

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

James E. Neumann, Collins Amany, and Kenneth M. Strzepek

May 2018

Guidelines for Benefit-Cost Analysis Project
Working Paper No. 11

Prepared for the Benefit-Cost Analysis Reference Case Guidance Project
Funded by the Bill and Melinda Gates Foundation

Visit us on the web: <https://sites.sph.harvard.edu/bcaguidelines/>

Preface

The Bill and Melinda Gates Foundation (BMGF) is supporting the development of guidelines for the economic evaluation of investments in health and development, particularly in low- and middle-income countries (“Benefit-Cost Analysis Reference Case: Principles, Methods, and Standards,” grant number OPP1160057). These guidelines will supplement the existing international Decision Support Initiative (iDSI) reference case, which provides general guidance on the overall framework for economic evaluation as well as specific guidance on the conduct of cost-effectiveness analysis. It includes 11 basic principles supported by a series of methodological specifications and reporting standards to guide their implementation.

This draft case study is part of a series of methods papers and case studies being conducted to support the extension of the reference case to include benefit-cost analysis. Although these papers will provide the basis for the benefit-cost analysis reference case guidance, the reference case may ultimately deviate from their recommendations in some cases.

This case study, reflects the work of a large team of collaborative researchers from the US and Uganda. The authors of this paper (Neumann, Amany, and Strzepek) wish to acknowledge the contributions of: Samuel Otuba, Ugandan Ministry of Water and Environment; James Thurlow, International Food Production Research Institute; Brent Boehlert and Jacqueline Willwerth, Industrial Economics Inc.; Emmanuel Olet, Independent Consultant (Uganda); and Benjamin Ssekamuli, Independent Consultant (Uganda).

More information on the project is available at <https://sites.sph.harvard.edu/bcaguidelines/>.

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

Abstract

This case study illustrates the application of a computable general equilibrium model to assess economy-wide costs and benefits of a specific investment program for water resources development and environmental management (including coincident health implications) which is being pursued by Uganda's Ministry of Water and Environment MWE). 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. 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 rivers and lakes), wetlands, and forests from their sources, through MWE and private 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. In addition, the results show that all sectors of the economy benefit substantially from the MWE investments. Overall, these investments are very efficient, with benefits greatly exceeding investment costs. For both a moderate and high investment scenario, 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. Further, this GDP growth benefits households substantially as incomes and consumption increase over time, which leads to alleviation of poverty. In addition, we estimate benefits using a traditional welfare economic benefits estimation approach, and find that the overall benefits are comparable to the GDP gains but are dominated by the avoided mortality component of economic benefits.

1. Introduction and Framing of the Analysis

This case study is the result of a project sponsored by the Uganda Ministry of Water and Environment, in conjunction with the World Bank and with in-kind support from the International Food Production and Research Institute (IFPRI). The basic problem addressed in this work is estimating economy-wide benefits of a proposed investment program, consisting of eight categories of investment, for two scenarios that involve differing trajectories of investment. Although the analysis was not focused on prioritization, the results could be used in a cost-benefit framework to assess the cost-effectiveness of alternative investments. This case study identifies results that would support an investment-specific benefit-cost analysis.¹

The management scenarios used in this analysis are derived from Uganda's National Development Plan II (2015-2020) (GOU 2015a) and Vision 2040 (GOU 2103) 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 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.

Within these three overall investment scenarios, the analysis focuses on eight specific investment programs. Differentiation of groups of investment programs into two groups - the Water Development and Environmental Management categories - is consistent with the two main divisions of MWE (water and environment) that would be expected to implement and oversee the eight specific investment programs. On the water development side, there are six investments (five are listed in Table 1), and on the environmental management side, there are two investments. The sixth water development investment is water storage, which provides benefits for all of the sources of water use (crops, livestock, industry, municipal/households, and hydropower). It is difficult to separate the benefits of water storage from the costs; as a result, in this analysis, we do not attempt to link water storage benefits to costs.

¹ The full report of the project, from which this case study has been derived, is available directly from MWE on their website: <http://www.mwe.go.ug/library/economic-study-2016-contribution-water-development-and-environment-resources-uganda%E2%80%99s>

Table 1: Summary of Water and Environmental Management Investments Analyzed

INVESTMENT PROGRAM	ECONOMIC SECTOR OR “IMPACT CHANNEL”	SUPPORTING INTERVENTIONS
WATER RESOURCES DEVELOPMENT INVESTMENTS		
1. Irrigation	Crop Production	Provision of irrigation water
2. Livestock	Livestock Production	Provision of water for livestock
3. Industry and Services	Water Available for Industry and Services	Water supply reliability to manufacturing
		Water supply reliability for service sector
		Water supply reliability to mining
4. Household	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
5. River Flow Management	Hydropower Generation	Water management for hydropower efficiency
ENVIRONMENTAL MANAGEMENT INVESTMENTS		
6. Forest Rehabilitation	Flood Damages to Infrastructure	Flood risk mitigation by land management
7. Wetlands Restoration	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

Costs for each investment program represent the direct investment costs, including capital, operation and maintenance costs associated with capital, supplies, and labor compensation (mainly for MWE staff). The benefits of each investment include a novel evaluation of ecosystem services for health and the environment, incorporated in a general equilibrium model of the Ugandan economy. The details of the estimation of benefits from the economy-wide, societal perspective are the most interesting part of the study, and are the main focus on the methods and results sections of the case study.

Costs and benefits in this study were assessed from a societal perspective. The investment costs are generally expected to be incurred by MWE, but the base case analyses assumed that investment would be undertaken by a donor working through MWE. As outlined in Strzepek et al. (2018), this is an important characteristic of the results, because a self-funded investment plan would require taxation of Ugandans, or perhaps a bond issue, to finance the required infrastructure, MWE staff time, and other components of costs. Under a self-funding scenario, or perhaps a scenario that reflected a “delayed payback” that might be characteristic of a World Bank loan to the Ugandan government, we expect the results would be very different in terms of the impact on the economy of undertaking these investments.² The advantage of using an outside funding scenario for these investments is that the

² In subsequent work we hope to explore these alternative funding scenarios in greater depth.

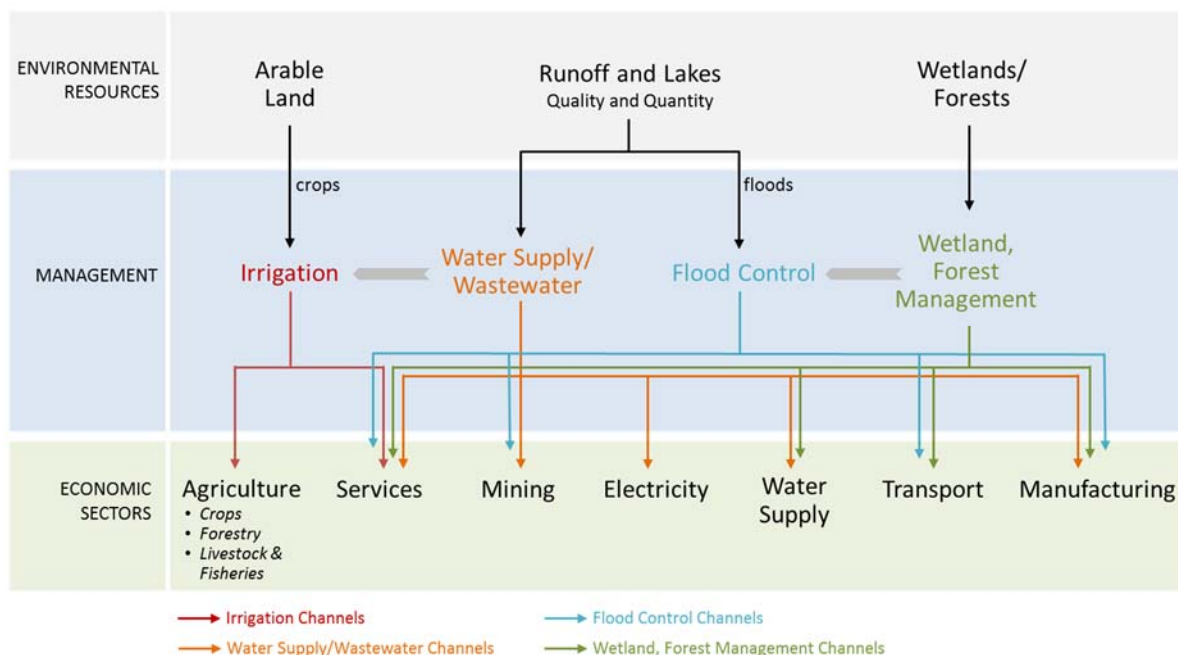
investment impact on the economy, which corresponds to the benefits side of a BCA, can be examined independent of the impact of the costs on the economy. There is value in knowing the economic impact of alternatives in both an external funder and internal funder approach.

The benefits in this case study are assessed from the broadest possible economy-wide (Ugandan) perspective, but are not denominated in economic welfare terms, a fact which distinguishes this work from a traditional benefit-cost analysis. Instead, the benefits are measured in effects on Gross Domestic Product (GDP), or on household consumption, a measure different from but with some relation to household welfare. Many economy-wide models are capable of measuring economic welfare implications of policies, usually in terms of “equivalent variation,” but that analysis was not undertaken here, as it would have required some reprogramming of the computable general equilibrium model of Uganda’s economy to yield those results. Nonetheless, using health and welfare results from the biophysical modeling inputs to the economy-wide model, it is possible in some cases to estimate welfare gains using a traditional benefit-cost analysis approach. At the end of this paper, we provide a comparison for one of the proposed investments (in water and sanitation for households, or WASH) between results from the economy-wide model and the results for a traditional benefit-cost analysis approach, conducted in a manner consistent with that recommended in other working papers in this series (Robinson et al. 2018a for avoided mortality effects, and Robinson and Hammitt 2018b for avoided nonfatal health effects).

2. Analytic Approach

This paper 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, which shows the relationship between environmental resources in the top row; MWE management actions in the center row; and sectors of the economy at the bottom. 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 used in the overall Ugandan economy for commodity production across a number of sectors, as well as to enhance human health. This paper refers to these pathways from environment to the economy as channels of impact. In Figure 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 (an environmental resource) can be managed through provision of irrigation water (an MWE management action), which then improves crop yield and yield reliability, and thus contributes to GDP from agriculture (an economic sector).

Figure 1 - General Framework for Modeling

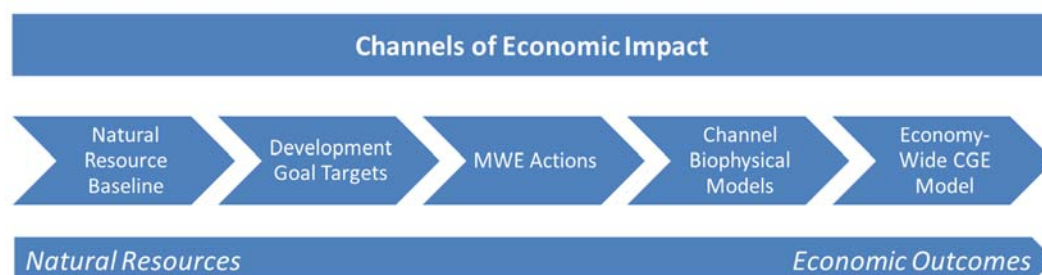


An economic study of this sort requires comparisons between alternative future states of the world – where economic indicators such as GDP, employment, consumer and producer economic welfare, and the total value of infrastructure benefits (measured as the “net present value” or total value over time) 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.

a. Analytical Framework

Because this analysis involves the interaction of the natural environment and the economy, as well as environmental health, we first need to establish baseline levels of the relevant natural resources and individual health. This is the first step shown on the left of Figure 2. The investment scenarios are then defined as tools to enhance the natural resource baseline – as noted in Section 1 of this paper, the investments are based on options to reach development goals, which is step 2 in Figure 2. The costs of these investments are costs necessary for MWE to measurably make progress toward these goal – step 3 in Figure 2.

Figure 2 - Analytical Framework



Biophysical models are then used in step 4 of Figure 2 to produce impact metrics related to specific management scenarios, which then enter the economic model in step 5 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.

b. 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 precipitation 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.

c. 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 2 has

one or more corresponding interventions that impact the pathway from environmental or water resource to the ultimate economic activity.

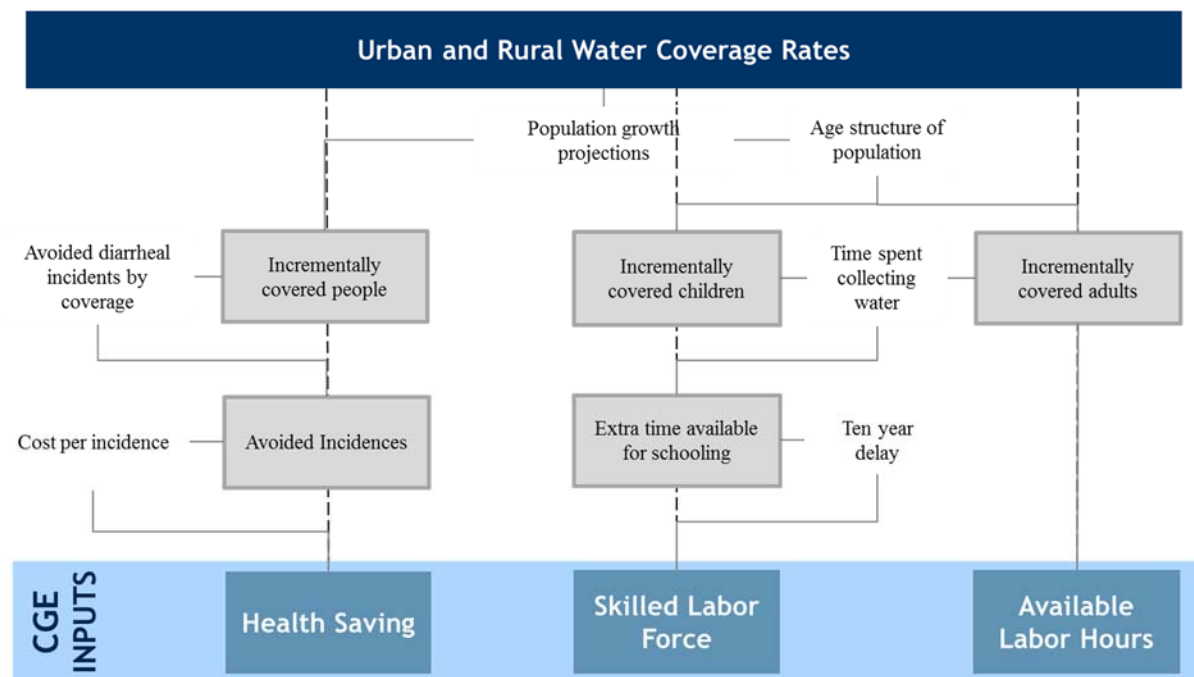
Table 2 - Channels of Economic Impact

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 and costs 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.

The detailed requirements of completing the analysis for one of these channels, the water supply and sanitation channel, are outlined in Figure 3 below. The important baseline data are urban and rural water supply coverage rates, illustrated in blue at the top of Figure 3. The study relies on a single urban and a single rural coverages rate at the national scale from Uganda's Sector Performance Report, although since the study was completed improved data are now available by district. Projections of population growth and the age structure of the population are derived from Uganda's Census (UBOS

2014a and 2014b). The key components remaining to be filled as the avoided diarrheal incidents per unit of additional safe water coverage, and the time spent collecting water – both are derived from Hutton (2012).

Figure 3: Detailed Illustration of the Water Supply and Sanitation Channel



Hutton (2012) summarizes WHO suggested economical quantifiable benefits of water and sanitation improvements in LMICs. Fink et al. (2011) report large health consequences of lacking access to water and sanitation for children under five years old in low- and middle-income countries. The impacts of childhood health may be seen economically much later in health care savings. The CGE model is able to track lagged benefits such as these.

Specifically, these linkages reflect the following assumptions:

- Increased labor supply from reduced water gathering time and sanitation savings:** All members of households receiving supplied water after 2015 are assumed to save 0.3 and 0.1 hours per day in rural and urban households respectively. Adults are responsible for about 52 percent of wood gathering (UBOS 2014a); therefore about half of the time saved per household is considered available for employment. Not all time available for labor will be used for labor. Following Hutton (2012), time available is cut in half to represent the gain in labor hours.
- Increased labor productivity from increased educational level:** Starting with the steps described above to get an estimate of time savings per household member and the split of adult and child time savings, the hours of savings for children are assumed to be fully used for additional education.
- Reduced days sick from diarrhea:** Hutton (2012) estimates that all members of households receiving improved water supply have 0.37 fewer cases of diarrhea per year, and those with improved sanitation see 0.28 fewer cases per year.

- For children, it is assumed that for each case, three full school days are lost. The education benefits was lagged by 10 years with the assumption that children are in school from 6 to 16 years of age, and thus 10 percent per year of impact would be added as an improvement in increased labor skills until it hit a maximum of 100 percent in ten years.
- For adults, it is assumed that for each case, two full days of labor are lost.
- **Reduced death from diarrhea:** Hutton (2012) estimates that for each new person covered by improved water supply there are 0.20 fewer deaths per 25,000 people per year, and for each new person covered by sanitation there are 0.51 fewer deaths per 25,000 people per year.
- **Increased savings in government health care spending:** The number of avoided cases of diarrhea per year described above is multiplied by a \$10 per case cost savings (Hutton 2012).

d. 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). More details can be found at Strzepek et al. (2018) and Strzepek et al. (2016)

Ecosystem services, including those that contribute to environmental health and economic production, 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 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.³ 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.⁴

³ 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.

⁴ The second and third approaches were also used in a qualitative manner in the project to provide estimates of the magnitude of benefits outside the national accounts framework, but for reasons of space those are omitted here.

3. Results

This section summarizes the results of the study in terms of costs, benefits, the comparison of costs and benefits across investment scenarios and programs, and distributional consequences.

a. Costs

Estimation of the direct costs of the investments is relatively straightforward; these are presented in Table 1 below. Costs are estimated as a planned trajectory of expenditures over time, and as incremental from the Business as Usual (BAU) baseline to the levels anticipated in the Moderate and High investment scenarios. Differentiation of groups of investments in the Water Development and Environmental Management categories is consistent with the two main divisions of MWE (water and environment) that would be expected to implement and oversee the investments. On the water development side, there are six investments, listed in the table, and on the environmental management side, there are two investments. As noted above, water storage is a cost that is included in the CGE economy-wide model, but the benefits of water storage are inextricably tied up with the other investments, so benefits are not directly attributed to the water storage investments.

Table 3: Mean annual investment costs by investment category (\$millions)

Investment Program		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 (2040 represents 2035-2040). *Household sector includes water supply and sanitation programs.

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 the MWE Strategic Sector Investment Plan (SSIP) (MWE 2009, 2015) and other similar sources. The split in the overall aggregate costs over the 2015 to 2040 period 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 as part of a more aggressive effort to meet development goals.

b. Summary of Direct Benefits

The estimated direct benefits of MWE investments, which effectively serve as inputs to the economy-wide model (CGE) are summarized below:

- **Irrigation/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.
- **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:** The study did not directly address non-market benefits of these investments, primarily because the CGE is difficult to parameterize for non-market effects (see Strzepek et al. 2018 on this topic). The omission of nonmarket benefits is acknowledged, however, as an important uncertainty. 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.

c. Benefits estimated through the economy-wide model

Table 4 summarizes the magnitude of outcomes from the two investment scenario comparisons, in GDP terms. 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 leads to an increase in 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: Total GDP Benefits in Different Investment Scenarios

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

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). 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. 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.

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.

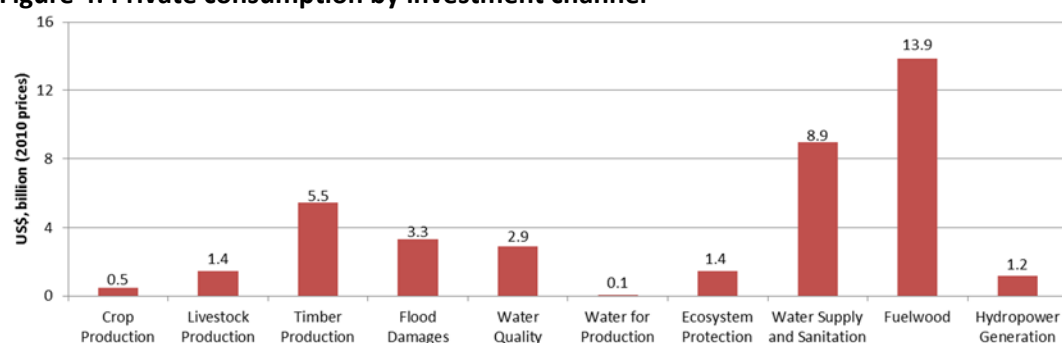
d. Insights on the distribution of benefits

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.

An alternative measure of economic impact is consumption⁵, 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.

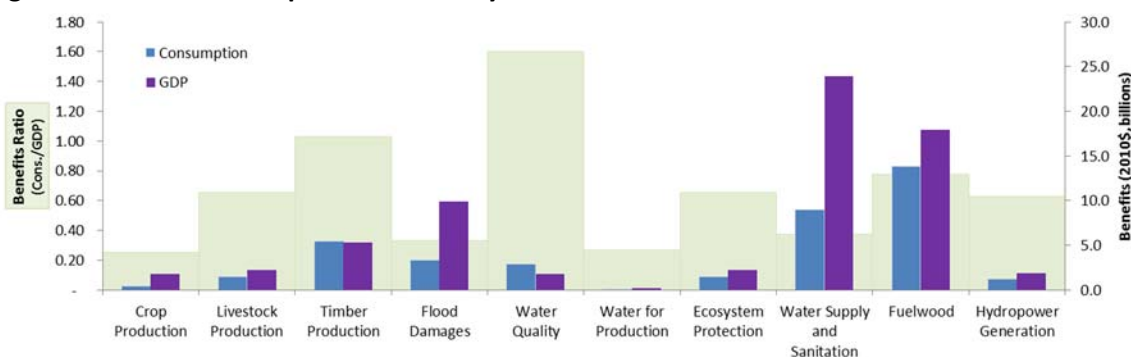
⁵ GDP is the sum of consumption, investment, government spending, and net exports.

Figure 4: 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 5, 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 for traded goods, such as fish and timber, 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 5: Private consumption and GDP by investment channel



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.

e. Comparison of benefits to costs

In a traditional benefit-cost framework, costs could be compared reliably to quantified and monetized benefits to assess whether the investments are worthwhile. In an aggregate sense, as illustrated in Table 4 above, the study did compare investment costs to the aggregate GDP benefits. For several reasons, however, disaggregated comparisons, by investment group, were not conducted in our original study:

- The investment costs modeled yield multiple benefits – this is especially apparent for the environmental management benefits.
- There are significant non-linearities in the nature of benefits which complicate a reliable disaggregation across scenarios.

- The main focus of the prior work was to establish 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) was done only at the aggregated, full national economy level, as shown in Table 4. For some categories of investments, however, these qualifications are less important. If we focus on the water supply and sanitation category, for example, the investments and their allocated GDP benefits are relatively self-contained (that is, they are not subject to the “multiple benefits” concern). Table 5 presents two sets of results: comparison of the results of the economy wide model with costs, and comparison of the results of monetizing the benefits for the water and sanitation (WASH) sector investment in a partial equilibrium framework. The latter results are based on application of a VSL for Uganda consistent with the Gates Foundation methods paper on mortality valuation (Robinson et al. 2018a), for the mortality component⁶; an avoided cost of illness of \$10 per avoided diarrhea case, as outlined above and consistent with Robinson et al. (2018b); and valuation of changes in labor availability using either the proposed minimum wage, or an estimate of the average Ugandan labor rate (Besamusca et al. 2012).

Table 5: Comparison of cumulative GDP gains and monetized partial equilibrium benefits to costs for the WASH investment (billion undiscounted 2015 USD)

	BAU to Moderate	BAU to High
Results from Economy-wide Model:		
Cumulative GDP gains	14.0	23.9
Total Investment Cost	0.8	1.0
Ratio GDP Gains to Cost	17.5	23.9
Monetized (Partial Equilibrium) Benefits:		
<i>Avoided mortality*</i>	8.9 to 41.8	10.0 to 47.1
<i>Avoided morbidity</i>	0.4	0.4
<i>Enhanced labor availability**</i>	0.8 to 1.3	0.9 to 1.6
Total monetized benefits	10.1 to 43.5	11.3 to 49.1
Ratio Monetized Benefits to Investment Cost	12.6 to 54.4	11.3 to 49.1

*Low end of mortality range uses Uganda VSL of \$18,860 (income elasticity of 1.5); high end uses \$107,100 (GNI * 160), converted from international \$ to 2015US\$ using ratio of GNIpc using PPP versus market exchange rate of 2.6; see Appendix D of Robinson et al. (2018a). VSL values were also adjusted for changes in GNI over time, using income elasticities applied longitudinally, consistent with recommendations in Robinson et al. (2018a).

** Low end of labor availability range uses minimum wage, high end uses average wage.

⁶ Robinson et al. (2018a) recommends: “Default VSL values should include the following: a. VSL = 160 * GNI per capita in the target country; b. VSL = 100 * GNI per capita in the target country; c. VSL extrapolated from a U.S. estimate to the target country using an elasticity of 1.5. The use of a constant ratio across countries under options (a) and (b) is equivalent to assuming that income elasticity is 1.0; recent work appears to be coalescing around this value. The ratio in option (a) is based on U.S. data, and reflects concerns that the lower VSL estimates found in many studies result from publication selection bias. The ratio in option (b) is based on meta-analysis conducted by the OECD. Option (c) reflects the elasticities found in extrapolating from a U.S. VSL to the VSLs from studies in low and middle income countries.”

The results in Table 5 yield important insights. First, the ratios of benefits to investment costs across the two approaches are quite similar – but the makeup of the benefits (total GDP or total monetized benefits) is likely different. The economy-wide modeling approach does not provide a disaggregated result for the three components of the partial equilibrium approach – mortality, morbidity, and labor market effects – though it could with additional runs. Second, although it would have been reasonable to expect that the partial equilibrium impact would be lower, because it ignores one effect captured in the economy-wide approach: the accumulating education benefit associated with reallocating time spent fetching water and sick time among children toward education. The partial equilibrium result is not lower, however, because of the large influence of the avoided mortality effect (based on application of a longitudinal income-adjusted VSL to the total numbers of deaths prevented in each of the 25 projection years).⁷ Third, there is clearly a difference between the implied beneficiaries of enhanced GDP and the implied beneficiaries in the partial equilibrium framework. The economy-wide model focuses on estimation of the collective benefits of these investments across the entire economy, while the partial equilibrium framework is designed to estimate the economic welfare gains to the direct recipients of the initial benefit (that is, households gaining a safe and clean water supply). As a result, it may merely be coincidence that the two estimates, in aggregate, are similar, as each is measuring the effects of widely differing groups of beneficiaries. An additional reason for this potentially surprising result is that the CGE allows for substitutability and also reflects non-linear trade-offs among factors of production, so that the marginal benefits of labor are not constant (as the partial equilibrium analysis assumes). Robinson et al. (2008) show for that the value of water in the Egyptian economy, a linear input-output analysis overestimates the value of water by five times that of a parallel CGE analysis, due primarily to the substitutability of water, capital, and labor as inputs for the agricultural sector.

Some may be tempted to conclude that the comparison in Table 5 of undiscounted results provides a skewed perspective because it ignores the timing of both costs and benefits, but we believe this is not the case, for two reasons. First, the concept of discounting future GDP is tenuous, and we are unclear about whether or how that could be done in a reasonable manner, even though the discounting of future monetized benefits is standard practice. Second, applying a 3% discount rate, the mortality component in Table 5 is reduced to \$6.3 to \$30.2 billion for the moderate investment scenario, and \$7.2 to \$35.2 billion for the high investment scenario. The reduction in total benefits from discounting is relatively small because, under both scenarios, the mortality benefits of extending clean water supply coverage occur early in the simulation, and there is no lag in the realization of a mortality benefit. In the end, it seems clear that both approaches yield the very robust result that the benefits of investments in household water supply and sanitation far exceed the costs.

A key difference in the results for macro-economic models versus traditional benefit-cost calculations is that the macro-models tend to be sensitive to accumulation of stocks (e.g., human capital through education, labor availability through health, and physical capital such as infrastructure that is protected from extreme events), while traditional benefit-cost analyses are designed to track annual flows (e.g., many years of reduced mortality and morbidity). One quality of the case study chosen here is that the

⁷ There is an emerging literature that compares results from macro-models to traditional benefit-cost calculations for health interventions – see Strzepek et al. (2018) for a summary of some of this literature – and the result of a very high mortality benefit in traditional benefit-cost analysis is not uncommon.

investments result in both outcomes – accumulation of capital (mostly human capital for the household water supply and sanitation channel) and a long series of avoided health effects. The natural conclusion, though, is that there is value in conducting both types of analysis, which yield different but equally important insights, wherever possible. Many times a portfolio of investments are being made in a single sector or across multiple sectors and the value of a CGE to policy makers facing tough budgetary decision is where there is complementarity or competition among the investments. This feature alone, regardless of the magnitude of the interaction, makes these tools useful for investment planning at the Ministry of Planning and Cabinet level.

4. References

Besamusca, Janna, Kea Tijdens, Godius Kahyarara, and Ernest Ngeh Tingum. 2012. Wages in Uganda: WageIndicator Data Report, WageIndicator survey 2012. WageIndicator Foundation, Amsterdam, The Netherlands.

Fink, Günther, Isabel Günther, and Kenneth Hill. 2011. "The effect of water and sanitation on child health: evidence from the demographic and health surveys 1986–2007." *International journal of epidemiology* 40.5: 1196-1204.

GOU (Government of Uganda). 2013. Uganda Vision 2040. Available at: <http://npa.ug/wp-content/themes/npatheme/documents/vision2040.pdf>

GOU. 2010. National Development Plan, 2010/11-2014/15. Kampala, Uganda: National Planning Authority, Government of Uganda.

GOU. 2015a. Second National Development Plan (NDPII) 2015/16-2019/20. Kampala, Uganda: National Planning Authority, Government of Uganda. June 2015.

GOU. 2015b. Ministry of Water and Environment Sector Performance Report 2015. Available at: [http://www.mwe.go.ug/sites/default/files/library/Water%20and%20Environment%20Sector Performance%20Report%202015.pdf](http://www.mwe.go.ug/sites/default/files/library/Water%20and%20Environment%20Sector%20Performance%20Report%202015.pdf)

Hutton, Guy. 2012. "Global costs and benefits of drinking-water supply and sanitation interventions to reach the MDG target and universal coverage." WHO.

Karanja, F., Emerton, L., Mafumbo, J., and W. Kakuru. 2001. Assessment of the Economic Value of Pallisa District Wetlands, Uganda, Biodiversity Economics Programme for Eastern Africa, IUCN – The World Conservation Union and Uganda National Wetlands Programme, Kampala.

MWE. (Uganda Ministry of Water and Environment). 2009. Strategic Sector Investment Plan for the Water and Sanitation Sector in Uganda. Kampala, Uganda: Ministry of Water and Environment, Government of Uganda.

MWE. 2015. Sector Performance Report. Kampala, Uganda: Ministry of Water and Environment, Government of Uganda. Accessed on September 1, 2015 from http://www.mwe.go.ug/index.php?option=com_docman&task=cat_view&Itemid=223&gid=15.

Robinson, Lisa A., James K. Hammitt, and Lucy O’Keeffe. 2018a. Valuing Mortality Risk Reductions in Global Benefit-Cost Analysis. Working paper prepared for the Benefit-Cost Analysis Reference Case Guidance Project, funded by the Bill and Melinda Gates Foundation. April 2018. Available at: <https://sites.sph.harvard.edu/bcaguidelines/>

Robinson, Lisa A. and James K. Hammitt. 2018b. Valuing Nonfatal Health Risk Reductions in Global Benefit-Cost Analysis. Working paper prepared for the Benefit-Cost Analysis Reference Case Guidance Project, funded by the Bill and Melinda Gates Foundation. April 2018. Available at: <https://sites.sph.harvard.edu/bcaguidelines/>

Robinson, Sherman, Ken Strzepek, Moataz El-Said, and Hans Lofgren. 2008. "The high dam at Aswan." *Indirect Impact of Dams: Case Studies from India, Egypt, and Brazil*. Washington, DC, and New Delhi, India: World Bank and Academic Foundation. Pp 227-273.

Strzepek, Kenneth, Brent Boehlert, Jacqueline Willwerth, and James Neumann. 2016. *The Contribution of Water Resources Development and Environmental Management to Uganda's Economy*. Available through the Ugandan Ministry of Water and Environment at: <http://www.mwe.go.ug/library/economic-study-2016-contribution-water-development-and-environment-resources-uganda%E2%80%99s>

Strzepek, Kenneth, Collins Amany, and James Neumann. 2018. *Assessing Economy-wide Effects of Environmental and Health Interventions in Support of Benefit-Cost Analysis*. Working paper prepared for the Benefit-Cost Analysis Reference Case Guidance Project, funded by the Bill and Melinda Gates Foundation. April 2018. Available at: <https://sites.sph.harvard.edu/bcaguidelines/>

Thurlow, J. 2008. *A Water and Agriculture-Focused Social Accounting Matrix (SAM) and Computable General Equilibrium (CGE) Model of South Africa* International Food Policy Research Institute (IFRPI), Washington DC, September.

UBOS (Uganda Bureau of Statistics). 2014a. *2014 Statistical Abstract*. Uganda Bureau of Statistics.

UBOS. 2014b. *Uganda National Household Survey 2012/2013*. Kampala Uganda; UBOS.

Woodward, Richard T., and Yong-Suhk Wui. 2001. "The economic value of wetland services: a meta-analysis." *Ecological Economics* 37.2 (2001): 257-270.