similar to that used in the UN WIDER Systematic Analysis of Climate Resilient Development (SACReD) framework, which focused on economy-wide modeling of climate change impacts in several sub-Saharan African countries. For example, the cost of building a new reservoir would be entered in the CGE, and the additional storage capacity available from building a reservoir would be entered to the biophysical models whose outputs affect the productivity of land in the CGE. This is then modeled in the CGE through a change in input factor productivity that affects economic production in agriculture or other water-using sectors.

Three investment scenarios are developed to create unique investment pathways from 2015 to 2040. The key to identifying the value of water and environmental resources and management is to define investment scenarios that vary enough to observe the differentiation in economic outcomes, but that also represent possible scenarios given the current level of investment and development goals in Uganda. The definition of these scenarios is based on a set of development indicators and targets reported in the MWE Sector Performance Reports (MWE 2015), Strategic Sector Investment Plan (MWE 2009), and the National Development Plan II (NDP II) (GoU 2010). Most of the channel investments defined can be matched with a development indicator, and the future trajectory of investments can be anchored to these targets. A discussion of the indicator targets referenced in this report can be found in Annex 3. The three future scenarios range from continued current level of investment growth (based on historical trends from 2008 to 2015) to achieving Vision 2040 goals (as stated in NDP II).

The investment trajectories are used to generate time series of investment costs and alterations to biophysical model inputs. The biophysical models are run under each investment scenario to produce series of impacts on land, labor, and capital productivity for the CGE, along with the series of corresponding investment costs. The CGE solves for a variety of economic indicators that are compared to assess the overall value of each investment scenario to Uganda's economy.

SCENARIOS AND UNCERTAINTIES

A suite of investment scenarios, defined by varied progress towards national development goals, is used to drive estimates of the value of proper resource management. When forecasting to the future, modeling of biophysical and economic conditions in the country is critical for successful implementation of the study. In order to capture the broadest possible range of future conditions, it is necessary to consider climate change and other uncertainties that have a potentially pronounced effect on estimation of national and regional economic outcomes, such as land use change, social discount rate, population growth, and economic growth.

Economic outcomes will also vary across time and space. The CGE model is run from 2010 to 2040. The economy wide model is run at the national level, based on the sum of regional inputs, allowing for results to be incorporate differences across the four administrative regions of Uganda.

MANAGEMENT AND INVESTMENT SCENARIOS

By running the models under a variety of management and investment scenarios, the analysis is able to report differences in economic indicators between scenarios, and attribute those differences to changes in management. The 2020 and 2040 targets cover an array of indicators including a competitive economy, increased employment and wealth, and skilled human capital. The national development goals most dependent on MWE management, with corresponding baseline achievement and growth targets, are shown in Table 2-2.

TABLE 2-2 DEVELOPMENT INDICATORS AND TARGETS, 2015-2040

INDICATOR		BASELINE	TARGETS		TARGET SOURCE
		2015	2020	2040	
Urban and Rural Water Supply	% of people within 1,000m (rural) of an improved water source	65%	79%	100%	SPR, SIP, V2040
	% of people within 200m (urban) of an improved water source	73%	100%	100%	SPR, SIP, V2040
Sanitation	Access to sanitation facilities (Rural)	35%	60%		V2040
	Access to sanitation facilities (Urban)		57%		V2040
Agriculture	Proportion of livestock supplied with water facilities-Cattle Corridor		70%	80%	SIP
	Proportion of livestock supplied with water facilities-non-Cattle Corridor		30%	60%	SIP
	Proportion of irrigation potential utilized- Type A		25%	70%	SIP
	Proportion of irrigation potential utilized- Type B		7%	20%	SIP
Land Management	% Uganda's land area covered by forest	11%	18%	24%	V2040
	% Uganda's land area covered by wetlands	9%	13%	13%	V2040

Note: SPR--Sector Performance Report 2014; SIP--Sector Investment Plan 2009; V2040--National Development Plan II

The following three target achievement schedules are used to define investment and management scenarios in this analysis:

- **BAU, Business-as-usual growth.** Investment and management across sectors continues to match historical rates (2008 through 2015) out to 2040. Paths to 2040 are modeled using either a linear or logarithmic function, depending on the appropriateness of each trajectory given financial and physical limitations.
- **Moderate: 50 percent of 2020 goals by 2020, trend continuing to 2040.** By 2020, only half of the progress towards 2020 goals is realized. A linear path is then extrapolated to 2040. Note, that for some targets, an alternative moderate investment target was used to ensure that the moderate investment path fell between BAU and high investment scenarios. This alternative definition set 2020 goals to be accomplished by 2040.
- **High: 100 percent to 2020 goals by 2020, then to 2040 goals.** Investment between 2015 and 2020 is consistent with 100 percent to 2020 goals by 2020, increasing from 2020 to 2040 to meet 2040 goals.

Information on levels of achievement from 2008-2015 were gathered from the MWE Sector Performance Reports (MWE 2015). Targets for 2020, and 2040 were found in the Strategic Sector Investment Plan (MWE 2009) and National Development Plan II (GoU NDPII).

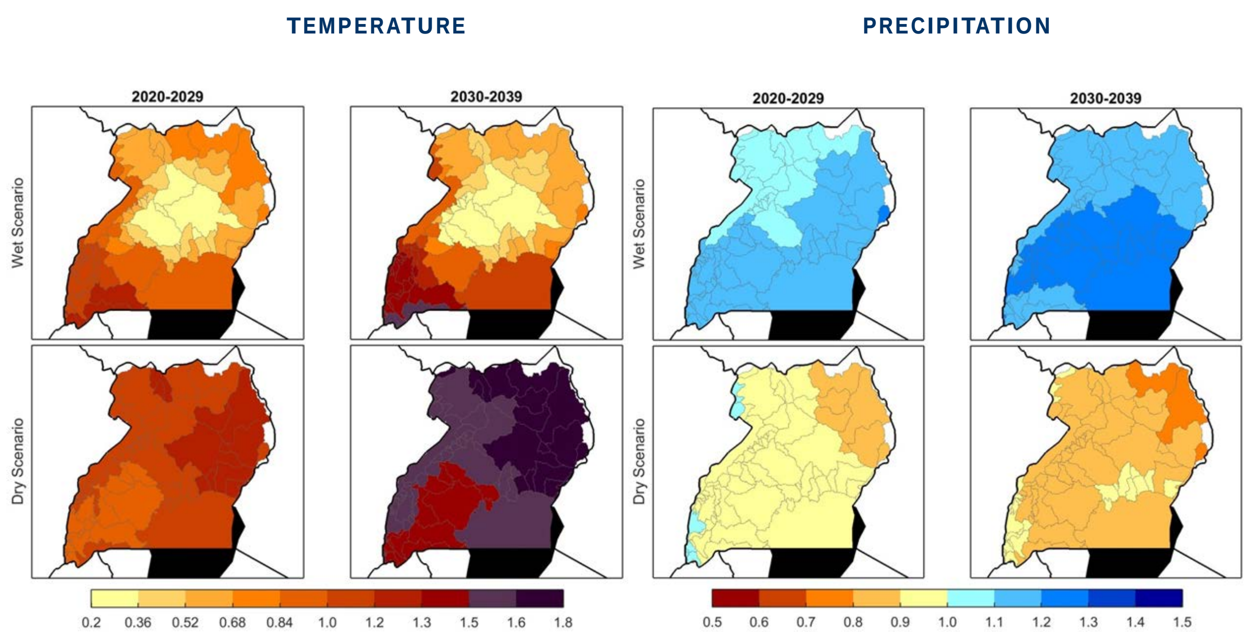
A direct relationship between the impact channel and a national development goal was not available for all channels. In those instances, the best available information was used to develop investment and management trajectories comparable to the definitions provided above. Annex 3 contains details of each investment trajectory.

CLIMATE UNCERTAINTIES

The World Bank and other organizations that fund large investments are increasingly requiring that "climate screening" be conducted to assess the vulnerability of their investment prior to finalization of loans. The sensitivity of water sector outcomes under the Business-as-usual growth investment scenario was analyzed using two alternative future climate change scenarios: one representing a "wet" future for Uganda, and the other representing a "dry" future. These were selected from a set of 43 emissions-climate model combination in the Coupled Model Intercomparison Project Phase 5 (CMIP-5) ensemble of General Circulation Models (GCMs) employed in the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report.[2]

Figure 2-3 shows the climate outcomes under the wet and dry scenarios from a 1950-1999 baseline through two future decades in the study period: 2020s (2020-2029) and 2030s (2030-3039). These are used for sensitivity analysis. The "dry" scenario shows a trend of decreasing precipitation and country-wide warming and the "wet" scenario shows a less intense increase in temperature than the dry scenario and a nearly universal increase in precipitation across the country.

FIGURE 2-3 CLIMATE CHANGE OUTCOMES SELECTED FOR SENSITIVITY ANALYSIS



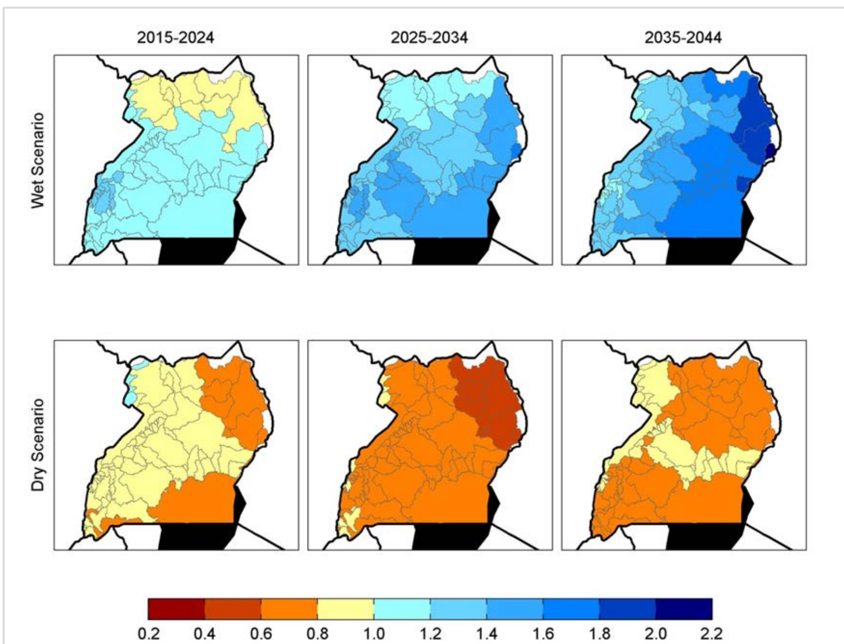
[2] The dry climate scenario is HadGEM2-AO rcp8.5 and the wet climate scenario is CCSM rcp4.5.

Effects of Climate Change on Water Availability and requirements

To characterize the effect of climate change on the water system, the Mike Hydro model was re-run using the climate scenarios. The results of this analysis relate to the hydropower generation and crop production channels.

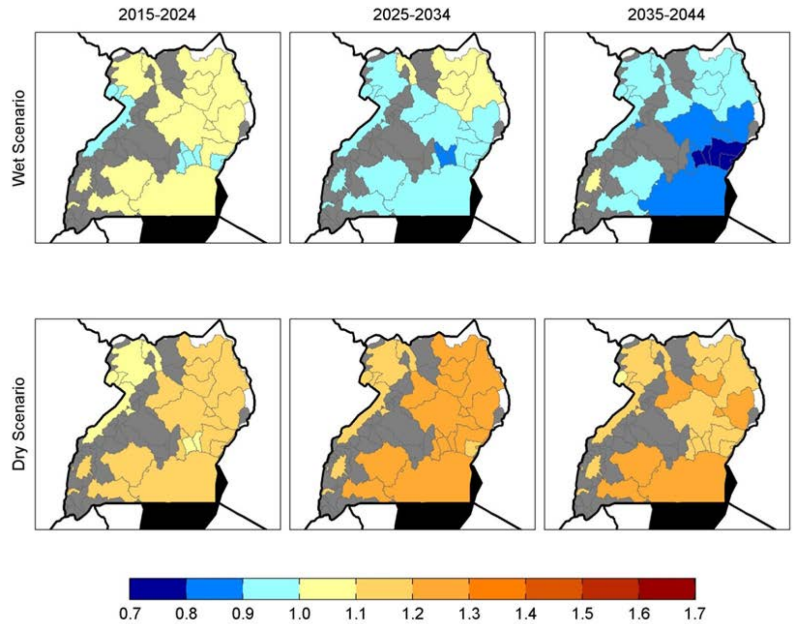
Runoff affects both hydropower generation and crop production. Higher runoff levels correspond to more river flow that can be harnessed for hydropower. For crop production, more runoff represents a decreased need for irrigation, as rainfed crops are able to get more water. Climate outcomes are presented for three projected time periods: 2015-2024, 2025-2034, and 2035-2044 as compared to an adjusted baseline of 1955-1980 for analysis. Figure 2-4 shows the ratio of runoff in future climate scenarios to runoff in the current climate. Under the wet scenario, runoff nearly doubles in the northeastern regions by the 2040s, while in the same areas it is less than half of baseline levels in the dry scenario. Calculation of runoff ratios was based on the Turc-Pike equation (Turc 1954; Pike 1964), which uses estimates of annual precipitation and potential evapotranspiration (PET) to produce annual runoff.

FIGURE 2-4 RUNOFF RATIOS



A change in need for irrigation is calculated as the irrigation water requirement (IWR) ratio. IWR was calculated using the reduced form International Food policy Research Institute (IFPRI) approach as described in World Water and Food to 2025 IFPRI publication (Rosegrant 2002). This equation uses precipitation, reference evapotranspiration, and crop factors to produce IWR. Figure 2-5 presents IWR ratios which were restricted to catchments containing a current or projected irrigation node, as shown by colored basins in the figures below. Requirements increase by up to 20 percent in the dry scenario, and decrease by up to 30 percent in the wet scenario.

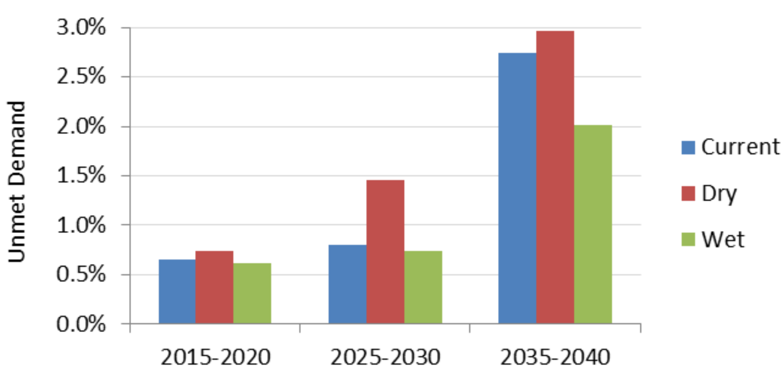
FIGURE 2-5 IRRIGATED WATER REQUIREMENT RATIOS



Effects of Climate Change on Unmet Irrigation Demand and Hydropower Generation

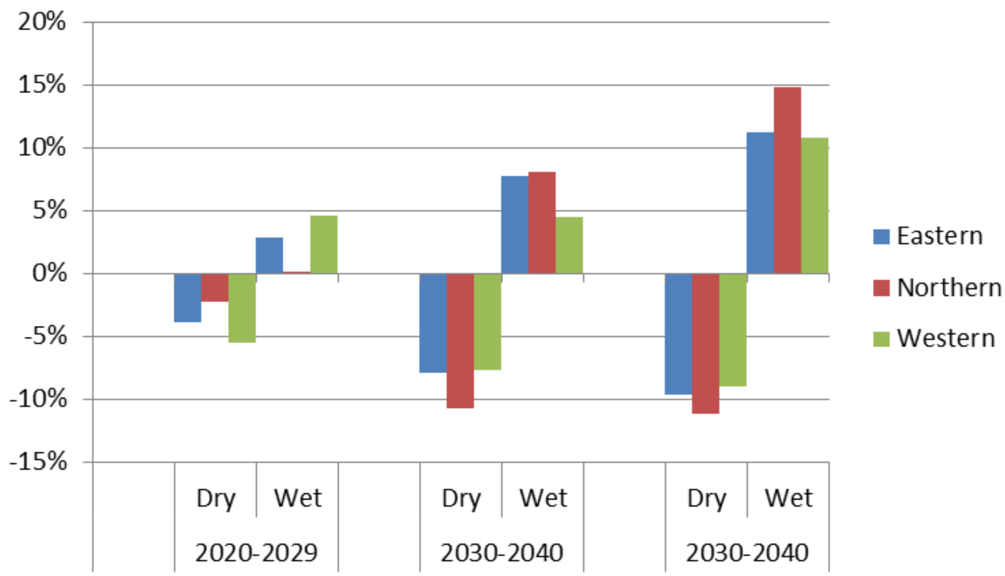
Crop production is influenced by unmet irrigation demand, which is the difference between the irrigated crop requirement and the water available for irrigation. In the current climate scenario, there is about a 0.5 to 1 percent deficit through 2030 and a 2.5 percent deficit by 2040. In 2025- 2030, the deficit nearly doubles to almost 1.5 percent in the dry scenario and remains very similar in the wet scenario (Figure 2-6). By 2040 the deficit increases slightly in the dry scenario and decreases by about one third in the wet scenario.

FIGURE 2-6 AVERAGE UNMET IRRIGATION DEMAND UNDER BASELINE, DRY, AND WET CLIMATE CONDITIONS (PERCENTAGE CHANGE)



Given the climatic outcomes presented above, hydropower generation varies across climate scenario as expected, with lower levels of generation in the dry scenario and higher generation in the wet scenario compared to the current climate scenario. The results for three future time periods are presented below in Figure 2-7. The changes in generation are of similar magnitude to the changes in precipitation during these time periods seen in Figure 2-3.

FIGURE 2-7 CHANGE IN HYDROPOWER GENERATION UNDER WET AND DRY FUTURE CLIMATES, RELATIVE TO CURRENT CLIMATE CONDITIONS



Note: There is no hydropower generation in the Central Region.

Potential Effects of Climate Change on Other Channels

While climate change will affect the economy of Uganda, and in particular, the channels of impact studied in this report, the magnitude and direction of this effect is uncertain. A wetter future climate may improve hydropower generation and crop yields, for example, but it may also lead to increased flooding damages depending on the pattern of precipitation. This analysis of a limited number of channels provides important context for understanding how climate change might affect the channels of impact in this study. A full analysis of climate change, however, considering more than two scenarios, should be conducted to fully reflect this uncertain factor which may affect the economy wide impacts of MWE investments. A more rigorous analysis of climate change therefore could be important in a future study. The remaining analyses assume historical climate patterns. Detailsof climate change sensitivity analysis are presented in Annex 13.

NON-CLIMATE UNCERTAINTIES

In addition to climate change, there are a range of other uncertainties that may have an effect on the outcomes of this analysis. Although not considered in this analysis, alternative levels of these factors that could be included in a future assessment are provided in Table 2-3.

TABLE 2-3 NON-CLIMATE UNCERTAINTIES FOR FUTURE ASSESSMENTS

NON-CLIMATE UNCERTAINTY	VALUES	COMMENTS
Benefits from non-quantifiable channels	Biodiversity, cultural importance, improved quality of life, carbon emission reduction, water treatment cost impacts, stable lake levels, etc.	There are many benefits that cannot be accounted for in this analysis. Some of these benefits are precluded from the CGE analysis because they are not included in national accounts (such as the value of improved quality of life from supplied drinking water). Others could not be included due to lack of data or relationships linking MWE actions to outcomes.
Discount rate	0%, 6% ,10%	Higher discount rates mean that projects with near term costs and long-term benefits will be downsized. The range of possible rates includes values best interpreted as social discount rates (2-7%) and higher rates commonly used by the World Bank to evaluate investments (6-12%) In this report, some of the summary results have been evaluated using rates of 0%, 6% and 10% in Chapter 4, to illustrate the effect of discounting, but no decision has been made regarding a discount rate to be used in the primary results, so most results are presented undiscounted.
Environmental flow requirement	5th and 15th flow percentile	The Q90, or 10th percentile, of flows is considered to be the minimum needed to sustain an ecosystem in "fair" condition (Smakhtin et al. 2004)
Crop yields	IFPRI low and high yield forecast	Crop yields directly affect the net economic benefits generated from within the agricultural sector.

BIOPHYSICAL MODELS

Biophysical models translate the data inputs and uncertainties described above into the physical state of Uganda's water resources and environmental goods and services. Figure 2-8 displays model relationships. The runoff, land use, and erosion models are a key component of the modeling system and provide inputs to the flooding, wetlands, and water systems/quality models. The water systems model produces information on water availability and hydropower generation. The crop production/irrigation model generates irrigation water demands that interact with the water resource systems model and the crop production model to estimate irrigated crop yields. Many of the biophysical models interact, allowing downstream processes to be affected by upstream management decisions.

FIGURE 2-8 RELATIONSHIPS BETWEEN BIOPHYSICAL MODELS

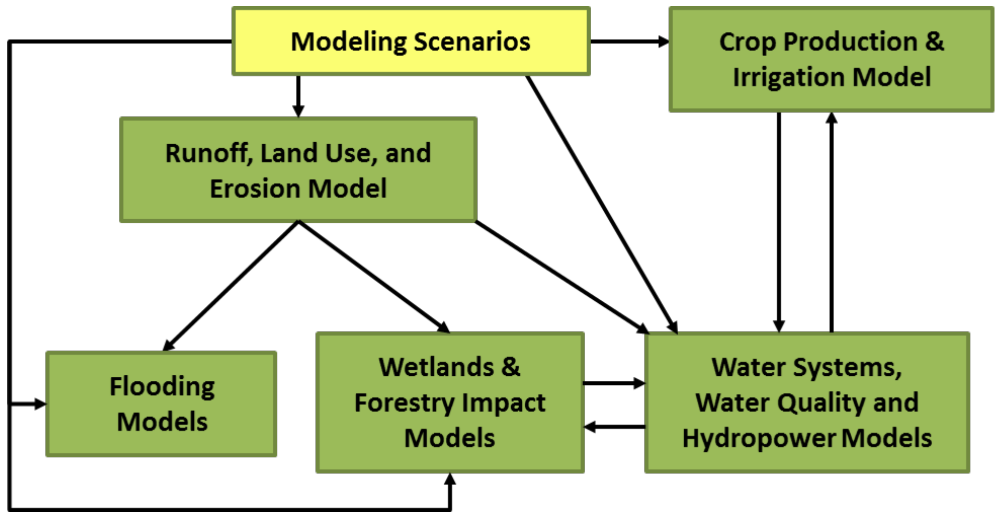


Table 2-4 briefly describes the modeling tools used in this analysis and their outputs. Note that this set of biophysical models was selected based on data available and preliminary assessments identifying which effects are most significant.

TABLE 2-4 BIOPHYSICAL MODELS USED IN THIS ASSESSMENT

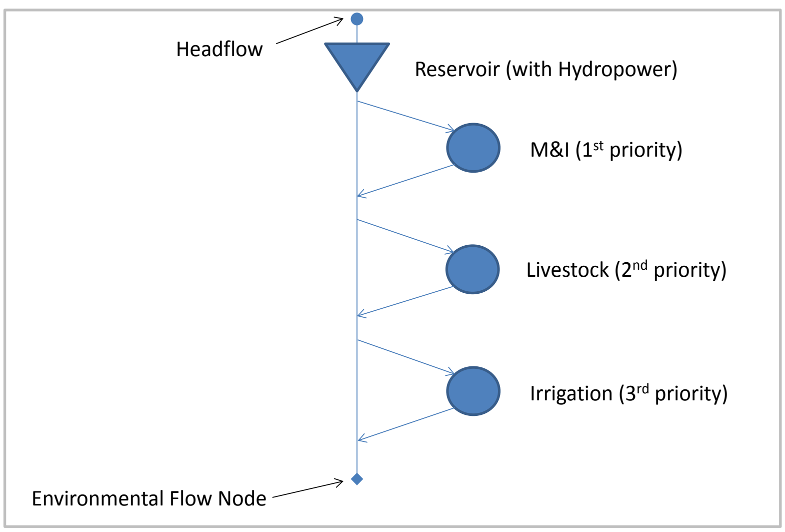
BIOPHYSICAL PROCESS	BIOPHYSICAL MODEL	DESCRIPTION AND COMMENTS
Water systems/ supply and hydropower	**Mike Hydro**	Provides a mathematical representation of the river basin encompassing the configuration of the main rivers and their tributaries, the hydrology of the basin in space and time, reservoirs, existing as well as potential major schemes and their various demands of water. Mike Hydro contains a hydropower production component. (See Annex 4)
River runoff	**NAM**	NAM is a model that is part of the Mike Hydro suite of tools, and produces simulated river runoff using gauged flow datasets.
Crop yield, irrigation needs (includes drought)	**FAO56**	A monthly tool for evaluating irrigation water requirements and rainfed yield deficits. Drought effects are captured through yield impacts. (See Annex 6)
Water quality	**LBWQ (Lake-Basin Water Quality)**	The Lake-Basin Water Quality (LBWQ) model is a parsimonious water quality modeling tool that evaluates how lake water quality is affected by land and water management with in its drainage basin. (See Annex 9)
Land use and erosion	**USLE (Universal Soil Loss Equation)**	The USLE approach is a widely-used mathematical model for describing soil erosion processes. (See Annex 8)

BIOPHYSICAL PROCESS	BIOPHYSICAL MODEL	DESCRIPTION AND COMMENTS
Flooding	**IPSS (Infrastructure Planning Support System)**	In IPSS, buildings and roads are damaged due to flood events. As with droughts, a Monte Carlo analysis is run (i.e., develop many synthetic streamflow runs) which will produce periodic flood events that can be used to estimate the current and projected costs of flooding in Uganda. (See Annex 10)
Forestry impact	**Reduced form timber yield models**	This model produces a stream of timber production over time and under different forest management regimes. Yield rates are derived from the literature to estimate timber production under each MWE management scenario.

MIKE HYDRO MODELING AND WATER DEMAND ESTIMATION

Many of the impact channels in this study involve analysis in Mike Hydro.[3] Mike Hydro is a decision support tool for water resource analysis. Users input demand nodes, supply infrastructure, and natural water availability to model water availability at the catchment level. Water is allocated across competing demands based on a defined prioritization level. Municipal demand (i.e. for domestic household use) is given the highest allocation priority, followed by industrial use, irrigation use, and finally, hydropower. The output of Mike Hydro includes spatially defined water shortage estimates by demand use. Figure 2-9 shows an example catchment structure.

FIGURE 2-9 EXAMPLE CATCHMENT STRUCTURE IN MIKE HYDRO



Monthly demands for each node were projected for all four scenarios from 2015 to 2040. Projected demand does not vary significantly between all scenarios; therefore, Mike Hydro is run twice for this analysis, representing low and high demand projections.

[3] Further details on the Uganda Mike Hydro model can be found in Annex 4.

Livestock demands remain constant between the two runs while two estimates of Municipal & Industrial, Hydropower and Irrigation demands and capacity are calculated to represent moderate and high levels of investment. Details on the estimation of demand projections can be found in Annex 5.

CHANNELS OF ECONOMIC IMPACT

Water and environmental goods and services enter the economy through a number of impact channels that transform natural resources to market goods and services (see Thurlow 2008). These pathways show the transition from raw natural product to economic goods, through biophysical and economic processes under defined management and investment scenarios. The intermediate goods, modified by MWE interventions, affect economic indicators by altering land, labor, and capital productivity across sectors. These then have an effect on economic outcomes, measured through metrics such as GDP, consumption, and employment.

Table 2-5 outlines the relationships between MWE interventions and economic activities in the Uganda economy through impact channels. Impacts are estimated primarily through biophysical models, however some reduced form statistical relationships are used where data availability or effect magnitude make biophysical models impractical. The outputs of these models are then entered into the economic model as changes to factors of production. A discussion of the channels of impact follows the table.

TABLE 2-5 CHANNELS OF IMPACT: INTERVENTIONS, APPROACH, AND CGE HOOKS

CHANNEL	MWE INTERVENTIONS	MODELING APPROACH	CGE HOOKS
WATER RESOURCES DEVELOPMENT			
Crop Production	Provision of irrigation water	**Mike Hydro** for water availability and **FAO56** for yield	Rainfed and irrigated yields (by crop); Irrigation costs
Livestock Production	Provision of water for livestock	**Mike Hydro** for water availability; **Reduced form** livestock yield model	Livestock production; Water supply costs
Water Available for Production	Water supply reliability to manufacturing Water supply reliability for service sector	**Mike Hydro** for water availability, **reservoir cost** model for investment needs; **USLE** for estimation of reservoir costs given sedimentation	Water availability; Water supply costs
Water Supply and Sanitation: Health and Time Use	Provision of urban water supply Provision of rural water supply	**Reduced form** model of water reliability and labor productivity, **reduced form** model of sanitation and diarrheal disease outcomes, **reduced form** model of diarrheal disease outcomes	Labor productivity impacts(health and education) and health care cost impacts; Water supply costs

CHANNEL	MWE INTERVENTIONS	MODELING APPROACH	CGE HOOKS
	Reduction in water-borne diseases through sanitation and education	and labor productivity	
Hydropower Generation	Flow management and monitoring on hydropower-equipped rivers	**Mike Hydro** to generate energy outputs, **reduced form** model of catchment management and hydropower generation efficiency	Hydropower production; River flow management costs
ENVIRONMENTAL MANAGEMENT			
Flood Damage to Infrastructure	Flood risk mitigation by land management	Reduced form model of catchment management and flood risk relationship, reservoir cost model for investment needs	Time series of damages; Catchment management costs
Timber Production	Forest and plantation management	**Reduced form** timber yield model	Timber production; Forest rehabilitation costs
Fuelwood: Health and Time Use	Enforcement of forest protection	**Reduced form** model of cooking fuel source and labor productivity, **reduced form** model of cooking fuel source and healthcare costs.	Labor productivity; Forest rehabilitation costs
Water Quality	Wetlands and forest management for natural filtration of fisheries	**LBWQ**, **reduced form** model of loadings and fishing catch rates relationship	Fisheries production; Catchment management costs
Ecosystem Protection	Ecosystem protection for eco-tourism	**Reduced form** model of land management and tourism relationship	Tourism industry impacts; Catchment management costs

CROP PRODUCTION

Although the overall share of Uganda's GDP that is derived from agriculture has declined significantly over time, from over 50 percent in the 1980s to about 20 percent in 2008, it still remains a major source of income for the majority of Ugandans (World Bank 2011). Over 85 percent of Uganda's population live in rural areas, and the majority depend on agriculture for their primary source of income (Gollin and Rogerson 2010).

MWE investments in irrigation infrastructure and water supply reservoirs affect the quantity and reliability of water supply for crop growing. Irrigation infrastructure expansion under each investment scenario is derived from the potential irrigation schemes in the NWRA (GoU 2013b). In order to also meet environmental objectives, none of the new irrigation is assumed to be located in wetlands. Investment trajectories are based on NDP II goals related to the proportion of irrigation potential utilized on

Type A and Type B lands, where Type A lands are closer to surface water and do not require bulk water transport or storage, and Type B lands do. Water availability has crop specific yield effects, which can result in changes in overall production or shifts between land usage and irrigation strategy by crop to optimize production.

Mike Hydro is used to model the availability of water for crop agriculture based on the defined investment in irrigation infrastructure and demands of other water users. FAO56, a crop yield model within the Mike Hydro suite, then estimates the water supply requirements, and irrigated and rainfed yields for staple crops for Ugandan farmers, producing a vector of yield shocks by crop and year from 2015 to 2040. These yields represent the importance of irrigation and water table water supply, and also indicate the effect of droughts for years where water availability is low.

The CGE is able to optimally allocate resources across different crops and sectors in response to changes in yield, and estimate how the shocks affect economic indicators. For example, during a dry year the yield model might show relatively higher yields for drought resistant crops, in which case the CGE might allocate more resources to producing those crops. Alternatively, if the drought resistant crops are more costly to produce than importing food, the CGE will import food to meet demand and shift the factors of production to other sectors of the economy. The investments associated with the given management scenario also enter the economic model as capital costs, affecting the amount of capital available for other sectors of the economy.

LIVESTOCK PRODUCTION

Livestock production is also important for both the economy and subsistence livelihoods. Almost all of the cattle, goats, sheep, and poultry produced in the country are owned by rural Ugandans living on small farms (FAO 2005).

Water supply for livestock requires investment in main canals and reservoirs, as well as cattle stands. The investment trajectory in this sector is based on the National Development Goal of the proportion of livestock supplied with water facilities by Cattle Corridor and Non-Cattle Corridor areas.[4] Current livestock water demand is estimated based on the number of tropical livestock units (TLUs) found in each administrative district and the animal-specific daily water requirement for supplied and non-supplied livestock. The daily consumption rates are initially found in the NWRA (GoU 2013b), and are adjusted to differ between supplied and non-supplied livestock based on literature values.[5] Future water demands reflect a growing proportion of livestock supplied water and a growing livestock population. Demand for water is fed into Mike Hydro, which returns the unmet demand for each catchment in each year. This deficiency is translated into livestock yield shocks based on the relationship between water consumption and livestock yields (20 percent, as seen in Brew, Carter, and Maddox 2008). Livestock with

[4] Cattle Corridor areas are defined as places where livestock play an important role in the economy.

[5] Supplied livestock are assumed to consume 15 percent more water than non-supplied livestock. More details on livestock water demand estimation are provided in Annex 5.

access to supplied water also have higher yields due to increased water consumption and fewer illnesses from poor quality water. These livestock yield shocks are input to the CGE.

WATER AVAILABLE FOR PRODUCTION

Non-agricultural industries, including manufacturing, services, and mining, rely on water to operate and together make up almost three quarters of Uganda's GDP. The growth rate of the manufacturing sector in Uganda fell from 13.8 percent in the 1990s to 6.6 percent in the 2000s. In 2013, 3.3 percent of jobs fell under the category of manufacturing (World Bank 2013b). Primary opportunities for growth in this sector include light manufacturing as well as connecting larger industries to small-scale or informal manufacturers (World Bank 2013b).[6]

This analysis assumes 100 percent of water demanded by the service sector and 25 percent of industrial demand is supplied by MWE (the remainder being self-supplied). Unconstrained water demand for service and industrial sectors is forecast based on expected GDP growth (see Annex 5). Under each investment scenario, MWE supplied water is only able to meet a portion of the demand growth it has historically been able to provide. This results in a growing amount of unmet demand for industries and services in the BAU and Moderate investment scenarios.

WATER SUPPLY AND SANITATION: HEALTH AND TIME USE

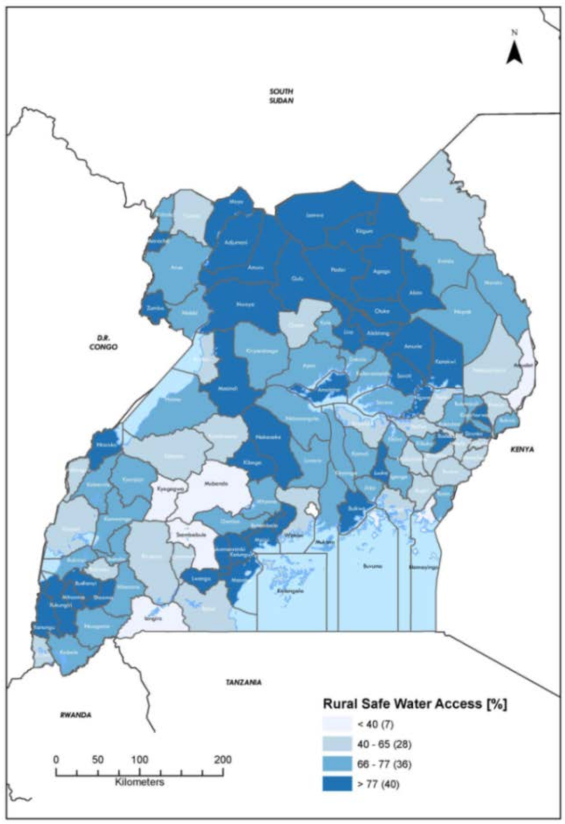
Although rural access to safe drinking water between 1990 and 2014 rose from just over 20 percent to 53 percent of the population, certain rural regions of Uganda still have very limited access to safe supply (Figure 2-10; MWE 2015). Poor sanitation also poses a critical health problem, particularly in rural Uganda. About 8.6 percent of the total government budget of Uganda was allocated to health care in 2014/2015 (GOU 2015). Sanitation and sewage systems in much of the country lack the resources to keep up with increasing demand for these needs.

Urban and rural water supply, as well as sanitation improvement initiatives, are MWE sponsored interventions. Water supply investments include building wells and pipes to increase rural access, and adding connections, building supply reservoirs, and repairing conveyance leaks in urban systems. In addition to improving quality of life for individuals, water supply and sanitation result in improved human capital, which in turn spurs further economic growth. With less time required for water collection, more people can work outside the home or pursue an education. This is particularly true for women, who are often responsible for water collection. This increases not only the overall supply

[6] Note that although direct effects on mining were not quantified in this study, it is a water-dependent sector and extraction of minerals contributed about 0.3 percent of Uganda's GDP in 2012-2013. The major exports of this industry are gold and cement, although many other minerals are identified as having large potential for development (GOU 2015). Between 2006 and 2011, artisanal and small-scale mining (ASM) incomes in Uganda rose from US$3/day to US$5-US$7 per day due to the formation of ASM associations (World Bank 2013a). These associations issue licenses, train workers, and promote community development. Mining may be a relatively small contributor to GDP but its relationship with water and the environment makes it integral to this assessment.

of labor in the economy, but as a result of increased educational opportunity, the supply of skilled labor sees a particularly strong increase. In addition, water supply and sanitation leads to better health outcomes. Fewer incidences of water-borne illness result in decreased healthcare spending.

FIGURE 2-10 PERCENT OF RURAL POPULATION THAT HAS ACCESS TO SAFE DRINKING WATER, 2015 (SOURCE: MWE 2015)



This analysis utilizes previous studies on the effects of water supply and sanitation improvements on human health outcomes, mainly through a reduction in water borne disease incidence, to derive a reduced form relationship between water supply and sanitation, and hours available for labor and health care costs. A relationship is also used to estimate the effect of increased educational opportunity on the composition of the labor force (i.e. the proportion of skilled versus unskilled laborers). Reducing access time to clean water has important distributional effects as water collection duties fall most heavily on young girls, precluding them from educational opportunities in some cases.

Infrastructure investment costs related to the supply scenario, as well as changes in health care costs, are included in the CGE. Changes in employee productivity due to water supply and sanitation enter the CGE as a change in skilled and unskilled labor hours. The economic impacts of the changing labor force are distributed across sectors of the economy optimally by the model.

HYDROPOWER GENERATION

In 2011, Uganda produced a total of approximately 2.5 billion kilowatt-hours (KWh) of electricity, of which 1.3 billion KWh (over 50 percent) was from hydroelectricity (EIA 2014). Uganda consumes more electricity than it produces and therefore the unmet demand must be purchased from surrounding countries at a higher rate than the rate of domestically produced electricity (World Bank 2011). As only 9 percent of Ugandans have access to installed electricity (EIA 2014), expanded hydropower capacity across Uganda stands to significantly improve livelihoods. Closing the gap between Uganda's electricity consumption and production would also result in large economic gains for the country.

MWE management actions affect the variability and ability to forecast river flow, which in turn affects the efficiency of hydropower generation. Mike Hydro is used to model river flow and large- and small-scale hydropower generation over the analysis period, using hydropower plant construction plans based on forecast energy demands. Generation is therefore a product of both capital investment and river flow. To isolate MWE's contribution to this sector, only the marginal generation due to improved river flow management is included in the model. Because of the large share of the electricity market occupied by hydropower, changes in production have general equilibrium effects in the CGE in terms of imports and investment in other sources of power.

Improvements to both large- and small-hydro generation through management were modeled such that the moderate and high investment plan reach full efficiency by 2040, although at different times. Large- and small-hydro plant generation is currently assumed to be underperforming by 5 and 25 percent, respectively, due to underinvestment in management actions. For large-hydro, 5 percent represents a conservative estimate based on a middle ground between two studies: (1) Chang et al. (2005), where a 3 percent improvement is obtained for a system in China and (2) Tilmant et al. (2010), where about a 20 percent increase in power production is obtained by management optimization on the Zambezi system in southern Africa. For small-hydro, observed monthly runoff for four locations in Uganda was used to model the added benefits of a small upstream reservoir. For this, a typical efficiency curve Kaldellis et al. (2005) and a simple, rule-based reservoir operation is used for the four locations. The added benefit of the small reservoir upstream varies across the four sites, from 28 - 60 percent additional generated power. Again using a conservative value, a 20 percent added benefit is applied.

FLOOD DAMAGES TO INFRASTRUCTURE

Flooding events disrupt daily life, cause damage to infrastructure, and impact human health, sometimes resulting in death. This analysis assesses the value of flood risk management in terms of damages to infrastructure. Sound infrastructure underlies the success of the economy across all sectors; and therefore flooding that damages infrastructure can cause impacts across the national economy. MWE management and investment decisions can reduce the risk and magnitude of flooding through sound land management, as forests and wetlands are natural buffers that dampen the impact of flood events.

The flooding model first processes these changes in land use through an algorithm developed by Olang and Fürst (2011) to develop a time series of maximum flood peak multipliers for each of the three investment scenarios. These multipliers are greater than one if forest and wetland cover declines, and less than one if these land use types increase. Using precipitation as a proxy for river runoff, a daily time series of historical rainfall is adjusted using the multipliers, and then the occurrence of design events (e.g., a 15-year return period for paved roads) are counted for each of the 84 river basins and three investment scenarios. Depreciation is assumed to increase with greater occurrence of flood events, and decrease with reductions in flood events.

The frequency and magnitude of flooding events impact the rate at which infrastructure requires repair or replacement. The CGE model incorporates these impacts as changes to the capital depreciation rate in the health, industry, education, water supply, transportation, and housing sectors.

WATER QUALITY

MWE is responsible for water quality in the country's most productive fisheries (i.e. Lake Kyoga, Lake Albert, Lake Victoria, and Lake Edward), and does so by managing contaminant loadings and conserving wetlands, which serve as natural filtration systems. Fish exports represented up to 15.2 percent of all agricultural exports in the time period between 2006 and 2010 (MAFAP 2013).

LBWQ is used to model water quality in the four major fisheries based on the management of nearby wetlands, forests, and other scenario specific inputs including changes in loadings associated with livestock water supply (i.e. as more livestock move away from rivers as their primary source of water, bank erosion and nutrient loadings are improved). A reduced form statistical relationship between catch rates and nutrient loadings, specifically dissolved oxygen (DO), is then used to estimate a time series of catch rates for these four fisheries, which are aggregated to calculate production shocks to the fishing industry.

TIMBER PRODUCTION

The forestry sector contributes about 5 percent of the nation's GDP. Beyond the national accounting impacts, forests can also provide indirect benefits such as soil protection, water conservation, climate control, and water flow regulation (Bush et al. 2004).

MWE regulates timber harvests to balance sustainable yields with continuous production and manages forest rehabilitation efforts. While forest area has been declining in recent years, under Vision 2040, 24 percent of Uganda's land area is to be forested (from a current 11 percent coverage rate). This will require significant investment and management by MWE to achieve this goal, as much of the current deforestation is due to rural communities encroaching on forested area, primarily for fuelwood. A portion of the forested land, both current and future, is devoted to timber production, particularly eucalyptus and pine. Assuming a constant proportion of productive forest to total forested area, based on figures provided in the National Forestry Plan (GOU 2013a), and yield rates for the primary species, total timber production is estimated in each year as available land for production changes.

FUELWOOD: HEALTH AND TIME USE

Over 95 percent of Ugandan households use firewood or charcoal as their primary cooking fuel (UBOS 2014c). Repeated exposure to the emissions from burning fuelwood is responsible for respiratory illnesses that can cause lost time at work and even death. These illnesses impact women and children disproportionately, as they spend the most time in proximity to the fuelwood cook stoves.

In order to reach the Vision 2040 forest cover target of 24 percent of the land area, households will need to switch away from fuelwood and charcoal to other fuel sources such as kerosene or electricity. This diversion from fuelwood will result in health cost savings and improved labor productivity due to fewer incidences of respiratory illness and reduced time spent gathering fuel.

This analysis utilizes previous studies on the health effects of fuelwood stoves to derive a relationship between fuel source and health care costs. A relationship is also used to estimate the effect of increased available time and educational opportunity on the size and composition of the labor force (i.e. the proportion of skilled versus unskilled laborers). These labor and cost impacts are entered into the CGE. The CGE is also able to incorporate the additional cost of the substitute fuel types.

ECOSYSTEMS PROTECTION

Tourism represents about 9 percent of total GDP (GOU 2015) and is highly dependent on sustainable management of natural resources. Ecotourism, and water based recreation in particular, is a large draw to the country. One in ten tourists to Uganda raft on the Nile, which involves direct contact with the water resource (GOU 2003). This analysis uses a notional analysis to show how improved water quality can affect water based recreation and tourism.

Land use management policies, particularly those related to maintaining forest and wetlands cover as they impact water based recreation have important consequences on the tourism industry. A review of existing literature is used to define a relationship between land management and impacts to the tourism industry.

ECONOMY-WIDE MODEL

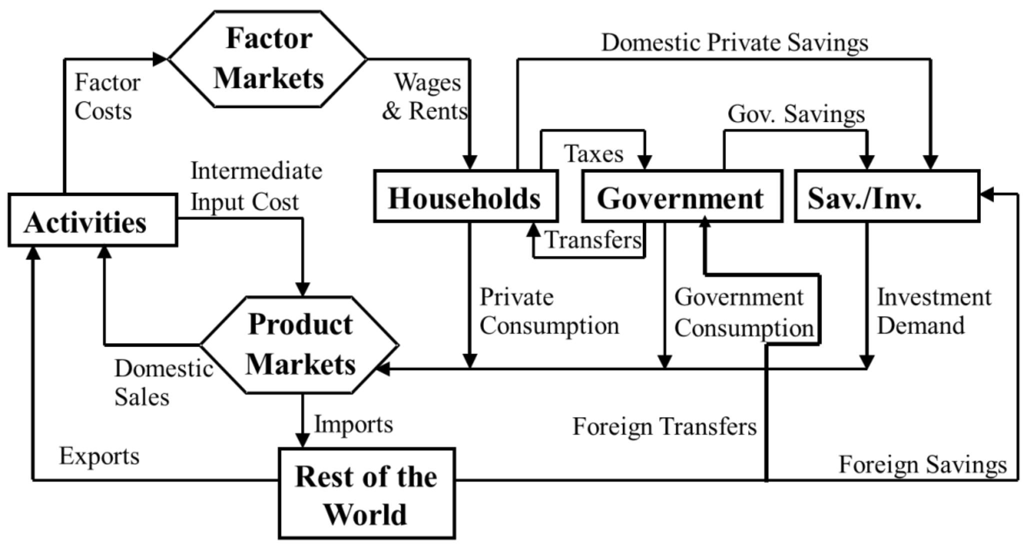
CGE models allow translation of management actions into economic effects, and provide a full accounting of production, consumption, and trade in a particular economy based on a set of defined parameters. They have become widely used in policy analysis in developing countries since their first applications in the mid-1970s. This analysis applies a modified version of IFPRI's Standard CGE model, which is written in GAMS. Below, a brief description of the Uganda CGE model is provided. For a more detailed discussion of the IFPRI standard model, see Lofgren et al. (2001).

OVERVIEW OF CGE MODEL

The Uganda CGE model follows the disaggregation of a Social Accounting Matrix (SAM), and was written as a set of simultaneous equations, many of which are non-linear. These equations define different actors' behavior, which in part follows simple rules captured by fixed coefficients (e.g., ad valorem tax rates). The model captures production and consumption behavior through non-linear, first-order optimality conditions of profit and utility maximization. The equations also include a set of "system constraints" that define macroeconomic equilibria (balances for savings-investment, the government, and current-account of the rest of the world) and equilibrium in markets for factors and commodities.

Figure 2-11 provides an overview of the links between the components of the standard IFPRI CGE model employed here, where the arrows represent payment flows. Disaggregation of the SAM determines the disaggregation of representative households, factors, and commodities. The model includes "real" flows for commodities or factor services that have arrows in the opposite direction—with the exception of taxes, transfers and savings. The activities carry out production, and allocate their income from output sales to intermediate inputs and factors.

FIGURE 2-11 STRUCTURE OF PAYMENT FLOWS IN THE STANDARD CGE MODEL



Source: Strzepek et al. 2007

DESCRIPTIONS OF FLOWS WITHIN THE ECONOMY

Producers are assumed to maximize profits subject to prices and a nested technology in two levels. At the top, output is a Leontief function of aggregates of value-added and intermediate inputs. At the second level, aggregate value-added is a constant elasticity of substitution (CES) function of factors, whereas the aggregate intermediate input is a Leontief function of disaggregated intermediate inputs. The agricultural sector is disaggregated to better represent the impact of droughts and water shortfalls. An external shock to the value added represents the yield shock on agricultural activities as well as the diminution in hydro-electric production due to water stress. This is described further in Robinson and Gueneau (2013). Each year, land is allocated efficiently across crops according to profitability.

Producers take prices as given when making their decisions, based on the assumption that they are small relative to the market and have no perfect forecast. After meeting home consumption demands, the model allocates outputs between the domestic market and exports in shares that respond to changes in the ratio between domestic and world producer prices. Supplies of exports in world markets follow the small-country assumption: they are absorbed by infinitely elastic demands at fixed prices. Supplies from domestic and world producers meet domestic market demands. For all commodities, the ratio of imports to domestic output demand responds to changes in the relative prices of imports and domestic output sold domestically. An infinitely elastic supply of imports at fixed prices meets import demand. In domestic markets for domestically sourced products, quantities demanded and supplied are assured to be equal through flexible prices.

Producers' factor costs are passed on as receipts to the household block in shares that reflect endowments. The household block may also receive transfers from other households, the government (which are CPI-indexed), and the rest of the world (fixed in foreign currency). Households spend these incomes on savings, direct taxes, transfers to other institutions, and consumption. This analysis models savings, direct taxes, and transfers as fixed income shares. For both home-consumed and market-purchased goods, consumption is divvied across commodities according to LES (Linear-Expenditure-System) demand functions, which are derived from utility maximization.

The government receives taxes from households and transfers from the rest of the world, which it then spends on consumption, transfers to households, and savings. The current account of the balance of payments (i.e., the rest of the world) receives foreign currency for imports, and then spends these earnings on exports, transfers to government, and on foreign savings. Finally, savings from all institutions are collected in the investment account and used to finance domestic investment.

Water and environmental goods are integrated in the CGE both as inputs to production and their impacts on labor, land, and capital productivity. Estimates of water use by sector are provided in Annex 5.

CGE MODEL OUTPUTS

Each model solution provides a wide range of economic indicators (e.g., GDP; consumption for households via estimation of value added to labor; sectoral production and trade volumes; and commodity prices). Changes in GDP are used as an indicator of total value of the investments to the economy, while changes in consumption provide an indication of whether those gains accrue to households (mainly as value added to wage-earners), or to the owners of capital (as value added to capital owners).

The ability of the CGE to model interactions between sectors is a significant benefit over partial equilibrium alternatives. In this study, the indicators estimated under each of the investment scenarios are compared to understand the relative value of each investment to the economy.

CHAPTER 3 | CHANNEL MODELING RESULTS

This chapter presents the channels modeling outlined in Chapter 2. The channel modeling includes biophysical modeling, as well as results of non-market valuation research for selected channels (for example, effects on wetlands). The channels models represent the intermediate steps necessary to translate biophysical modeling results into inputs for the general equilibrium model. The ten impact channels reviewed in this chapter correspond to those areas in which MWE engages in investments that represent costs to the economy, but that also modify biophysical outcomes in ways that contribute, through the channels, to enhanced economic productivity. These ten channels are: crops; livestock; water for industry and services; water supply and sanitation; hydropower; flood damages to infrastructure; timber production; fuelwood effects on health and time use; water quality; and ecosystem protection. We first review the trajectory of overall investment costs associated with MWE environmental management actions anticipated over the next 25 years, then review the estimated benefits of those investments for each of the channels, in biophysical and, in some cases, economic terms.

INVESTMENT COSTS

Water resources development and environmental management actions typically involve capital and annual investment costs to effect beneficial changes to water resource quantity and quality, to environmental quality, and to land management. As outlined in Chapter 2, the estimated investment costs are derive mostly from the current MWE Strategic Sector Investment Plan, which includes estimates of both total and unit investment costs for nearly all of the planned sectoral investments, linked to specific water and environmental management goals. Both capital and annual recurring costs are included in the estimates presented here.[7]

The results in Table 3-1 below reflect the change in annual average investment costs between enhanced investment scenarios and BAU. The results indicate that costs generally increase over time in the moderate investment scenario, but are "frontloaded" in the high investment scenario. The total cost for the high scenario, relative to BAU, is 57 percent higher than for the moderate scenario (considering the three results represent average annual costs, for a 10 year, a second 10 year, and a final 6 year period, in aggregate), and the great majority of the difference in scenarios is accounted for by investments made in the first decade (the 2015 to 2025 period, centered on 2020).

[7] For more details on cost estimation, see Annex 12.

TABLE 3-1 CHANGE IN ANNUAL AVERAGE INVESTMENT COSTS FOR BAU TO MODERATE, AND MODERATE TO HIGH INVESTMENT SCENARIOS

	2020	2030	2040
Moderate - BAU Investment	$159	$213	$267
High - BAU Investment	$420	$227	$314

Note: Costs in undiscounted annual $2015 USD (millions), averaged over 10 year periods centered on the year shown (2040 represents 2035-2040).

Disaggregated incremental costs for nine investment focus areas are provided in Table 3-2. These largely correspond to the channels outlined in Chapter 2, and below in the remainder of this chapter, except that flood, fuelwood, water quality, and ecosystem protection benefits accrue as a by-product of forest and wetland management efforts, and household water sector investments yield benefits in terms of health. Note that costs for alternative fuels to replace wood and charcoal are not included here, because they are technically not an MWE investment, but these new fuel costs are reflected in the full CGE runs as households incur a market cost for kerosene or natural gas fired cookstoves. As indicated in the table, investments such as forest rehabilitation, wetlands restoration, water storage, livestock, and irrigation account for most of the difference between the high and moderate scenarios. Overall, the environmental management actions account for a higher share of the upfront investment, but in later years continued investment in the water sector means that in aggregate the two main categories (water and environment) account for comparable portions of the overall investment costs (roughly $4.3 billion for water development, and $4 billion for environmental management for the high scenario over the full 26 year period).

For some investments, such as forest rehabilitation and wetlands restoration, the change in cost, especially between the high to moderate scenario, are much greater in the earlier time periods due to aggressive near term goals in the high scenario. In general, costs in all sectors increase over time as demand for MWE services, natural resource investment targets, or both increase.

TABLE 3-2 MEAN ANNUAL INVESTMENT COSTS BY SECTOR ($MILLIONS)

Investment		Moderate-BAU Investment			High-BAU Investment		
		2020	2030	2040	2020	2030	2040
Water Development	Water Storage	$14	$33	$47	$23	$55	$78
	Irrigation	$8	$18	$23	$27	$60	$76
	Livestock	$1	$2	$2	$10	$15	$19
	Household*	$25	$29	$46	$35	$32	$56
	Industry and Services	$3	$11	$28	$5	$15	$35
	River Flow Management	$0.2	$0.1	$0.1	$0.2	$0.1	$0.1
Environmental Management	Forest Rehabilitation	$41	$46	$46	$135	$50	$50
	Wetlands Restoration	$67	$74	$74	$185	$0	$0

Note: Costs in undiscounted annual $2015 USD (millions), averaged over 10 year periods centered on the year shown. *Household sector includes water supply and sanitation programs.

Storage requirements, in units of million cubic meters, are provided in Table 3-3 below. The storage requirements reflect biophysical modeling of hydrologic conditions in each of the four regions of Uganda, and projections of water demand in each region, along with the amount of erosion and soil deposits expected given land cover. Hydrologic conditions, and in particular the projection of monthly flow and flow variation, dictate whether storage can be a solution to conditions of unmet water demand. Hydrologic conditions, coupled with projected water demand therefore largely determine the variation in new storage requirements across regions. Differences in storage requirements between the moderate and high investment scenarios are a reflection of the level of water demand – for example, a high level of investment in irrigation infrastructure creates a higher irrigation water demand, and in turn a higher level of storage requirement.

TABLE 3-3 PROJECTED REGIONAL STORAGE REQUIREMENT TO MEET 2040 DEMANDS (MCM)

Investment Scenario	Central	Eastern	Northern	Western
Base 2015 Storage	294	250	154	13
Moderate Investment Scenario	1216	994	586	234
High Investment Scenario	1223	2195	1706	269

Storage requirements represent a multi-sector investment. Detailed cost estimates for these investments are provided in Annex 7, disaggregated by region and investment scenario, and are reflected as a monetized investment requirement when passed to the CGE.

In a traditional benefit-cost framework, costs could be compared reliably to quantified and monetized benefits to assess whether the investments are worthwhile. For several reasons, such a comparison is not necessarily appropriate here. First, many of the costs outlined above have multiple benefits – for example, water storage infrastructure affects water availability for crops, livestock, and municipal and industrial demands, providing multiple benefits. The “joint costs” nature of these investments makes it difficult to conduct a reliable sector-disaggregated benefit-cost analysis. Second, there are significant non-linearities in the nature of benefits that might be attributed to individual investments – as a result, only packages of investments might potentially be amenable to benefit-cost comparisons, not necessarily individual investment components. Third, and most important, the main focus of this work is establishing a defensible linkage between MWE management actions and investments on the one hand (which constitute costs), and economic productivity on the other hand (a metric for benefits). As a result, some of the benefits of these investments, as described in the sectoral results sections below, are quantified to the extent necessary for their inclusion in the CGE, but are not directly monetized. For those categories, the only monetization of benefits is done through the aggregated analysis of GDP and other measures in the CGE.

There are also large, and in some cases very large, omitted categories of benefits that do not lend themselves to inclusion in the CGE. For example, the health sector results omit a very large component of willingness-to-pay to avoid waterborne disease – the benefits below capture an estimate of the market costs associated with avoided disease, but omit all components of non-market aspects. Most individuals behave in ways that reveal a high willingness to pay to avoid disease, but most of this behavior is not reflected in national product accounts. Many ecosystem values are also omitted, as shown in the last sector of this chapter for wetlands and forests. While much of the information assembled here provides a stronger basis for conducting benefit-cost comparisons for sectoral investments, since that is not the main focus of this work we do not attempt rigorous benefit cost comparisons here, but focus instead on the impact of these investments on the Ugandan economy.

WATER RESOURCES DEVELOPMENT BENEFITS

Estimated benefits of MWE water management and investment across the ten channels, which are used as inputs to the macro-economic modeling described in Chapter 4, are outlined below. Further details on these impacts can be found in Annex 11.

CROP PRODUCTION

The main direct benefit to crops of MWE investments in irrigation infrastructure is an expansion in irrigated crop area. Table 3-4 below provides a summary of this projected expansion by crop, investment scenario, and region. The largest increases across investment scenarios are for rice, vegetables, and sugarcane – smaller increases are projected for flowers and maize. Increases in irrigated crop areas translate to higher overall agricultural yields, as irrigated areas have both higher yields and lower variability in yield compared to rainfed areas, subject to the condition that sufficient surface water resources are available to support the irrigation. The CGE is programmed to use crop areas, and estimated rainfed and irrigated yields by crop as inputs, and uses this information along with estimates of regional prices (for import substitutes) and local prices (estimated within the CGE) to calculate economic production for the crops component of the agriculture sector.

TABLE 3-4 PROJECTED IRRIGATED CROP AREAS IN 2040 (HA)

Crop	BAU Investment Scenario				Moderate Investment Scenario				High Investment Scenario			
	Central	Eastern	Northern	Western	Central	Eastern	Northern	Western	Central	Eastern	Northern	Western
Avocado	3	0	0	0	3	0	0	0	3	0	0	0
Beans	0	1	0	0	0	8	0	0	0	21	0	0
Coffee	4	0	0	0	3	3	0	0	5	8	0	0
Flower	213	0	0	10	236	920	0	10	648	2,500	0	30
Maize	0	60	0	0	0	1,616	403	0	0	4,603	1,176	0
Rice	0	1846	55	0	3,569	28,748	19,195	2,024	10,416	80,389	55,933	5,909
Sugarcane	322	1505	0	0	1,821	7,593	576	147	4,739	19,463	1,681	430
Vegetables	0	0	4	672	0	0	7,930	8,486	0	0	23,143	23,483

The biophysical models are also used to provide estimates of year-to-year variability in rainfed crop yields. Rainfed crop variability, shown in Table 3-5, is crop and region specific and reflects crop yield modeling with respect to historical precipitation, temperature, soil, and potential evapotranspiration conditions.[8] The coefficient of variation is used in the CGE to represent the higher yield variability of rainfed versus irrigated crops – lower yield variability for irrigated crops is one of the difficult to estimate benefits of an increase in irrigated area that nonetheless can be captured in the CGE.

TABLE 3-5 COEFFICIENTS OF VARIATION ON RAINFED CROP YIELDS, 2015-2040

Crop	Central	Eastern	Northern	Western
Plantain Bananas	0.29	0.32	0.24	0.26
Finger Millet	0.31	0.36	0.28	0.37
Maize	0.30	0.35	0.29	0.25
Sorghum	0.18	0.27	0.21	0.21
Rice	0.30	0.35	0.28	0.28
Sweet Potatoes	0.30	0.33	0.32	0.34
Irish Potatoes	0.28	0.36	0.37	0.32
Cassava	0.30	0.34	0.32	0.33
Beans	0.29	0.34	0.24	0.34
Field Peas	0.28	0.35	0.25	0.29
Cow Peas	0.30	0.37	0.31	0.23
Pigeon Peas	N/A	0.36	0.34	0.30
Ground Nuts	0.13	0.11	0.06	0.09
Soya Beans	0.17	0.18	0.13	0.16
SimSim	0.16	0.14	0.10	0.09

The benefits of irrigation may be limited by the availability of water for irrigation. Unmet water demands in the irrigation sector therefore depress yields relative to the potential yield. The biophysical models provide an estimate of unmet water demands by region, crop, and scenario, and these can be combined with the elasticity of yield with respect to water availability to estimate the unmet water demand penalties, shown in Table 3-6. Maize, rice, and sugarcane, as relatively water intensive crops, show the greatest yield deficits in Table 3-6. Deficits are larger in the high investment scenario because of competition for water from other sectors, which increases unmet irrigation water demand.

[8] Further details on crop yields and irrigation requirement modeling can be found in Annex 6.

TABLE 3-6 PROJECTED IMPACTS ON IRRIGATED YIELDS DUE TO UNMET IRRIGATION REQUIREMENTS, 2035-2040

Region	Moderate Investment Scenario				High Investment Scenario			
	Central	Eastern	Northern	Western	Central	Eastern	Northern	Western
Avocado	0%	N/A	N/A	N/A	0%	N/A	N/A	N/A
Beans	N/A	0%	N/A	N/A	N/A	3%	N/A	N/A
Coffee	0%	0%	N/A	0%	0%	0%	N/A	0%
Flower	0%	0%	N/A	0%	0%	0%	N/A	0%
Maize	N/A	22%	28%	N/A	N/A	33%	44%	N/A
Rice	0%	23%	5%	0%	0%	30%	7%	0%
Sugarcane	0%	7%	31%	0%	0%	11%	48%	0%
Vegetables	N/A	N/A	0%	1%	N/A	N/A	0%	1%

LIVESTOCK PRODUCTION

The livestock component of the agricultural sector also requires water to achieve full productivity. Poor water access for livestock therefore limits productivity, but investments in increased access can reduce these limits. As shown in Table 3-7, baseline investments in improving water access, as well as an increasing trend in the number of head of livestock over time, are projected to increase livestock yields by a small amount in the first period, and larger amounts in the 2025 to 2030 period, and 2035 to 2040 period. Investments that are incrementally higher than BAU in the moderate and high investment scenarios provide somewhat higher levels of livestock productivity through increased access to water, with the high investment providing a productivity increase of roughly 5 percent more than the BAU by 2040. These results are fed to the CGE as productivity increases for the sector.

TABLE 3-7 MEAN IMPACTS TO LIVESTOCK YIELDS DUE TO IMPROVED WATER ACCESS RELATIVE TO 2015 LEVELS

Investment Scenario	Time Period	Central	Eastern	Northern	Western
Moderate - BAU	2015-2020	0.1%	0.1%	0.1%	0.1%
	2025-2030	0.7%	0.6%	0.7%	0.6%
	2035-2040	1.5%	1.3%	1.5%	1.4%
High - BAU	2015-2020	0.0%	0.0%	0.0%	0.0%
	2025-2030	1.4%	1.4%	1.4%	1.4%
	2035-2040	4.8%	5.4%	4.6%	5.2%

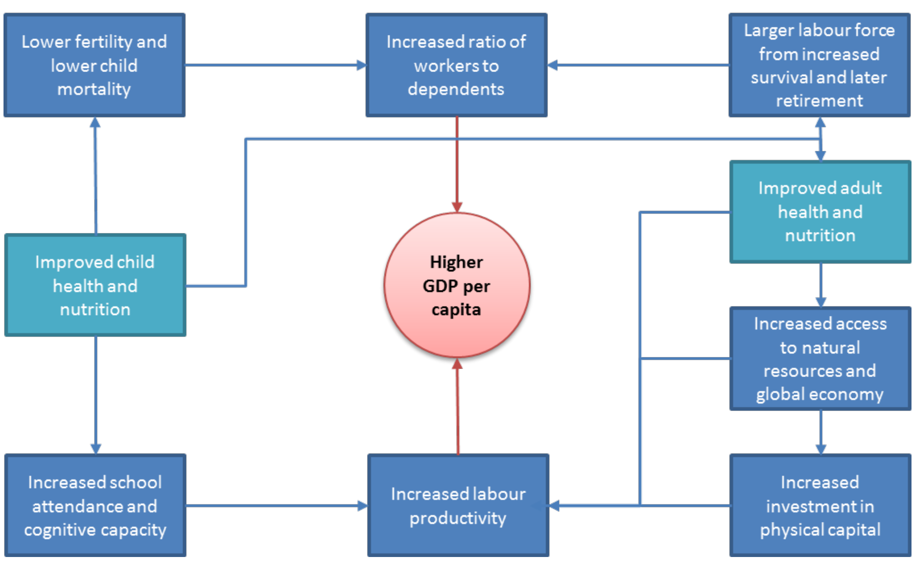
WATER AVAILABLE FOR PRODUCTION

Non-agricultural water, for industry, service sector, and governmental users, may be limited by unmet water demands estimated in the Mike Hydro biophysical model. Investments in water supply to the industrial and services sectors include both MWE investment in distributed water and industry self-supply costs. As shown in the investment costs sector above, most of the investments are in the BAU scenario, and only a relatively small incremental investment (on the order of a few million USD annually) is incorporated in the moderate and high investment scenario, above that in the BAU. The additional investment represents MWE water supply growing to meet the increasing demands projected as the industry and service sectors grow. These investments do increase available water for these sectors substantially, however, over the 2015 to 2040 study period. The increase is proportional by region, and is consistent with about a 4.4 fold increase in the BAU scenario from 2015 to 2040, and 4.6 and 5.1 fold increases for the moderate and high investment scenarios, respectively.

WATER SUPPLY AND SANITATION: HEALTH AND TIME USE

Starting with the classic volume by Saunders and Warford (1976) the economics of village water supply has become a major topic in the public health economics arena. The Water and Sanitation and Hygiene (WASH) nexus and the role of each element (water, sanitation, and hygiene) individually and in concert on human mortality and morbidity, especially on young children has received much research. With the demand for limited government investment funds there has been a recent push to show that these improvements in WASH not only translate into socially desirable improvements in public health but additionally lead to economic growth. These linkages are explained in Lancet (2013) and presented in Figure 3-1. This study likewise will investigate how the impacts of improved public health from investments in WASH by MWE will lead to economic growth.

FIGURE 3-1 LINKAGE OF WASH AND ECONOMIC GROWTH



Source: Lancet, 2013.

Health shocks are derived from four elements:

- the value of time saved from water gatherings, which leads to an increase in labor availability,
- the increase in productive labor hours due to reduced water-borne diseases,
- the increase in skilled labor from children using the reduced time gathering water to attend schools, and
- direct savings in health care cost.

These linkages are used in conjunction with the coverage of water supply and sanitation to create labor productivity shock vectors entered into the CGE. Details of the assumptions underlying this analysis can be found in Annex 11. Table 3-8 provides the results of fourth component of this analysis, which shows the cumulative heath care savings when moving from BAU to moderate, and from BAU to high investment. The total cumulative savings across regions, and across the 25 year period, under the two scenarios is $870 million and $1.0 billion, respectively.

TABLE 3-8 CUMULATIVE 2015-2040 HEALTH CARE SAVINGS BETWEEN THE MODERATE AND BAU SCENARIOS, AND THE HIGH AND BAU SCENARIOS (MILLION USD).

Investment Scenario	Central	Eastern	Northern	Western
Moderate - BAU	$193.6	$235.7	$285.1	$154.4
High - BAU	$224.6	$271.0	$340.2	$177.6

Table 3-9 provides the results of the first three components of this analysis, translated to show the impact of time-saving on the total labor hour endowment (Panel A) and the skilled labor hour endowment (Panel B), over three time periods and over the four regions. The skilled labor increase is associated with enhanced time for education among children who would otherwise, absent the investments, be gathering clean water. As indicated in the table, both total labor and skilled labor endowment increases are largest in the Northern region, and in both cases the increase grows over time – this is particularly true of the skilled labor component, where schooling must be complete before a skilled labor benefit to the economy is realized.

TABLE 3-9 IMPACT OF ENHANCED INVESTMENT ON INCREASE OF LABOR HOURS ENDOWMENT RELATIVE TO 2015

PANEL A: CHANGE IN TOTAL LABOR HOUR ENDOWMENT

Investment Scenario	Time Period	Central	Eastern	Northern	Western
Moderate - BAU	2015-2020	0.4%	0.5%	0.5%	0.5%
	2025-2030	2.0%	2.3%	3.4%	1.8%
	2035-2040	2.5%	3.1%	4.1%	2.4%
High-BAU	2015-2020	1.0%	1.2%	1.4%	1.0%
	2025-2030	2.3%	2.7%	3.8%	2.2%
	2035-2040	3.0%	3.7%	4.7%	3.0%

PANEL B: CHANGE IN SKILLED LABOR HOUR ENDOWMENT

Investment Scenario	Time Period	Central	Eastern	Northern	Western
Moderate - BAU	2015-2020	0.1%	0.1%	0.1%	0.1%
	2025-2030	1.3%	1.4%	2.1%	1.1%
	2035-2040	2.3%	2.7%	3.4%	2.3%
High-BAU	2015-2020	0.2%	0.2%	0.2%	0.1%
	2025-2030	1.0%	1.2%	1.4%	1.1%
	2035-2040	2.2%	2.8%	3.0%	2.6%

HYDROPOWER GENERATION

Electricity production is limited mainly by hydrology and by competing consumptive water demands, but can be enhanced by investments in new hydropower infrastructure, or by water management activities that enhance production. The Mike Hydro biophysical model reflects new hydropower investments (largely though not entirely the purview of the Ministry of Energy, particularly along the Nile) and existing plants. The incremental increases in hydropower that would be associated with MWE water management is processed outside of the model. The model provides an estimate of year by year hydropower production based on expected infrastructure investment.

The results are presented in gigawatt-hours of production in Table 3-10, for those small plants that would be influenced by MWE water management policies. As shown in the table, hydropower production varies substantially by region (the Central region is not suitable for hydropower and by year (affected by the timing of investments and the rate of increasing management between scenarios). These MWE small plant investments are only reflected in the high investment scenario. These physical effects (hydropower production) results can be directly valued in the electric energy sector of the CGE in combination with the endogenously determined Ugandan electric energy price in the model.

TABLE 3-10 AVERAGE ANNNUAL INCREASE IN HYDROPOWER GENERATION (GWH)

Time Period	Moderate to BAU				High to BAU			
	Central	Eastern	Northern	Western	Central	Eastern	Northern	Western
2015-2020	0	22	2	61	0	0	6	305
2025-2030	0	226	248	671	0	0	42	997
2035-2040	0	187	207	791	0	187	207	791

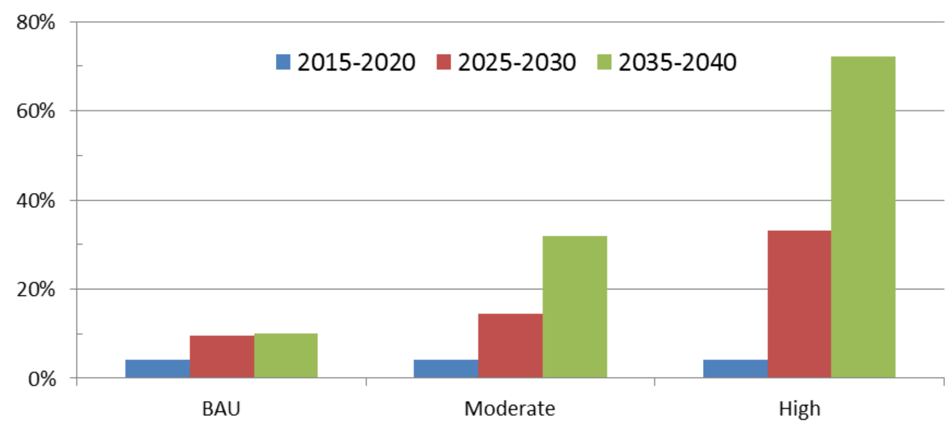
ENVIRONMENTAL MANAGEMENT BENEFITS

Estimated benefits of MWE's environmental management and investment are outlined below. These estimates are used in the economy-wide modeling analyses described in Chapter 4.

TIMBER PRODUCTION

Forest yields are affected by both environmental conditions and by efforts to expand production through afforestation. For this sector, the Project Team estimated the potential for forest production if suitable land were converted to forest in each region, consistent with the planned afforestation goals. In the BAU scenario, even though overall forested land is decreasing, plantation land is projected to grow according to historic rates of growth in the timber sector. The moderate and high investment scenarios consider partial and full implementation of the forest management plan. Both show large increases over time and consistently across all regions, relative to the BAU scenario. Under the BAU, forest yields increase by 10 percent by 2040, but under the moderate investment yields increase 32 percent, and under the high investment scenario by 72 percent. The results are presented in Figure 3-2, and are used as scalars to adjust the forest production sector in the CGE.

FIGURE 3-2 IMPACTS TO FOREST YIELDS RELATIVE TO CURRENT (2015) YIELDS



FUELWOOD: HEALTH AND TIME USE

Investments in forest protection to meet the Vision 2040 afforestation goals imply that households gradually move away from fuelwood and charcoal as their primary source of cooking fuel. There will be costs to this shift in fuel type - in addition to the costs incurred by MWE to implement the afforestation program; households will also need to pay for kerosene or other fossil fuels to replace wood for cooking and heating needs. Such a shift, however, also entails additional benefits to health and labor productivity. The fuel costs are reflected in the CGE by higher direct expenditures by households on fossil fuels, which, because Uganda has no substantial domestic production will need to be imported. The benefits of this program, however, are substantial, and are described in this section.

A shift from firewood and charcoal to fossil based cooking and heating, in addition to being consistent with MWE's afforestation goals, provides three categories of benefits:

- Time savings, as fuelwood no longer needs to be gathered, which frees up labor for market uses and education.
- Health benefits, as a shift from wood and charcoal to fossil based cookstove fuels has been shown to greatly reduce exposures to airborne fine particulates, which cause serious respiratory disease and can lead to premature mortality.
- Greenhouse gas mitigation benefits, because even though fossil fuel burning also produces greenhouse gases, the greater fuel efficiency of fossil cookstoves (or even improved wood and charcoal stoves) reduces energy use and therefore greenhouse gas emissions.

For this study, the first two categories of benefits are quantified and fed to the CGE, while the last category is omitted because an economic value for greenhouse gas emission reductions in Uganda has not yet been reliably established.

The health benefits are estimated as avoided health care costs associated with lower respiratory disease incidence. These costs are presented in Table 3-11. Although the time trend is not presented, these benefits are realized only after a lag, as the health benefits do not accrue immediately after air pollutant exposure cessation.

TABLE 3-11 CUMULATIVE 2015-2040 HEALTH CARE SAVINGS BETWEEN THE MODERATE AND BAU SCENARIOS, AND THE HIGH AND BAU SCENARIOS. (MILLIONS $USD)

Investment Scenario	Central	Eastern	Northern	Western
Moderate - BAU	$2,814.1	$1,918.0	$1,661.5	$2,190.5
High-BAU	$2,938.9	$2,015.9	$1,745.5	$2,297.9

The time savings associated with reduced fuelwood use and need for gathering, and the resulting increase in labor hour endowment available for other work, is provided in Table 3-12 below.

TABLE 3-12 IMPACT OF ENHANCED INVESTMENT ON INCREASE OF LABOR HOURS ENDOWMENT RELATIVE TO 2015

Investment Scenario	Time Period	Central	Eastern	Northern	Western
Moderate - BAU	2015-2020	4.2%	3.2%	3.5%	3.7%
	2025-2030	20.7%	15.2%	16.7%	17.6%
	2035-2040	35.2%	24.1%	26.5%	28.6%
High-BAU	2015-2020	6.5%	5.1%	5.6%	5.8%
	2025-2030	20.7%	15.2%	16.7%	17.6%
	2035-2040	35.2%	24.1%	26.5%	28.6%

FLOOD DAMAGE TO INFRASTRUCTURE

To assess the impact of MWE land management on flood damage to infrastructure, this assessment uses a transportation infrastructure flood damage model to estimate the damage to the transportation sector, then relies on empirical studies for the relative damages in other sectors. Additional literature values relate MWE land management to flood frequency, which when combined with the damage models, estimates the value of MWE management as avoided damages.

A transportation infrastructure analysis on flooding estimates the costs of floods when infrastructure is designed for different flood return periods or intervals (RI) (i.e. if a return period is 10 years, there is a roughly 1 in 10 chance that flood will occur in any given year). The historical precipitation magnitudes for five, 15, and 20 year flood events were estimated for Uganda, based on current land use and other climatological variables. Damage estimates were then calculated for three additional scenarios using the precipitation magnitude for each return interval, increased by 10, 20, or 30 percent, simulating potential impacts of land use management changes, as shown in Table 3-13.

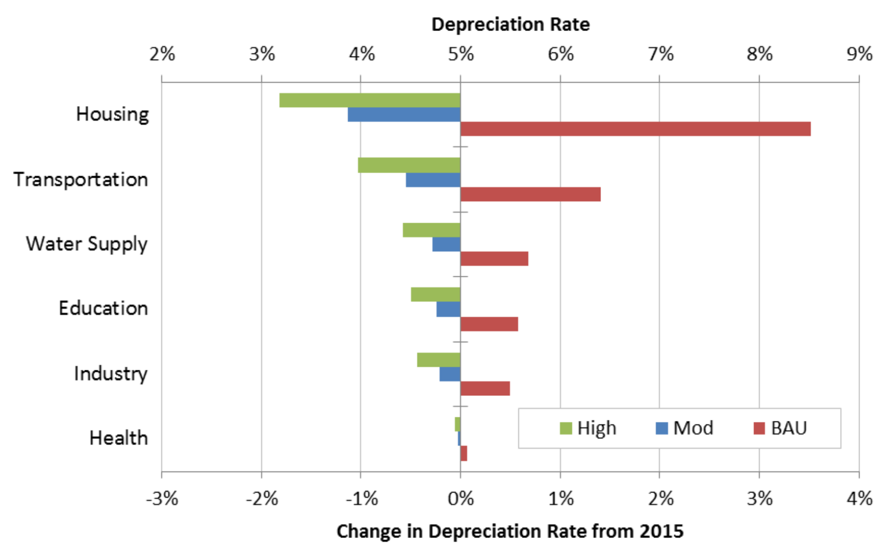
TABLE 3-13 COSTS OF FLOODING ON EXISTING ROADS INVENTORY (2015-2040 TOTAL COST, MILL $USD, DISCOUNTED3%)

	GRAVEL			PAVED
Precipitation Magnitude *R I Design*	**15**	**10**	**5**	**15**
Historic	$57.71	61.80	$68.68	$7.23
+10% Historic	$67.52	$72.07	$79.65	$8.46
+20% Historic	$77.68	$82.67	$90.98	$9.74
+30% Historic	$88.32	$93.71	$102.78	$11.07

The effect of land management on flood extent is estimated by reference to an empirical study of the reduction in flood levels in neighboring Kenya (Olang and Fürst 2011). The relationship between precipitation magnitude and flood damages is combined with the relationship between land management and flood outcomes to estimate transportation damages under each investment scenario. The relative magnitude of transportation damages to damages in other sectors of the economy is derived from a report on damages of a 2015 flood in Malawi (Government of Malawi 2015).

The avoided damage estimates are passed to the CGE as a multiplier on the depreciation rate on capital in each affected sector, which is effectively a total factor productivity shock. The base depreciation rate is assumed to be 5 percent per year. Flooding damages, represented by the costs shown in Table 3-13, are translated to incremental increases in depreciation via periodic floods, as shown in Figure 3-3 below. Under the BAU, the depreciation rates increase in all sectors modeled, including almost doubling in the housing sector – such a change in flood risk is not inconsistent with flood risk changes that might be expected in the BAU as a result of climate change. Under the moderate and high scenarios, investments in land management yield decreases in flood damages, and therefore decreases in depreciation of capital stock. Again the largest impacts are seen in the housing sector; however transportation also sees a 20 percent decrease in the depreciation rate in the high investment scenario.

FIGURE 3-3 IMPACTS TO CAPITAL DEPRECIATION DUE TO FLOODING RELATIVE TO CURRENT (2015) LEVELS 2030-2040

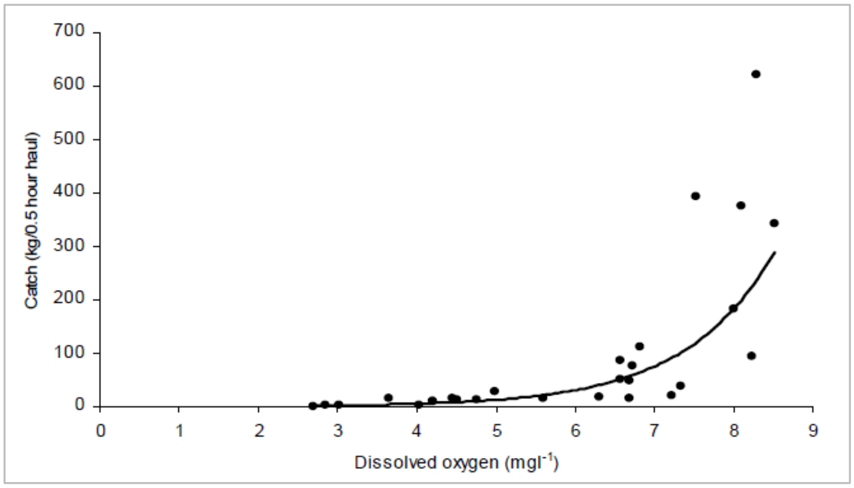


WATER QUALITY

Fish catch is directly affected by water quality. Using the LBWQ model and a reduced-form relationship between fish catch and dissolved oxygen (DO) concentration, this analysis evaluates the potential effects of catchment management, afforestation, and other land management actions on the fishing economy in Uganda. As noted in Chapter 2, the focus is on the four major lakes in Uganda: Victoria, Edwards, Albert, and Kyoga. Details of the water quality modeling approach are provided in Annex 7.

The relationship between DO concentration and catch rate is provided below in Figure 3-4 (adopted from Njiru et al. 2012). This formulation produces shocks to fishing activity, based on changes in water quality, and the shocks are used as a direct input to the fisheries production sector in the CGE.

FIGURE 3-4 TRENDS IN NILE PERCH CATCHES WITH CHANGES IN DISSOLVED OXYGEN IN LAKE VICTORIA, KENYA IN 2010



Source: Njiru et al.

The result of these calculations is provided in Table 3-14 below. An ongoing trend of reduction in dissolved oxygen and fisheries catch rate results in a declining BAU trend in all four regions (not shown in the table, but reflected in the BAU scenario). The moderate and high investment scenarios, by contrast and as shown in the table, slow and then reverse this trend, resulting in improvements in fish catch rates over time relative to BAU, owing to investments in afforestation and wetland restoration that improve water quality.

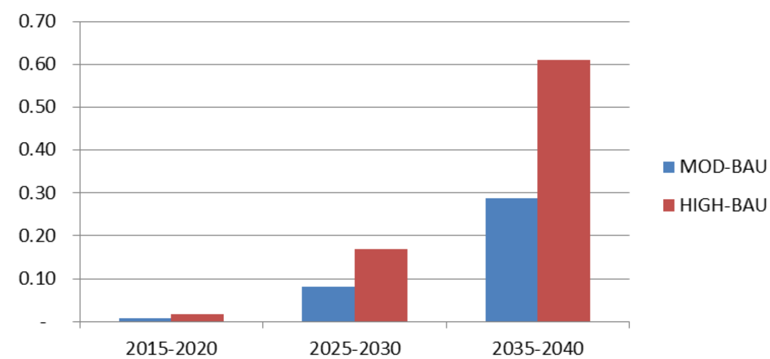
TABLE 3-14 IMPACTS ON FISHING PRODUCTION RELATIVE TO BAU LEVELS

Investment Scenario	Time Period	Central	Eastern	Northern	Western
Moderate - BAU	2015-2020	3.2%	1.8%	7.0%	9.5%
	2025-2030	13.5%	12.6%	23.1%	26.4%
	2035-2040	23.1%	24.6%	35.4%	36.1%
High-BAU	2015-2020	28.1%	35.2%	41.3%	45.9%
	2025-2030	49.5%	58.6%	77.6%	85.3%
	2035-2040	40.7%	42.7%	70.9%	76.6%

ECOSYSTEM PROTECTION

The effects of land management on tourism are addressed in a partial manner by focusing on the impacts on water based recreation. This analysis assumes that under improved land management, particularly forest and wetlands protection, attributes of a water based recreation trips in Uganda, such as water quality, natural surroundings (i.e. less development), and wildlife viewing opportunities will increase such that this portion of the tourism sector will grow five to ten percent faster than the current growth rate of the tourism sector overall (5 percent under moderate investment; 10 percent under high investment). The impact of the increased growth rate is especially significant in the later years of the analysis although the impacts can also be seen in the first five years. These proportional shocks are transferred to the CGE.

FIGURE 3-5 INCREASE IN SECTORAL PRODUCTIVITY MULTIPLIER RELATIVE TO BAU



Each of the impacts estimated above, the results of both water resource development and environmental management, enter the CGE sot eh full impacts, both direct and indirect, can be evaluated.

NON-MARKET WATER RESOURCES AND ENVIRONMENTAL MANAGEMENT BENEFITS

In addition to the economic benefits incorporated into the CGE model, wetlands and forests provide a variety of ecological benefits that are not quantified by the model. Past studies have attempted to quantify some of these benefits. General work in the literature has established a wide range of non-market, ecological service flow values, usually expressed in units of dollars per unit area of wetlands. Forests, while less well studied, and largely unstudied in Uganda, provide clear market values for timber production, and as outlined above can provide quantifiable and readily monetized values associated with flood protection. Forests also support recreation and tourism (a main focus for the tourism channel described above), carbon sequestration services (which serve to effectively contain carbon which might otherwise contribute to global climate change), and biodiversity and existence values. Attempts to catalogue and quantify these effects have not to date focused on Uganda, and only a few studies have addressed values in Africa, but the annual per hectare values can range from a few dollars to well over $1,000 (see SCBD 2001).

Wetland values in in Uganda and in Africa more broadly, provide a stronger basis for establishing a set of ecosystem service values. For example, in 2001, Karanja et al. published values on goods and services provided by wetlands in Uganda's Pallisa District. The district contains approximately 71,000 hectares of wetlands, mainly within the Kyoga-Lwere, Mpologoma, and Namatala drainage systems. The Pallisa District, along with the Kabale and Masaka districts, was identified by this study as "having important wetlands, that face severe threats, and require urgent management interventions." The study aimed to capture the total economic value of wetlands, including both use and non-use values. A second study, by Woodward and Wui (2001), provides an alternative means for estimating the economic value of wetlands. A summary of these benefits and their valuation is provided in this section.

Table 3-15 below is a representative list of ecological goods and services provided by wetlands, but is not comprehensive of all the possible benefits of wetlands. Additional benefits include grazing; herbal and traditional medicines; flood attenuation; provision of fishery nurseries; micro-climate regulation; and others. Other studies conducted in South Africa (Turpie et al. 2010) and New Zealand (Clarkson et al. 2013) suggest that provisioning services could range from $84 to over $17,000 per hectare; regulating services could range from $17,000 to $45,000 per hectare, habitat services could range from just under $1,000 to about $3,500 per hectare, and cultural services could range from $4,000 to $8,400 per hectare. Tourism values alone can range widely, from $160 to over $40,000 per hectare. These ranges illustrate the importance of understanding the context in which values are estimated. In addition, these studies suggest that wetlands values are not likely to be static – it is reasonable to expect that the values will change over time, depending on economic co-dependencies and substitutes both locally and throughout the economy.

TABLE 3-15 SUMMARY OF WETLAND SERVICE VALUES

Wetland Service	Value (2016 $/ha)		Wetland Service	Value (2016 $/ha)
Yams cultivation	$135.65		Sand harvesting	$0.01
Grass harvesting for roof thatching	$21.55		Sugarcane revenues	$0.62
Raw papyrus	$24.43		Rice growing	$57.58
Papyrus mats	$0.26		Rice milling	$43.57
Palm mats	$0.04		Soil fertility maintenance	$5.39
Fish value	$6.85		Water recharge	$25.79
Water transport	$1.96		Water treatment	$7.25
Wetland trees	$96.85		Water irrigation	$117.45
Pottery	$10.87			
Total economic value of wetlands - Karanja et al. 2001				**$556.14**

Wetland Service	Value (2016 $/ha)		Wetland Service	Value (2016 $/ha)
Flood control	$69.00		Habitat	$48.00
Groundwater recharge	$55.00		Recreation	$245.00
Water quality management	$66.00		Amenity	$1.00
Total economic value of wetlands - Woodward and Wui 2001				**$484**

The summary of per hectare values for wetland services provided above provides a means of assessing the non-market, total estimated wetland values under the moderate and high investment scenarios. The moderate investment scenario is consistent with 10.9 percent wetland coverage in 2015, and projects that wetland coverage decreases to 10% in 2020, and remains at 10 percent through 2040 (consistent with a total of just under 2 million hectares of wetlands throughout Uganda by 2040. In the high investment scenario, wetland coverage starts at the same 10.9 percent in 2015 base value, but increases to 13 percent by 2020 and remains at that level through 2040.

Using the valuation estimates from both of the two sources summarized above, the total ecosystem service value of all wetland services in 2020 are approximately $970 million to $1.11 billion annually in the moderate investment scenario, and $1.26 to $1.44 billion annually in the high investment case. These estimates imply a marginal value of the high investment case, relative to the moderate investment case, of approximately $300 million annually.

These Uganda-specific valuations may in fact be substantial under-estimates – for example, a recent study of the total economic value of wetlands in three agro-ecological zones in Uganda (the southwestern farmlands, Lake Victoria crescent, and Kyoga plains) – suggests that net benefits per hectare annual could be in excess of $10,000 (Kakuru et al. 2013). A large component of that total is attributed to non-use values, a type of cultural value, and other large components are associated with livestock watering and crop farming, which are at least partially accounted for in the quantified components of the channels described above.

Unfortunately, as described in Annex 1, per hectare non-market valuation estimates such as this are not typically accepted as methodologically robust by international standards. In addition, economic welfare based estimates such as this are not readily incorporated in national product accounts. As a result, these values are not reflected in the CGE modeling described in Chapter 4.

This chapter presents the results of the general equilibrium model including 1) estimates of the dependence of the economy on water and 2) the effects of MWE management on the economy.

DEPENDENCE OF THE ECONOMY ON WATER RESOURCES

The CGE model is able to produce a suite of results reflecting specific economic growth assumptions, biophysical model usage, and investment scenarios. While the reliability of the CGE is greatly improved by refined biophysical inputs, it is also able to produce results for general cases. Results of the general runs (i.e. no defined hooks to the biophysical models) give insights as to the sectors most dependent on water and environmental resources, and which biophysical processes are likely to have the most significant effects on economic indicators. The results presented below help us to identify the sectors and underlying biophysical processes with the strongest dependence on water and natural resources. A key finding of this analysis is that water is inexpensive and generally plentiful in Uganda—the issue is how water is managed. Ensuring water reaches the right locations, at the right times, at the right level of quality will reduce constraints to future economic growth and structural transformation.

Key results from the analysis of the dependence of the economy on water resources include:

- The agriculture sector is, as expected, the main *direct* user of non-energy related water in the economy, while the most water intensive products are from manufacturing. As Uganda seeks to industrialize, water management will be critical to ensure steady growth of industrial sectors.
- Manufacturing depends on electricity inputs more than any other sector of the economy, and electricity is produced primarily through hydropower generation.
- Achieving the social goals of improved education and public health also rely heavily on water-dependent electricity production.
- Meeting 2040 growth targets will require dramatic increases in the delivery of managed water.
- Without proper investments in water management and distribution, GDP could suffer significantly.

- Insufficient investment in water management will have much larger effects on specific water-dependent activities in the agricultural, manufacturing, and services sectors.

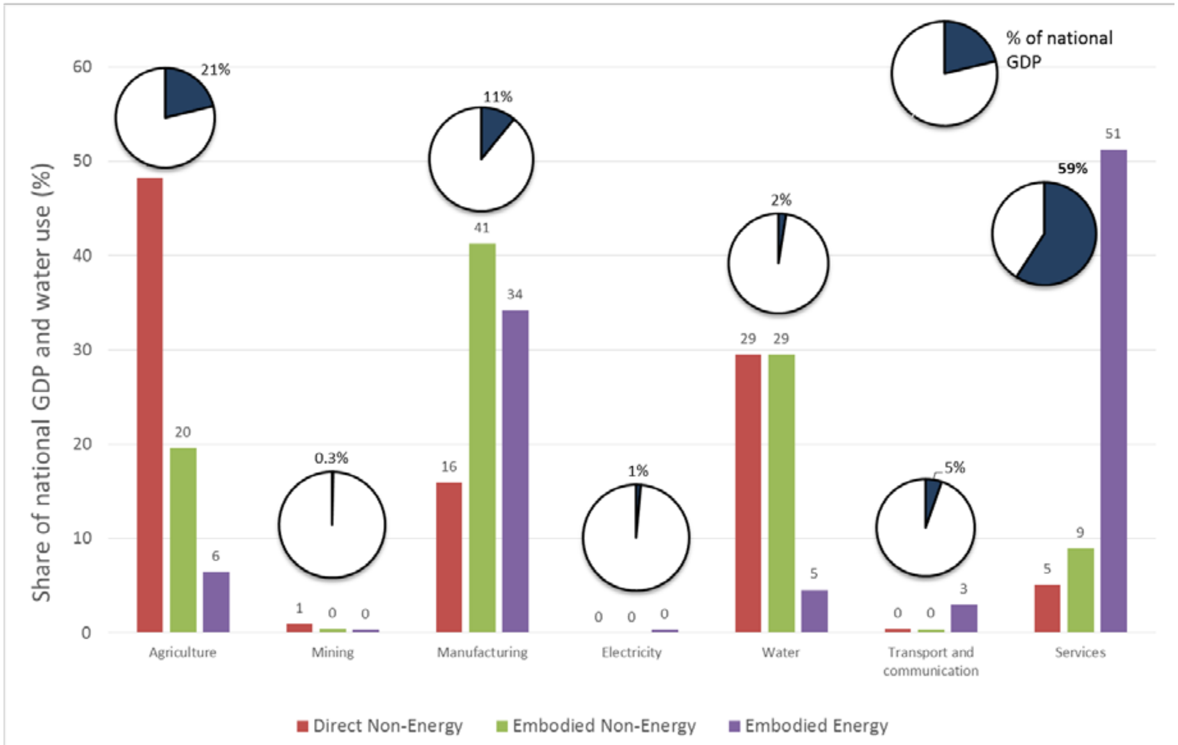
These findings rely on the three measures below to evaluate the dependence of each economic activity on water.

- **Direct non-energy water use**. The measured average annual use of water to support the activity. For example, irrigation water used to produce crops or water used for domestic households' purposes.
- **Embodied non-energy water use**. The final water content of a finished product, which includes the water embodied in inputs to an economic activity. For example, processed foods, which are produced by the manufacturing sector, is a major user of water-intensive agricultural inputs such as crops and livestock.
- **Embodied energy water use**. Roughly 80 percent of installed electricity generation capacity in Uganda is hydropower, and production of hydropower requires approximately 16 billion cubic meters of water per year – this is 20 times more than the total of all other water uses combined. Because of this critical dependence on water for electricity production, embodied energy water use based on the share of electricity production used in each economic activity is presented. While several agencies and factors play a role in electricity production beyond MWE, a reliable and steady flow of water, regulated by upstream storage and land management, is critical for reliable generation.

DEPENDENCE OF UGANDA'S CURRENT ECONOMY ON WATER RESOURCES

As shown in Figure 4-1 each of the main sectors in the Ugandan economy rely on water, in some combination of direct non-energy, embodied non-energy, or embodied energy use. The service sector, which contributes the largest share of national GDP, is also the largest user of embodied energy. Agriculture, another large sector in the economy, is the primary user of direct non-energy use. Manufacturing, a key industry for economic growth, uses 41 percent of embodied non-energy water.

FIGURE 4-1 SHARE OF WATER USE AND NATIONAL GDP BY ECONOMIC SECTOR

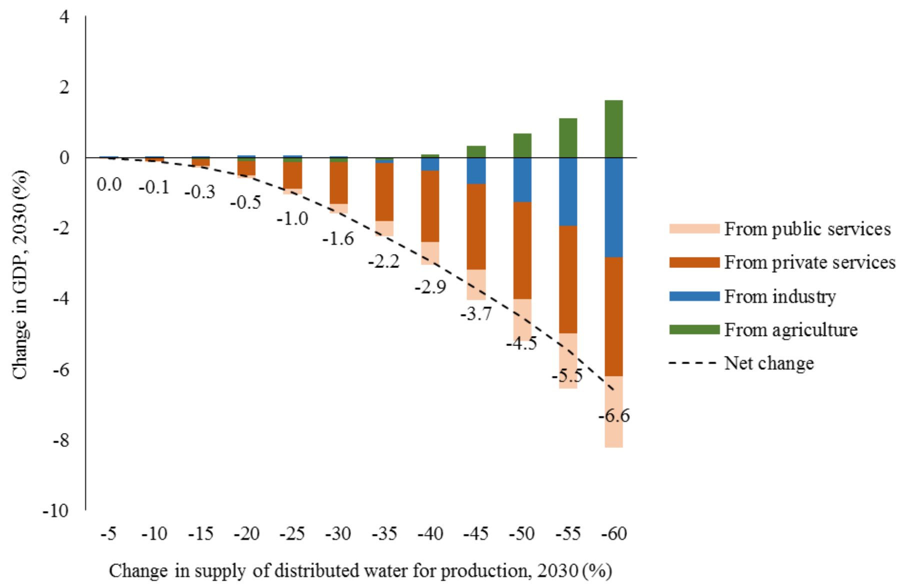


ECONOMIC GROWTH IMPACTS OF CONSTRAINED WATER AVAILABILITY

To estimate the potential economic growth impacts of water supply, water availability is constrained at intervals of 5 percent reductions to understand how the CGE trades off water supply between sectors and what the ultimate effect water scarcity has on GDP. The difference in GDP generated between the scenarios can be thought to represent the value of water supply, and therefore provides a preliminary estimate of MWE management of the resource.

As seen in Figure 4-2, when water supply is first constrained, private services are hurt. As the constraints tighten, public services begin to hurt more, followed by industry. At some point the resources that are displaced from water intensive sectors move *en masse* into agriculture, causing agriculture's GDP to start rising.

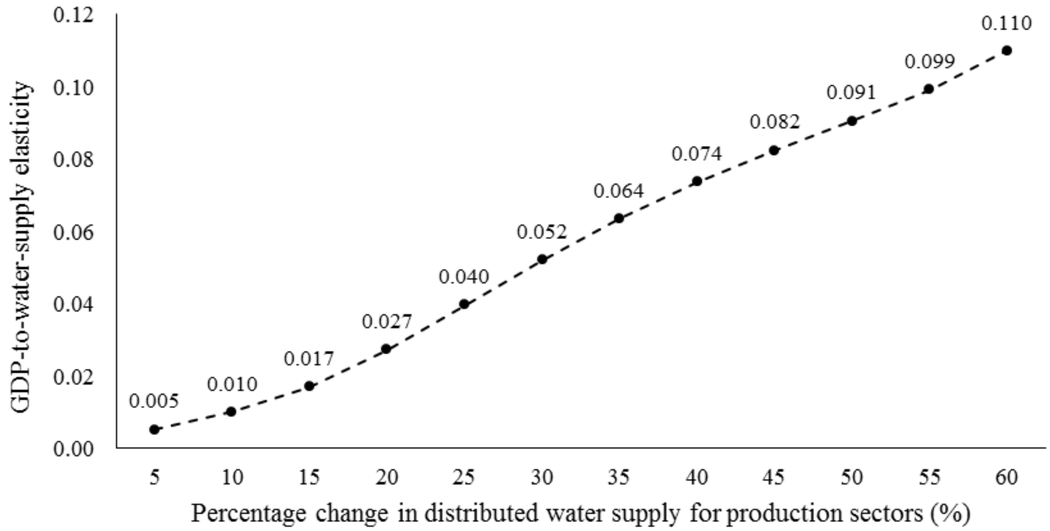
FIGURE 4-2 **DECLINE IN NATIONAL GDP FOLLOWING A DECLINE IN DISTRIBUTED TOTAL WATER SUPPLIED TO PRODUCTION SECTORS**



Source: Uganda CGE-W simulation results.

At larger water supply reductions it becomes harder to find sectors where water use can be reduced, leading to increasing rates of decline. This is best shown by the increasing elasticity of GDP to water supply, seen in Figure 4-3. In other words, a percentage reduction in water supply when water is relatively unconstrained does not have a large impact on GDP. The economy is able to substitute factors of production (i.e. more land, labor, or capital) to keep economic activity relatively stable. At higher levels of water supply constraint, a percentage reduction has a much bigger impact on GDP, as the potential substitute factors of production have already been reallocated to other industries.

FIGURE 4-3 ELASTICITY OF GDP WITH RESPECT TO DISTRIBUTED WATER SUPPLIED TO PRODUCTION SECTORS



Source: Uganda CGE-W simulation results.
Notes: The estimated elasticity shows the percentage increase in GDP with respect to a one percent increase in total distributed water supplied to production sectors.

EFFECT OF MWE MANAGEMENT ON UGANDA'S ECONOMY

The main application of the CGE is to estimate the value of MWE management in terms of enhanced economic outcomes stemming from management decisions. This section presents results for each channel individually, but begins with observations on the economy as a whole.

The biophysical channel models consider three different investment scenarios until 2040: business as usual growth (BAU), high, and moderate levels of investments in each of the impact channels described in Chapters 2 and 3. The high investment scenario reflects MWE investments and biophysical effects as outlined in Chapters 2 and 3, which encompasses full achievement of MWE's sector investments, but also fulfillment of Uganda's Vision 2040 and National Development Plan (NDP).

Table 4-1 compares the GDP growth results from the high investment scenario CGE model with (i) what was observed during 2010-2015; and (ii) the NDP and Vision 2040 targeted growth rates for the 2015-2040 period. The model closely tracks the level and composition of agriculture, industry and services GDP. This structural outcome is based on a continuation of observed trends in population and labor supply (3% per year), crop land expansion (1% per year), and capital accumulation rates (5% per year). The channel models described in Chapters 2 and 3 above exogenously determine growth in the sectors affected by the impact channels. We manually adjust the rate of technical change within each subsector in order to match the rate of GDP growth targeted in the NDP. The latter is effectively a residual that incorporates, amongst other things, the actions of other government ministries that have their own Vision 2040 objectives and investment plans.

TABLE 4-1 SECTORAL GDP GROWTH RATES IN THE HIGH INVESTMENT SCENARIO, 2010-2040

	Average annual growth (%)			
	2010-2015		2015-2040	
	Observed	Simulated	NDP	Simulated
National	3.9	4.2	7.0	7.0
Agriculture	0.2	1.7	5.5	4.1
Industry	5.5	5.6	6.5	9.3
Services	5.0	4.9	7.0	7.4

Source: Own calculations using NPA (2010) and Uganda CGE-W simulation results.
Notes: NDP targets are taken from the 2010/11-2014/15 National Development Plan UBOS (2015).

Our objective is to use the CGE-W model to estimate the contribution of MWE investments to the observed outcomes by comparing two pairs of investment scenarios. The first pair is the difference between the BAU and the moderate investment scenario. The second pair is the difference between the BAU and the high investment scenario. Simply put, we are asking what share of economic growth over 2015-2040 can be attributed to MWE's investments in the various impact channels discussed above.

Estimation of the results by sector requires switching from the high to the BAU, or the moderate to the BAU, one channel at a time in order to (i) estimate the incremental contribution of each channel; and (ii) their collective contribution. Note that we are simulating a reduction in MWE investment levels and so we expect GDP growth to decline – the extent of the decline is the contribution of that particular channel.

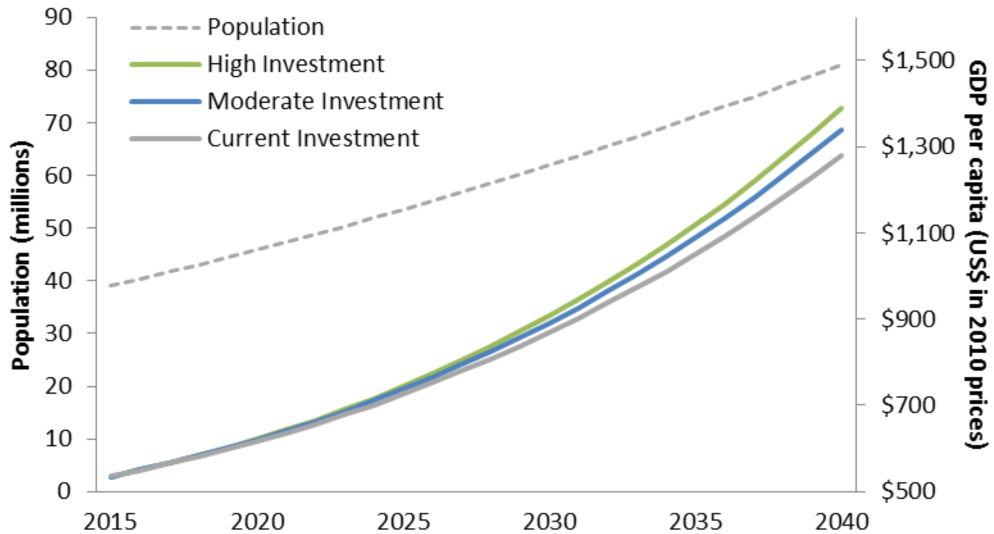
The model provides detailed information on the sectoral and distributional outcomes of MWE investments. We focus here on macro-level outcomes – the impact of MWE investments on national GDP and total absorption (the latter is an aggregate measure of national welfare). GDP and total private consumption are two of the high-level macro-indicators used to evaluate national policies and development strategies like Vision 2040 and the NDP.

The major findings from this analysis are as follows:

- MWE's proposed investments in water and environment yield significant economy wide impacts – by 2040, the beneficial effects of these investments result in a 8.7 percent difference between BAU and high investment scenarios, equivalent to $111 per capita, as illustrated in Figure 4-4.

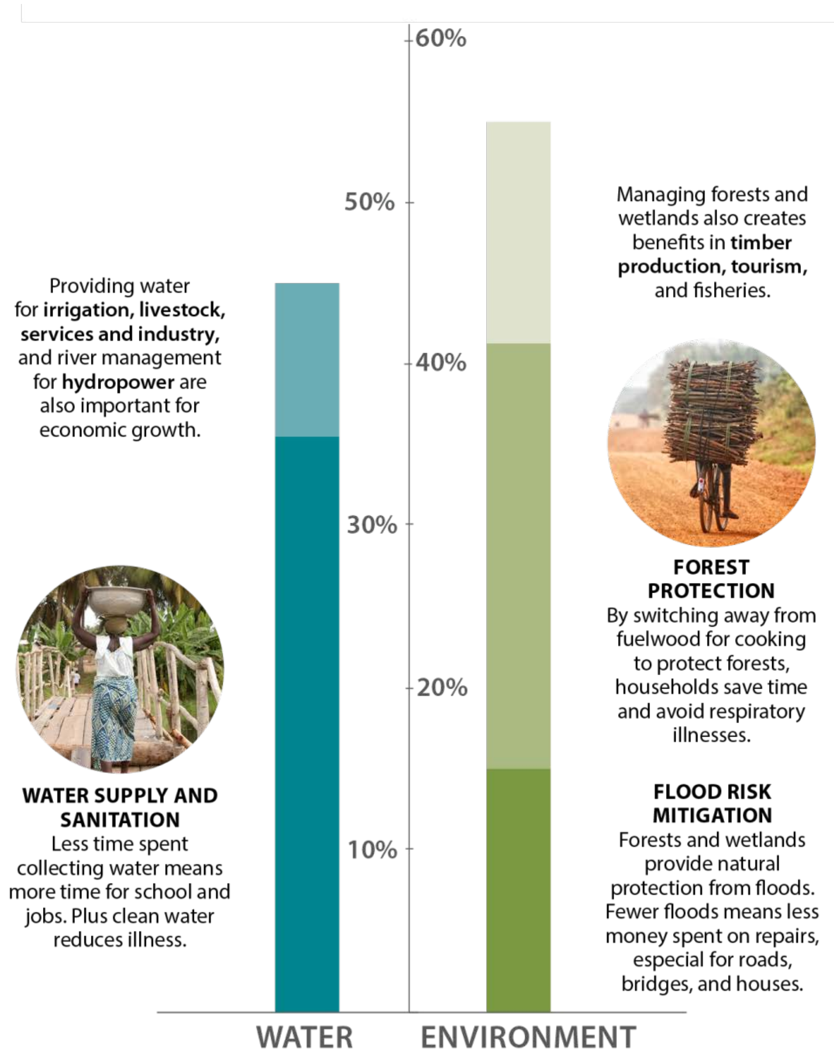
- These investments are very efficient, with benefits greatly exceeding investment costs. For both the moderate and high investment scenarios, the GDP returns alone are roughly 7 to 8 times the investment cost in undiscounted terms, and at least 3 to 4 times investment costs when benefits and costs are discounted at 10%. The results clearly show that the investments provide direct GDP benefits well in excess of their costs.

FIGURE 4-4 GDP PER CAPITA GROWTH (2015-2040)



- The water development and environmental management components of the MWE investment plans are comparable in magnitude of both costs and impact on the economy, with the water supply and sanitation component of the water development investments having the greatest GDP impact, and the forestry and firewood replacement investments of the environmental management component having the greatest GDP impact among investments in that category. The WASH investments alone account for roughly 35 percent of the total economic benefits of MWE investments, as illustrated in Figure 4-5.
- GDP benefits include direct facilitation of economic activity through such actions as water provision and timber replanting, as well as indirect effects on capital protection through reduced flooding and on fishing through water filtration services of wetlands protection. Nonetheless, a very large component of the benefits is realized through enhanced health (and reduction in the need for government support of health care costs for waterborne or airborne exposures to pollutants), and for the "gathering time" savings that water and non-timber fuelwood provision provides for adults to participate more fully in the growing labor market, and children to enhance labor market skills through education. All of these factors are critically important to support the type of development and economic growth envisioned for Uganda in the Vision 2040 initiatives.

FIGURE 4-5 DISTRIBUTION OF GDP GAINS FROM MWE INVESTMENTS BY CHANNEL

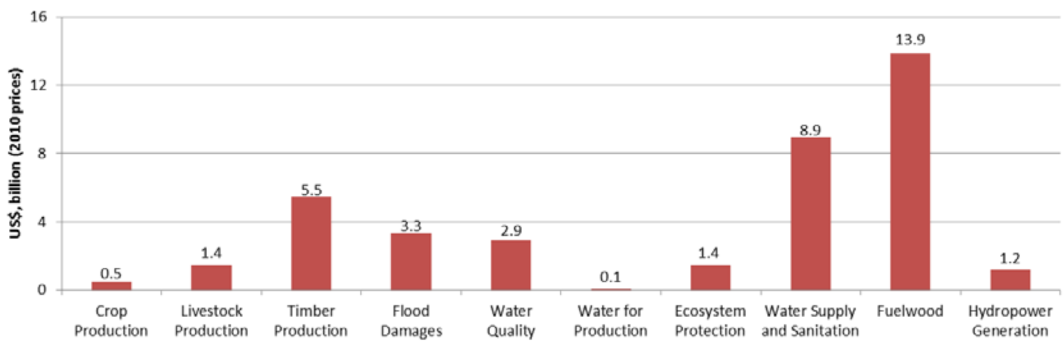


As shown in Figure 4-4 above, the CGE simulations project that the Ugandan economy will grow much faster than population growth in all scenarios. This finding represents an important prerequisite to economic development – clearly it is necessary if the goal is to increase aggregate GDP/capita that GDP grow faster than population - but most important to note is that MWE investments are a significant catalyst to encourage such growth. The difference between the BAU, moderate, and high investment scenarios is significant, but if MWE's investments are somehow not made, this lack of investment would prevent the economy from reaching its full potential in a measurable way.

When looking at national benefits of enhanced investment, it is not only the total magnitude of the benefit that matters, but also how that benefit is distributed. This is especially important for understanding how these investments impact poverty reduction measures. While our model does not output benefits by income class, we are able to understand something about the distribution of direct benefits based on the channel mechanisms themselves. For example, benefits from water supply and sanitation and fuelwood are likely to be realized by lower income categories that currently do not have access to supplied water or improved fuel sources.

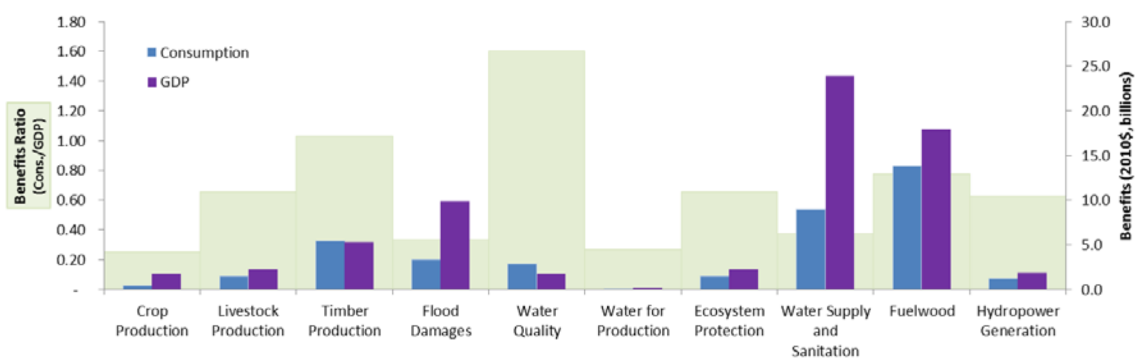
However, indirect benefits via multiplier mechanism have reported on GDP. An alternative measure of economic impact is consumption[9], which represents the benefits to households (as opposed to the government or capital formation through investments). The benefits of each channel in terms of consumption are presented in Figure 4-6.

FIGURE 4-6 PRIVATE CONSUMPTION BY INVESTMENT CHANNEL



Overall consumption benefits through 2040 are about 58 percent of the total GDP benefits and vary by individual channel. As seen in Figure 4-7, water quality and timber production have higher consumption benefits than GDP benefits. The CGE is constrained to meet trade balance (i.e. exports = imports), so the increase in exports necessitates an increase in imports, which in turn can reduce demand for domestically produced goods. This suppresses the apparent benefits when measured by GDP alone. When benefits are measured by consumption, however, the returns to labor are generally high and a proper interpretation is that the investment provides substantial benefits to the poor

FIGURE 4-7 PRIVATE CONSUMPTION AND GDP BY INVESTMENT CHANNEL



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[9] **GDP** is the sum of **consumption**, **investment**, **government** spending, and **net exports**.

DETAILED ECONOMY-WIDE, CHANNEL, AND SECTORAL EFFECTS OF MWE INVESTMENTS

Table 4-2 summarizes the magnitude of outcomes from the two investment scenario comparisons. All channels yield increases in GDP, except for fishing, where the gains are small or slightly negative, owing largely to the large increase in productivity which yields to fish exports large enough to affect currency exchange, even slightly. Gains in the agriculture sector grow as the investment intensity grows from BAU to moderate, and then from moderate to high, from about $1.7 billion to $4.1 billion (taking irrigation and livestock together). The forestry sector, which represents a large portion of total GDP, shows strong GDP gains, with $5.5 billion in GDP gains from yield for the BAU to high comparison, but the flood risk reduction is almost twice that size, over $10 billion in gains, owing the large effect on protection of capital that might otherwise be destroyed from floods.

TABLE 4-2 SIZE OF IMPACTS IN DIFFERENT INVESTMENT SCENARIOS

	Cumulative GDP gains 2015-2040 (billion USD)	
Channel	BAU to Mod	BAU to High
Crop Production	0.9	1.8
Livestock Production	0.8	2.2
Timber Management	1.5	5.3
Flood Damage to Infrastructure	8.5	9.9
Water Quality	0.0	1.8
Water Available for Production	0.1	0.2
Ecosystem Protection	1.1	2.2
Water Supply and Sanitation	14.0	23.9
Fuelwood	9.3	17.9
Hydropower Generation	1.9	1.9
All channels	**38.1**	**67.1**
Total Investment Cost	5.3	8.4
Ratio GDP Gains to Cost	**7.2**	**8.0**

As noted above, however, by far the largest gains are attributed to gains in health associated with WASH and firewood replacement initiatives. A key lesson is that investments in water and environment overall can significantly enhance health, providing a boost to economic growth from the combination of reduced health care expenditures and time freed from water and wood gathering which can be used to supply labor to a rapidly growing and industrializing economy (or, simply to a more productive agriculture sector). As noted in Chapter 3, the health sector results are based only on the direct and indirect GDP gains, and are actually an underestimate of the full impact because they omit what is likely a large non-market welfare gain associated with high willingness to pay to avoid waterborne and cookstove- smoke-induced disease.

The aggregate GDP gains from investment far outstrip the aggregate investment costs, as shown in Table 4-3 below. Undiscounted return ratios are in excess of 7 times investments costs for both scenarios. Because many benefits are realized after a lag period relative to when the investment costs are incurred, the discounted return ratios are less, but remain greater than 3 times costs at 10 percent discount rate for the high scenario, and almost 4 times costs for the moderate investment scenario.

TABLE 4-3 INVESTMENT RETURN RATIOS AT VARYING DISCOUNT RATES (BILLIONS USD)

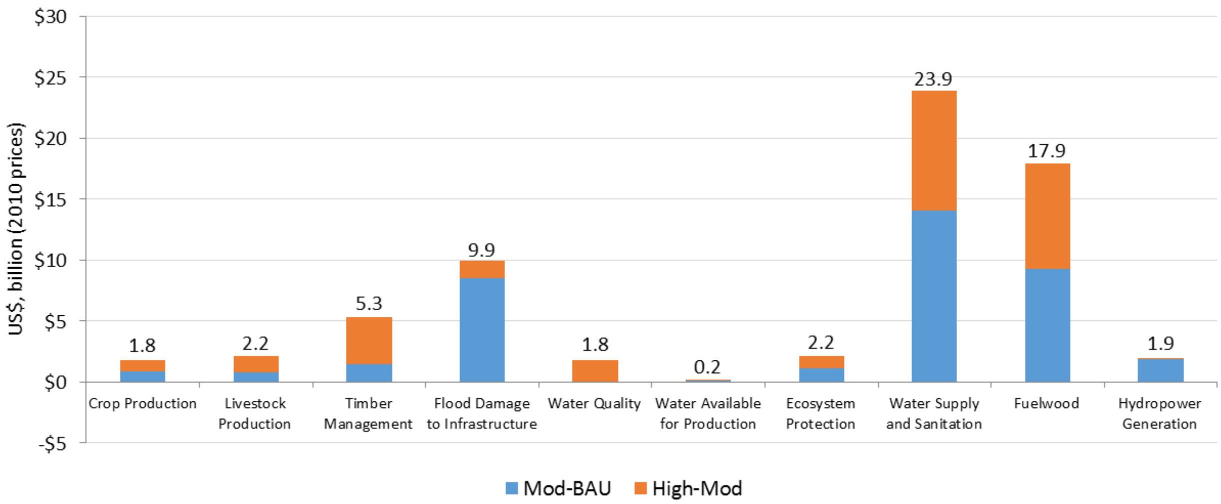
No discounting			
	Costs	Benefits	Return Ratio
MOD-BAU	$ 5.34	$ 38.13	7.14
HIGH-BAU	$ 8.40	$ 67.19	8.00

6%			
	Costs	Benefits	Return Ratio
MOD-BAU	$ 2.55	$ 12.80	5.02
HIGH-BAU	$ 4.91	$ 22.28	4.54

10%			
	Costs	Benefits	Return Ratio
MOD-BAU	$ 1.74	$ 6.75	3.87
HIGH-BAU	$ 3.82	$ 11.62	3.04

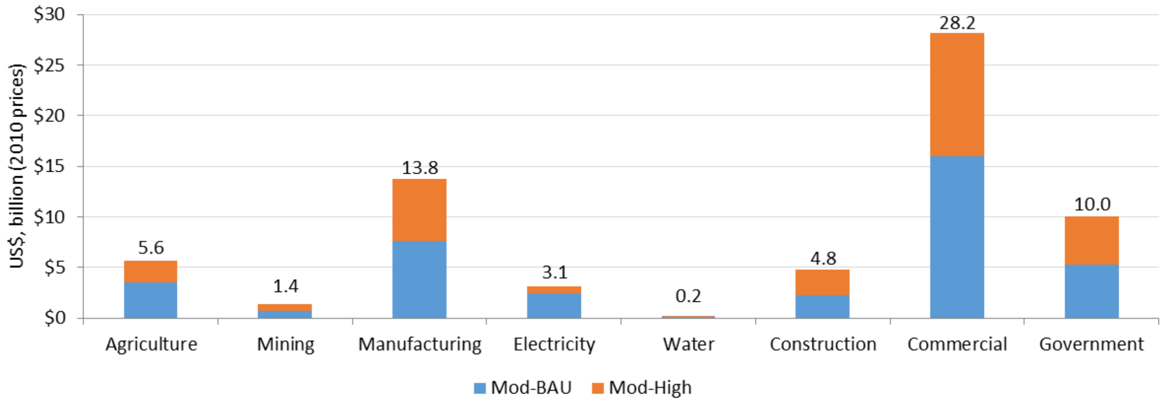
The overall results for all channels suggest that MWE investments increasing from BAU to moderate would yield a cumulative GDP gain of $38.1 billion, for a total investment cost of $5.3 billion. Similarly, the comparison of BAU to high investment suggests that overall GDP gains of $67.2 billion would be much larger than the investment cost of $8.4 billion. The distribution of GDP impacts by investment channel and scenario is graphically depicted in Figure 4-8 below.

FIGURE 4-8 CUMULATIVE GDP IMPACTS BY INVESTMENT CHANNEL FOR EACH INVESTMENT SCENARIO (BILLION USD, 2015 TO 2040)



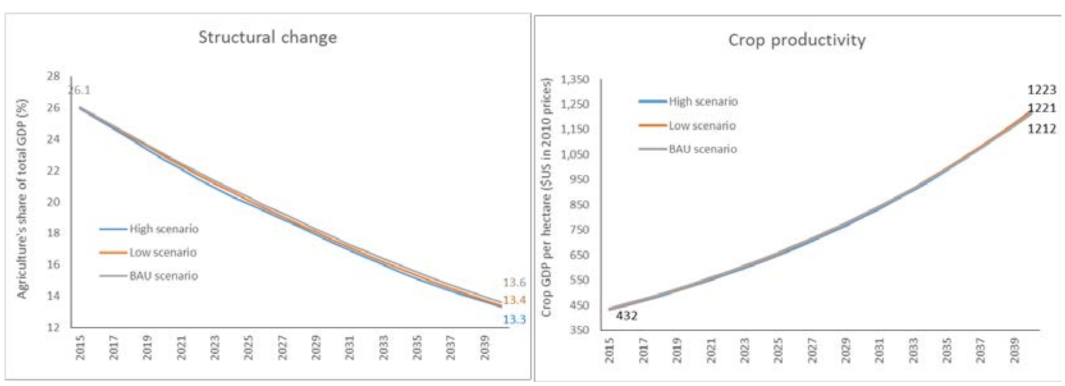
The economic sectoral results suggest an interesting story about how Uganda is projected to develop under the National Development Plan, and how MWE investments affect the productivity of agricultural lands, in particular. As indicated in Figure 4-9 below, many sectors that are not necessarily direct beneficiaries of MWE investments, such as manufacturing and commercial economic sectors, account for the largest share of the cumulative GDP gains. Economic sectors under the agriculture category are among the largest direct benefactors of MWE investment, but the gains of a more productive agriculture sector filter through the entire economy. Within the agriculture category, many of the benefits are associated with impacts in the forestry sector, but irrigated agriculture is also a major component of these GDP benefits. Rainfed agriculture, on the other hand, shows reduced productivity, in part because of conversion of rainfed to irrigated agriculture, and in part because of conversion to forest lands.

FIGURE 4-9 CUMULATIVE GDP IMPACTS BY ECONOMIC SECTOR (ALL CHANNELS COMBINED) FOR EACH INVESTMENT SCENARIO (BILLION USD, 2015 TO 2040)



The transitional path for agriculture, however, is one that is common in development economics, with agriculture's share of total GDP declining as other sectors grow (precisely as envisioned in Uganda's National Development Plan). As shown in the left panel of Figure 4-10, agriculture's share in GDP was 29.3 percent in 2010, but declines to between 13.3 and 13.6 percent of the economy under all scenarios – this is less about a shrinking agriculture sector and more about a rapidly growing overall economy, which while not all attributable to MWE investments, is synergistically enhanced by those investments. Agriculture's share of the economy under the high scenario is actually lower than under BAU, precisely because MWE investments grow other sectors of the overall economy faster under the investment scenarios (that is, the overall GDP denominator is larger).

FIGURE 4-10 CHANGES IN THE SHARE OF AGRICULTURE IN TOTAL GDP, AND IN AGRICULTURAL PRODUCTIVITY OVER THE STUDY PERIOD (2015 TO 2040)



As shown in the right panel of Figure 4-10, crop productivity per hectare is rising rapidly under all three scenarios, but it is actually slightly lower under the high investment scenario, for two reasons: 1) Some high productivity agriculture land transitions from agriculture to forestry, pushing agriculture to more marginal grassland for conversion; and 2) MWE investments increase crop yields but also encourage workers to leave agriculture through spillover effects that make industry and services attractive, and so crop GDP growth decelerates slightly and the economic returns to labor and capital increase outside of agriculture (a common development pathway).

These results also have important implications for the water sector. As earlier work for MWE revealed, while agriculture is a major user of water (via irrigation), many agricultural products are supplied to the manufacturing sector, where they are used to produce final goods for export or consumption. As such, the water used in agriculture becomes embodied within manufactured goods. For example, the water used to grow cereals becomes embodied within the flour used to produce bread within the manufacturing sector. This means that many of Uganda’s industrial products indirectly contain the value-added within agriculture’s water. As such, Vision 2040’s targets of Uganda becoming a more industrialized and service-oriented economy does not imply that there will be a reduction in water demand, especially since agriculture will continue to grow in absolute terms, even while its share of GDP is falling.

Our analysis indicates that investments in water and the environment can generate high returns for Uganda’s economy. Full realization of the development potential of Uganda’s economy requires continued effort to fund and implement the MWE Vision 2040 investments in water and the environment.

CHAPTER 5 | RECOMMENDATIONS

The analysis described in this report represents a major step forward for MWE as they seek to enable growth and development of Uganda's key industries – agriculture, forestry, and a new wave of manufacturing – while also playing a critical role in the development of human resources and long-term human capital by providing clean water and sanitation services. A key underpinning of the approach the analytic results is that the quality of the physical environment – embodied in water and land – represents a critical piece of the overall development strategy for Uganda. The report shows MWE investments play two critical roles – removing barriers to growth, particularly by providing water of sufficient quality for irrigation, direct human use, and manufacturing, and ensuring that land is allocated to productive agriculture and forest uses; and enabling new growth in agriculture (through irrigation expansion), hydropower, and, indirectly, human capital by maintaining health.

While the report provides a significant milestone, more work needs to be done to ensure that MWE fully capitalizes on its role as an economic growth facilitator in Uganda:

a. ***Update and revise MWE's Strategic Sector Investment Plan (SSIP)***. The prior SSIP provides a critical input to this study, in particular, providing specific investment details, and a schedule for those investments, that defines BAU and high investment scenarios used here. This study, however, provides a new perspective on both the GDP and sector growth returns on those investments, and on the complementarity of investments across the economy, which ought to be considered in future SSIP updates. In addition, this study shows the need to resolve apparent inconsistencies between the plans for extensification of the agriculture and forestry sectors, particularly regarding land allocation among these two important initiatives. The next version of the SSIP should more clearly outline how intensification and extensification efforts in these sectors ought to be deployed to achieve maximum economic impact. As part of this effort, it would be useful to develop specific plans for better measuring the effects of the SSIP in future assessments, for example by improving data collection and management on water and air quality, in particular as they affect human health outcomes.

b. ***Consider more carefully the specific regional allocation of investments***. Further, the next SSIP should consider more specifically the optimal regional allocation of investment effort, while taking into account the comparative natural resource advantages of each region. For example, development of irrigation water resources in areas of relative water scarcity may serve the goal of equitable distribution of investment resources, but may or may not provide the largest returns on investment, particularly when considering the spillover effects on other industries and the labor implications of agricultural sector investments.

c. ***Fully reconcile MWE's investment plans with the plans of other Ministries***. Certainly, the overall investment plans of the Ministry of Finance are important in any economic simulation of the returns on investment – for example, interest rate and trade policies more broadly will affect the investment climate. Other important focus areas are:

   1. Ministry of Energy (for both large and small hydropower infrastructure investments);

   2. Ministry of Agriculture, Animal Industry, and Fisheries, to ensure that parallel investments in agriculture and livestock intensification in particular work synergistically with MWE's plans;

   3. Ministry for Trade and Industry, related to possible industrial policy and efforts to foster growth in specific areas that might rely on water and/or environmental quality as a factor of production, as well as to ensure that export markets are fostered for those industries where expanded production might grow faster than Uganda's internal demand;

   4. Ministry of State for Relief and Disaster Preparedness (and perhaps the Ministry for Works and Transport), to better understand the current profile of flood risks and how MWE can focus catchment management efforts to have the greatest flood risk reduction impact; and

   5. Ministry of Health, to ensure that efforts to enhance health through clean water provision and sanitation investments are well coordinated with local health education efforts in these areas.

d. ***Continue a series of active discussions with the Ministry of Finance*** regarding tools, data, and assumptions to characterize the economic performance of MWE-led investments.

e. ***Deliver on realizing the full potential of MWE's investments***. Most importantly, begin efforts to deliver on the planned investments, in cooperation with relevant private sector and government stakeholders, to enhance the likelihood of obtaining the substantial returns to sector and overall GDP growth that this study has confirmed. There are two key reasons for urgency in moving forward with these investments:

   1. Returns to investments in physical and human capital tend to accumulate over time, and effectively multiply benefits by contributing to growth in the near term, growth which itself provides further opportunities for growth in the next period.

   2. The economic environment for complementary private sector investments, investments which also contribute to growth, is often heavily influenced by

positive expectations – the effective communication of government action can substantially enhance these expectations.

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