CLIMATE RISK AND BUSINESS
HYDROPOWER

Kafue Gorge Lower
Zambia

International Finance Corporation
World Bank Group

Acknowledgements

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Starting in 2008, IFC initiated the Climate Risk and Adaptation Program, a series of pilot studies that analyzes climate risks and adaptation options for projects in various sectors and regions. The studies' focus are private sector projects but with a significant emphasis on the cooperation and synergies with the public sector, research institutions and the civil society. To help understand and respond to the risks of climate change, IFC is developing best practices in assessing private sector risk and adaptation strategies.

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Abbreviations, Acronyms

AEZ	Agro-Ecological Zone
BCA	Benefit Cost Analysis
BCR	Benefit Cost Ratio
CMS	Cubic Meter per Second
CMI3	Coupled Model Intercomparison Project – Phase 3
CO_2	Carbon Dioxide
DMI	Domestic, Mining, and Industry
DOS	U.S. Department of State
DWA	Department of Water Affairs
ECHAM5	GCM Model Maintained by Max Planck Institute for Meteorology
EIU	Economist Intelligence Unit
ENSO	El-Nino Southern Oscillation
FAO	United Nations Food and Agricultural Organization
FEMA	U.S. Federal Emergency Management Agency
GCM	Global Circulation Model
GDP	Gross Domestic Product
GEF	Global Environment Fund
GHG	Greenhouse Gas
GNI	Gross National Income
GRZ	Government of the Republic of Zambia
GWH	Gigawatt-hour
Ha	Hectare
HEC	Hydrologic Engineering Center
HMS	Hydrologic Modeling System (USACE HEC)
IFC	International Finance Corporation
IPCC	Intergovernmental Panel on Climate Change
IPSL	Institute Pierre Simon Laplace
IT	Itezhi Tezhi
KBDI	Keetch-Byram Drought Index
KGL	Kafue Gorge Lower
KGU	Kafue Gorge Upper
KM^2	Square Kilometer
KW	Kilowatt
KWH	Kilowatt Hour
M	Meter
M^3	Cubic Meter
MM	Millimeter
MACO	Ministry of Agriculture and Cooperatives of Zambia
MARA	Mapping Malaria Risk in Africa
MEWD	Ministry of Environment and Water Development
MCM	Million Cubic Meters
MRI	Meteorological Research Institute
MW	Megawatt
MWH	Megawatt-hour
NAPA	National Adaptation Programs of Action (Zambia)
NASA	U.S. National Aeronautics and Space Agency
POSE	Physical, Organizational, Social, Economic
PRECPTOT	Total Annual Precipitation
PWF	Present Worth Factor
RCLIMDEX	Climate Indices analysis tool; R-platform version
ResSim	Reservoir System Simulation (USACE HEC)
RETScreen	Renewable Energy Technology Screening Tool
SCS	U.S. Soil Conservation Service
SDII	Simple Daily Intensity Index
SEIA	Strategic Environmental Impact Assessment
SRES	Special Report on Emissions Scenarios
STAPLEE	Social, Technical, Administrative, Political, Legal, Economical, Environmental
SWP	Scott, Wilson, Piesold
USACE	United States Army Corps of Engineers
USD	U.S. Dollar
USDA/ARS	U.S. Department of Agriculture/Agriculture Research Service
WB	World Bank
WCRP	World Climate Research Programme
WG	Weather Generator (general)
WRI	World Resources Institute
WWF	World Wildlife Federation
WXGEN	Weather Generator (Richardson)
ZAWA	Zambian Wildlife Authority
ZESCO	ZESCO Limited

1. Introduction

It is a strategic priority of the International Finance Corporation (IFC) to incorporate assessment of climate change impacts throughout its operations. As the private sector member of the World Bank Group, IFC assists private companies in identifying business risks and opportunities associated with climate change. To help its clients understand and respond to the risks of climate change, IFC is developing best practices to assess climate change risks and to inform appropriate adaptation strategies.

This report, part of IFC's Climate Change Risk Case Studies series, documents the approach and findings associated with the Kafue Gorge Lower (KGL) Hydropower Project Climate Change Risk Assessment. This project was implemented to (1) develop and apply an approach to assess the impacts of climate change, (2) identify risks and opportunities associated with climate change impacts, and (3) develop frameworks and tools to support climate change risk assessment, planning, and adaptation strategies.

1.1 Project Background

This evaluation of climate change risks to the operational and financial viability of the KGL hydropower plant examines a diverse and complex set of data and issues, including: Zambia's current conditions (related to energy demand and supply), the potential direct and indirect impacts of climate change on power demand and supply, and possible adaptive responses. This project background section introduces current country conditions and overviews the study area for this project.

1.1.1 Zambia Current Conditions

Currently, poverty is widespread in Zambia, which had a 2008 per capita annual Gross National Income (GNI) of $949.71 measured in US dollars (USD) (World Bank, 2010) with about two-thirds of Zambians living in poverty (US Department of State [DOS], 2010). Zambia's population of 12 million is among the poorest in Africa, with about 68% of all Zambians living on less than one dollar a day (World Resources Institute [WRI], 2010). However, the country is rich in natural resources, with large areas of fertile land and a rich endowment of copper and other resources.

Recent economic trends have generally been positive and copper mining is a growing industry. Major exports are dominated by copper and cobalt mining (73%) and the remaining contributors – mostly agriculture, with some manufacturing and tourism – are keeping up with (in nominal growth) or outperforming (in real terms) mining. As a result, despite high inflation and a number of adverse supply shocks (e.g., drought, high world oil prices, and fuel shortages due to oil refinery production interruptions), the Zambian economy has been performing relatively well, with real Gross Domestic Product (GDP) growth of 6.2 and 6.0%, respectively in 2007 and 2008 (Economist Intelligence Unit [EIU], 2009). Due to the worldwide economic downturn, real GDP estimated for 2009 and 2010 were 2.5% and 3.8%, respectively (EIU, 2009). While the copper sector was hit hard by the global economic downturn and some mines halted production due to price decreases, Zambian copper production remained strong in early 2009 based on strong investment in recent years (EIU, 2009). The agricultural sector (especially maize) also looked strong for 2009 (EIU, 2009).

Employment in Zambia is about predominantly (75%) in the agricultural sector, with about 19% in the service sector, and 6% in mining and manufacturing (US DOS, 2010). Increasing industrial and other economic growth, combined with population growth (estimated at 2.4% per annum in 2000, with slightly higher annual rates in urban areas), will likely increase energy needs (Zambia, 2010, United Nations [UN]

Data, 2010). In addition, rising individual energy demand and urbanization in areas such as Lusaka will increase Zambian energy demand in the future.

The majority of Zambia's power supply is provided through hydropower operations along the two primary rivers, the Zambezi and the Kafue. Additional power generation will be required for further economic development in Zambia. For example, the mining sector requires a reliable and growing supply of energy. Organized and sustainable development of the power sector, steady improvement in the provision of reliable and affordable electricity services, and greater access to electricity are important determinants of Zambia's economic performance and the quality of life of Zambians.

In recent years, electricity shortages have had a detrimental effect on industry; however, Zambia has a high potential for hydropower generation. Government policies are focusing funds and attention toward improving energy and transportation infrastructure (EIU, 2008). Power supply requirements within the country are satisfied predominantly by ZESCO, the vertically-integrated, state-owned utility company. Currently, hydropower provides a majority of the power supply in Zambia; in the past, Zambia was a large regional electricity exporter, but this has been curtailed in recent years due to rehabilitation work on the country's main hydropower stations. As discussed in this report, new hydropower projects (such, as KGL) are planned (EIU, 2008). Peak demand was estimated at about 1,400 Megawatts (MW) for the country in 2008 (EIU, 2008). In 2007, the mining industry used 59% of the country's electricity.

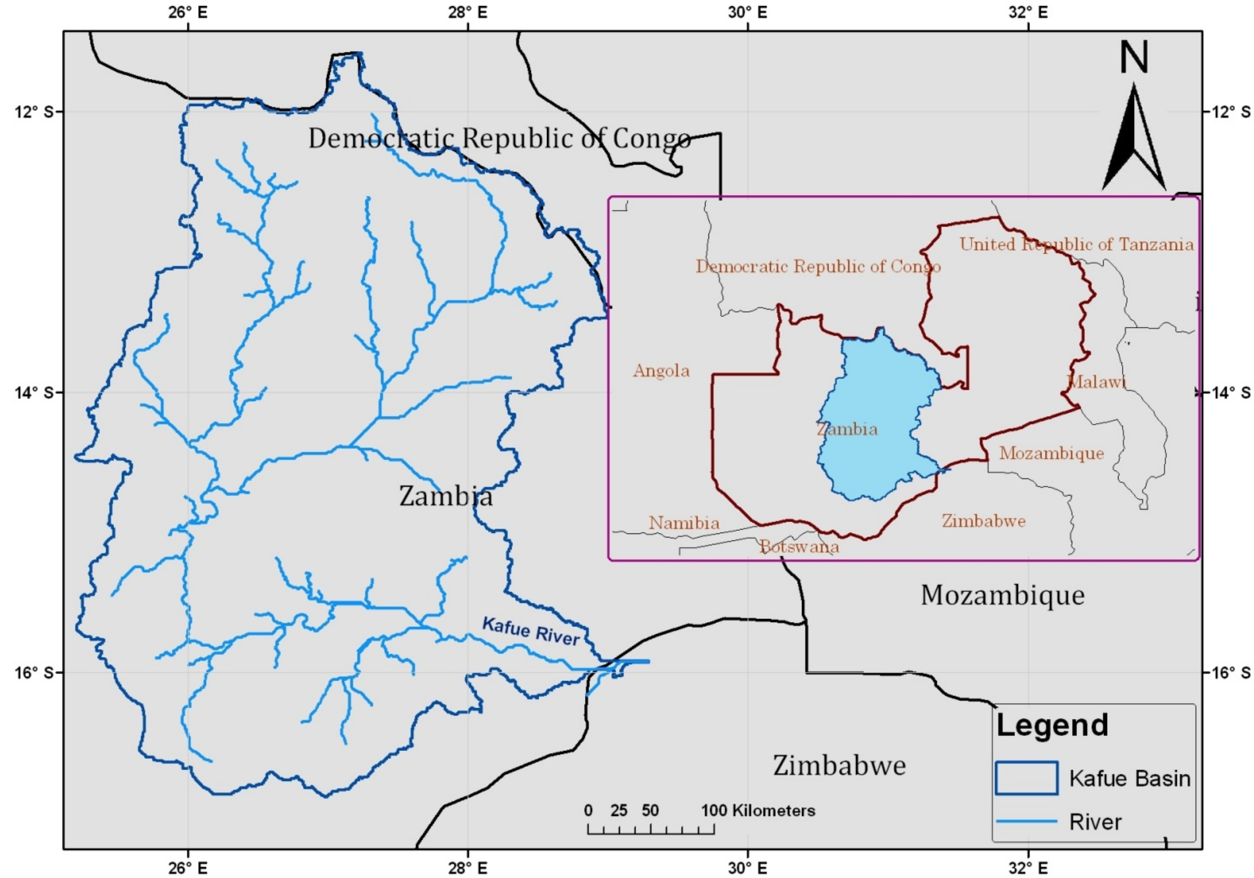
This study considers planned operations at a new hydropower plant along the Kafue River, specifically, the KGL dam and hydropower plant. The following section provides additional information on the project study area and power plans for the area.

1.1.2 Project Study Area

The Kafue River Basin plays a central role in Zambia's economy with most of the nation's mining, industrial, and agricultural activities and approximately 50% of Zambia's total population concentrated within the basin area (Mwelwa, 2004). A map of the Kafue River Basin is provided in Figure 1-1; the figure shows the location of the Basin within Zambia on the right (insert) and includes a representation of the major streams within the Basin on the left portion of the figure.

The Kafue River is one of the major tributaries of the Zambezi River. The area of the Kafue River Basin measures about 156,000 square kilometers (km^2) and lies entirely within the borders of Zambia. The basin area occupies about 20% of Zambia's total land area. The Kafue River Basin, which comprises the project study area, originates in the Copper Belt Province at an elevation of 1,456 meters (m) above sea level and terminates at an elevation of 366 m above sea level at its confluence with the Zambezi River. The total length of the Kafue River is about 1,500 km (Williams, 1977; Imagen Consulting Ltd, 2008). After originating at the Zambia-Congo divide, the Kafue River flows southwards or south-westwards close to the Lukanga Swamps and then into the Itezhi-Tezhi (IT) reservoir. The IT reservoir is a man-made reservoir constructed from 1973 to 1976; it was originally developed to provide additional water storage to support operation of the Kafue Gorge Upper (KGU) dam and hydropower project (downstream of the reservoir). The KGU dam and reservoir were constructed in 1972, but the geography in this area did not allow the KGU reservoir to provide all of the water storage capacity for the KGU hydropower plant.

Figure 1-1: Location Map of Kafue River Basin



After the IT reservoir, the Kafue River turns eastwards and flows for about 350 km across the Kafue Flats and into the KGU reservoir. The Kafue Flats are a wide and flat area of the river, with natural water flow moving slowly across the flats at a shallow depth. The Kafue Flats are a valuable natural resource and planning considerations for hydropower are working to incorporate means to protect this conservation area.

Along the Kafue River, there are currently three areas with operating and/or planned hydropower projects: (1) the IT dam (existing) and hydropower power plant (planned/existing in the short term); (2) the KGU dam and hydropower plant (existing); and (3) the KGL dam and hydropower plant (planned). The planned KGL project is the focus of this climate change risk assessment project.

The KGL site lies about 65 km upstream of the confluence of the Kafue River with the Zambezi River, and about 20 km downstream from the existing KGU hydropower plant. Power unit capacities and operational parameters are presented in greater detail in the reservoir (energy) modeling section of this report (Section 3.2). For modeling purposes, all units (existing and planned) are modeled as operating power stations in this study.

Flow into the KGU reservoir is regulated by the IT dam, which creates the 6,008 million cubic meters (mcm) IT reservoir located on the Kafue River about 230 km upstream and west of the KGU hydropower project. Since the initiation of this climate change risk assessment project for KGL, plans for a 120 megawatt (MW) turbine project at the IT dam have evolved rapidly. This new, planned capacity has been incorporated into the project assessment.

In addition to flows released from the IT dam, there are various local intervening inflows between the IT reservoir and the KGU hydropower project site. Flows released from the IT reservoir pass through the natural wetland area of the Kafue Flats. This area contains substantial environmental and ecological assets. Stakeholders including ZESCO, the World Wildlife Federation (WWF), and others are continuing to negotiate and plan for appropriate water release schemes from the IT reservoir to protect wildlife and fauna in the Kafue Flats area (Schelle and Pittock, 2005).

1.1.3 Climate Change Issues

Zambia's reliance on hydropower to meet current and future electricity demand faces three types of challenges: (1) increased economic development leading to growing demand for water for other uses; (2) the potential for increased water needs to address conservation goals in light of the potential impact of climate change and climate variability on water supply and evaporation; and (3) increase power demands requiring additional water for hydropower. Conservation needs include non-consumptive, timed releases to support the Kafue Flats; other uses include water demands for irrigation (primary volume), domestic use, mining, and industry. Many stakeholders within government and the public and private sectors appreciate the need to better understand the timing and extent of supply-demand tensions related to water, with meaningful financial and technical resources being dedicated to better evaluating the complexity of the challenges and identifying possible solutions.

1.2 Project Purpose

This project was implemented to develop and implement an approach for identifying and evaluating potential climate change impacts on hydropower energy production. The project is intended to test approaches that can support evaluation of climate change impacts on the planned KGL project, as well as to identify and test approaches that may apply to consideration of climate change impacts on other infrastructure projects. To achieve this purpose, the project evaluated the KGL project and potential climate change impacts, including consideration of: water for and energy production, financial performance, natural hazard risks, other (competing) uses, and adaptation measures.

Given that climate change studies and risk assessments are an evolving field, this report presents findings and recommendations, as well as strengths and limitations of the data and methodologies applied and uncertainties associated with the modeling and data inputs and outputs. The project approach recognizes that while certain uncertainties are associated with quantifying climate change impacts, there is a pressing need to plan for climate change impacts. In the future, climate change impacts will exacerbate already existing challenges associated with competing resource demands.

1.3 Project Approach

Publicly available models and existing data were used to (1) project temperature and precipitation with climate change impacts, (2) study climate change impacts on basin flow and energy production (with competing uses evaluated), and (3) estimate financial impacts on KGL. Risk assessment approaches were then applied to evaluate potential direct and indirect impacts associated with climate change (natural hazard impacts and other use needs [agriculture, conservation, domestic and industry/mining uses]) and how these might impact ZESCO operations. Finally, adaptation goals and strategies were identified and evaluated using a systematic framework.

This project evaluated potential future climate scenarios, using six Global Climate Models (GCMs) combined with two emissions scenarios from the Special Report on Emissions Scenarios (SRES) (Nakicenovic, N., et al., 2000). These inputs provide estimates of future temperature and precipitation conditions. These results were then used to project water supply and energy generation, drawing on publicly available hydrologic and reservoir (energy) modeling tools. The resulting levels of power generation were then incorporated into the financial analysis to help characterize potential climate change risks to the KGL hydropower project.

In addition to understanding the potential impacts of climate change on the supply of water, this assessment evaluates the potential impacts associated with demand for water from other uses. Aside from the obvious need for potable water to support populations in both urban and rural areas, water is also needed (1) to supply the industrial sector (including mining use and discharge), (2) to provide for the irrigation of crops on large commercial and small family farms, (3) to support livelihoods (e.g., livestock husbandry, fishing, and tourism in the Kafue Flats area), and (4) to help achieve conservation goals (e.g., protection of the ecosystem and natural resources of the Kafue Flats). Climate change impacts, combined with estimated population and economic growth in Zambia, are expected to increase water and energy demands over time.

The assumptions for conservation and other use scenarios were based on data available from prior studies, such as a 2003 Strategic Environmental Impact Assessment (Scott Wilson Piesold [SWP], 2003). During the course of the project, the modeling results using these assumptions and scenarios were evaluated in light of more recent information, such as the World Bank's draft "Multi-Sector Impact Opportunity Assessment" (MSIOA,World Bank, 2009) and the "Strategic Environmental Assessment (SEA) of the Sugar Sector in Zambia" (Palerm, et al., 2010).

1.3.1 Evaluation Scenarios

As indicated above, the study used six GCM models and two SRES emission scenarios to project a set temperatures and precipitation levels over four time periods (base, early-, mid-, and late-century) for the Kafue River Basin. Ultimately, the study focused on three GCMs and both of the SRES emission scenarios, which resulted in a total of six sets of outputs for temperature and precipitation (across four time horizons each); one output was generated for each GCM/emission scenario combination. The outputs from each GCM/emission scenario combination were used as inputs for the hydrologic flow modeling of the Kafue River Basin, which provided flow rates across four time horizons for each of the GCM/emission scenarios. Next, the reservoir (energy) model was used to estimate power generation in each time horizon for the maximum power scenario (P-1), as well as for eight alternative water use scenarios; these power generation projections were then used as inputs to the financial model. Figure 1-2 depicts the detailed assessment approach; Figure 1-3 shows a simplified version of the approach; Figure 1-4 presents the orientation image used to guide readers through subsequent sections of this report.

Seven of the eight alternative water use scenarios shown in the modeling scheme are based on scenarios presented in the 2003 SEIA (SWP, 2003). The P-1 scenario reflects the level of power generation that could be achieved with "business as usual" increases in water demand for irrigation, and domestic, mining, and industrial (DMI) uses, and with no releases of water from the IT dam for conservation purposes. The I-3, I-6, and I-9 scenarios include the same water abstractions assumed for the P-1 scenario, as well as additional volumes of water abstracted, primarily for irrigation (thereby reducing available water for power generation). The eighth scenario, I-10, was added to provide for a higher level of demand for irrigation in the mid- and late-century periods. Similarly, the C-1, C-2, and C-3 scenarios include the same abstraction assumptions as the P-1 scenario, but with varying volumes and timings of releases assumed for conservation purposes. This report refers to the water use scenarios as the maximum power scenario (P-1), the development scenarios (I-3, I-6, I-9, and I-10), and the conservation scenarios (C-1, C-2, and C-3). Section 3.2.1.2 provides further details on the power, development, and conservation scenarios.

Figure 1-2: Detailed Assessment Approach

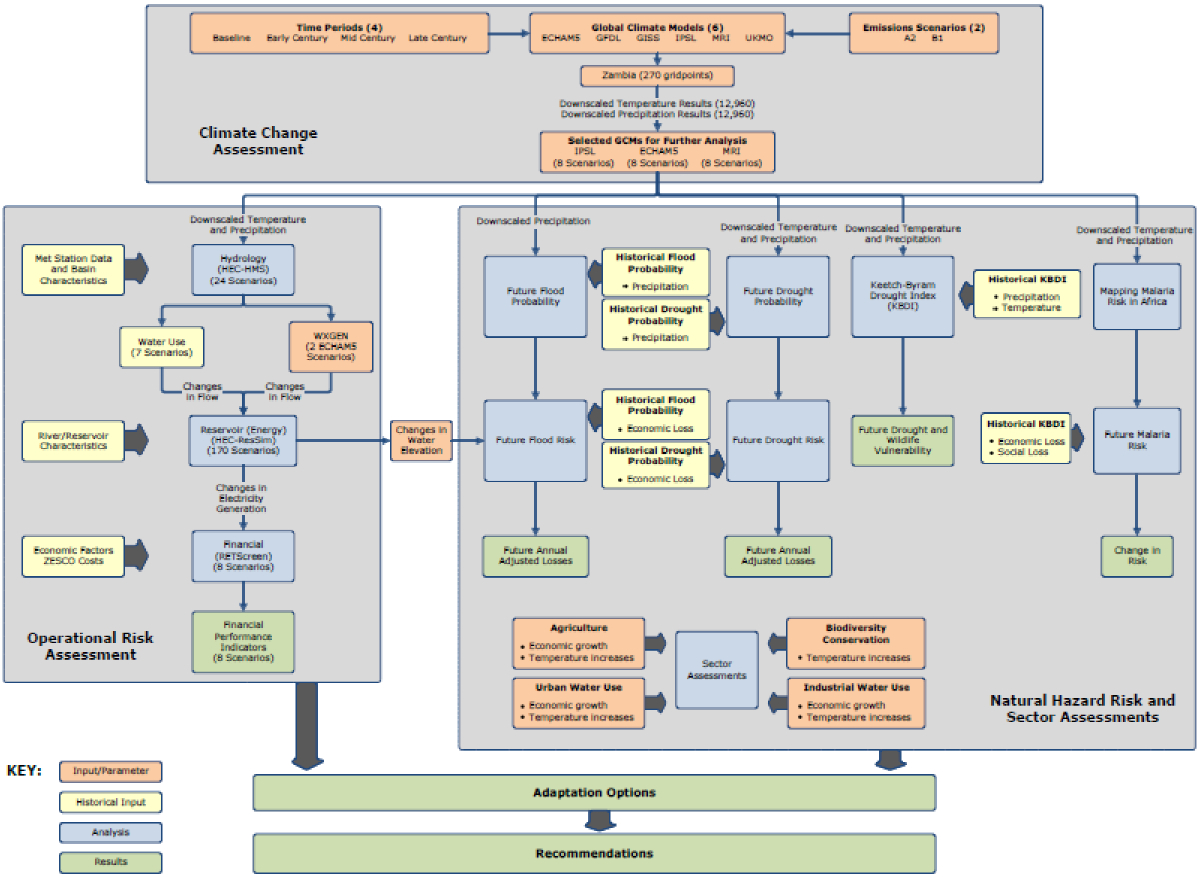


Figure 1-3: Simplified Assessment Approach

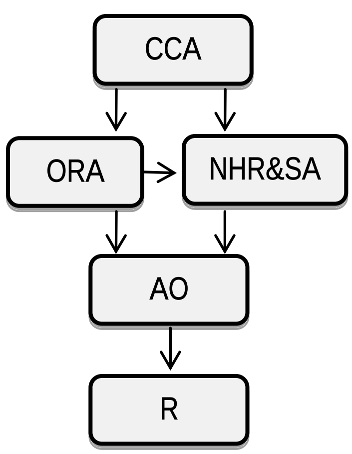


Figure 1-4: Assessment Approach

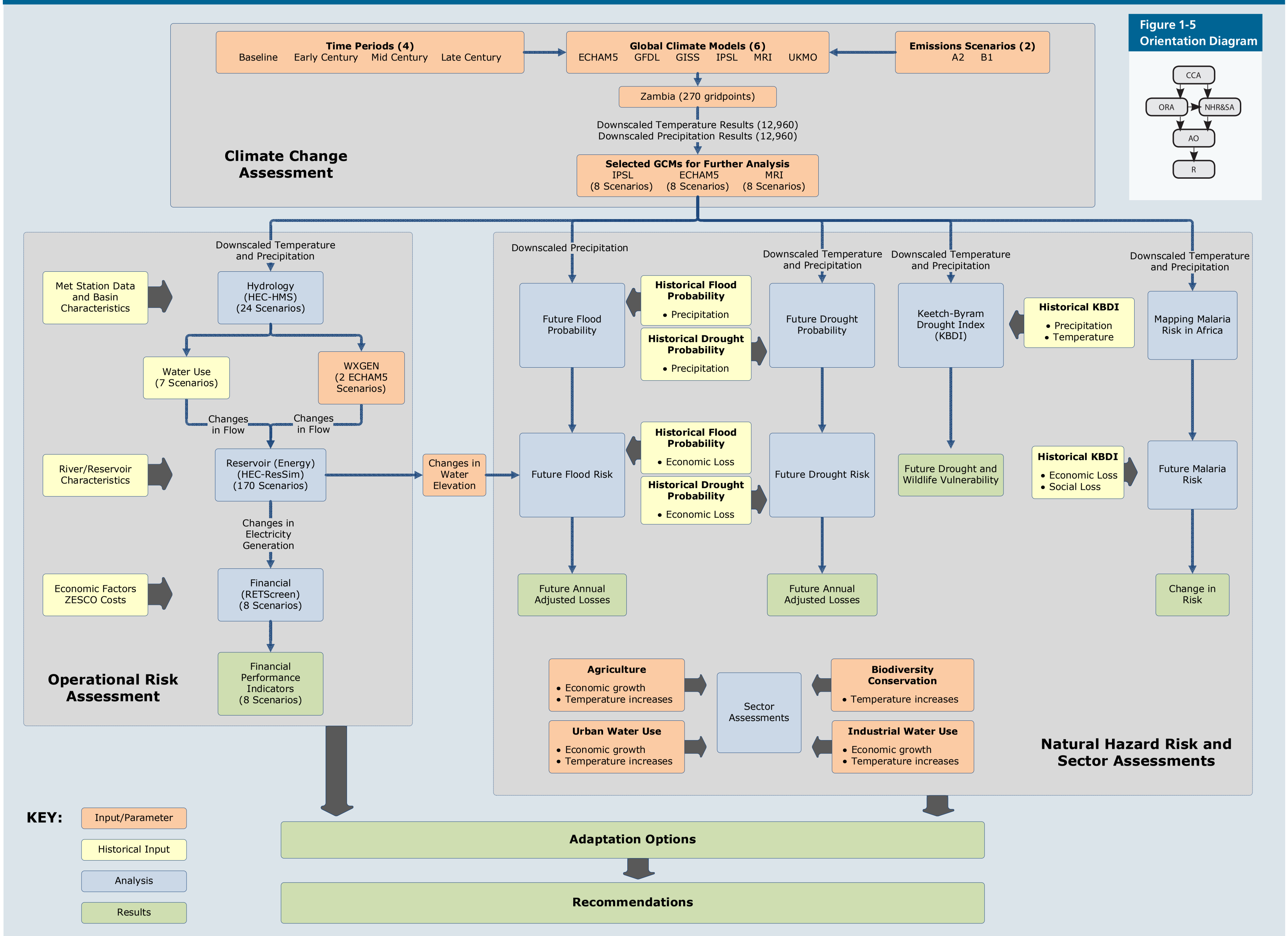
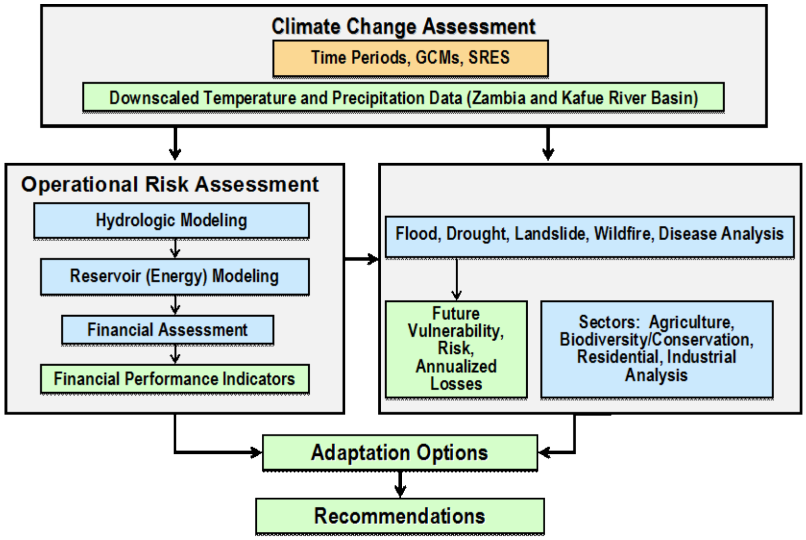


Figure 1-3: Simplified Assessment Approach



1.3.2 Risks and Adaptation

The project also developed and implemented (1) risk assessment approaches to consider potential direct and indirect impacts associated with climate change (risk considerations for natural hazards and economic sectors) and (2) a framework for identifying and evaluating adaptation goals and strategies. These approaches and tools are used to evaluate the modeling findings in terms of risks to KGL and ZESCO and to identify priority climate change risks to KGL and ZESCO over time and potential adaptation options that support ZESCO operations and the surrounding area.

1.4 Project Initiation and Information Sources

Project initiation included discussions to agree upon project implementation details, including the site visit. The site visit was implemented in September 2009 and included a prepared presentation for various organizations and entities. During each site visit meeting, information and input was also collected, including any responses to project requests for information.

Stakeholder meetings were pursued with two objectives: (1) increase awareness of the project, share the project approach and goals, and obtain input and involvement, and (2) collect background information and local data to improve the quality of the assessment. Not all stakeholders were available to meet during the trip; however, meetings were held with the following 14 entities:

1. Center for Energy, Environment, and Economics of Zambia (CEEEZ)
2. Department of Water Affairs
3. Environmental Council of Zambia
4. International Union for the Conservation of Nature (IUCN)
5. Kafue District Health Clinic
6. Ministry of Agriculture and Cooperatives (MACO)

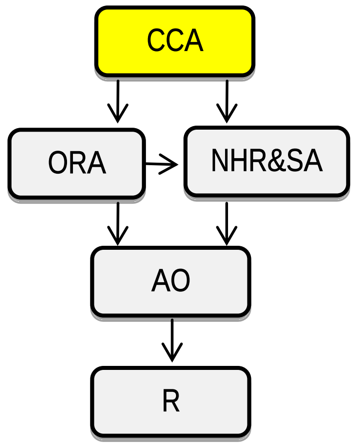
7. Ministry of Tourism, Environment and Natural Resources, Climate Change Facilitation Unit
8. Office of Public Private Partnership Initiatives (OPPPI)
9. UN Development Programme
10. University of Zambia (UNZA)
11. Zambezi River Authority
12. Zambia Meteorological Department
13. Zambia Wildlife Authority (ZAWA)
14. ZESCO

Several meetings with key staff at the Zambia Meteorology Department led to the acquisition of daily data from 12 meteorological stations in the Kafue River Basin area for a 30-year period between 1975 and 2005. Additional project information included past reports, studies, and operational data provided by the World Bank and ZESCO and obtained through research by the project team. Resources provided and used are cited in the body of this report and listed in Section 8.0, References.

2. Climate Change Assessment

2.1 Climate Change Assessment Approach

This section discusses the climate change assessment (CCA) portion of the study, including the selection of time horizons, GCMs, and emissions scenarios.



2.1.1 Time Horizons

This project evaluates the period from 2010 through 2100. This time horizon was selected for its ability to capture the planned lifetime of the KGL hydropower project. It is worth noting, however, that it is widely acknowledged in the climate change science community that the ability of models to forecast the future climate beyond 2050 with reasonable confidence is low (as illustrated by the increasing divergence of the projections shown in Figure 2-1, next page).

For this assessment, the remaining 90 years of this century were divided into three equal periods, defined as early-century (2010 to 2039); mid-century (2040 to 2069); and late-century (2070 to 2099). Thirty-year time horizons are commonly used in climate change impact studies because a 30-year period is sufficiently long to "dampen" (through averaging) much of the year-to-year climatic variability, but is short enough to approximate future climate as relatively stable within the period. The beginning of the mid-century period corresponds well with the approximate timing of the planned transition of the KGL hydropower project from public to private project ownership.

2.1.2 Global Circulation Models (GCMs)

The International Panel on Climate Change (IPCC) Fourth Assessment Report is a widely accepted, peer-reviewed assessment of the science of climate change (IPCC, 2007). The IPCC assessment is based on the results of the Coupled Model Intercomparison Project – Phase 3 (CMIP3), a project of the World Climate Research Programme (WCRP) (Meehl, et al., 2007). CMIP3 is a repository for the results of GCM runs performed by dozens of research groups worldwide across a range of global greenhouse gas (GHG) emissions scenarios. The GCM runs of the CMIP3 represent (1) the most current knowledge about the global climate system and its response to GHG concentrations and (2) the most current computational methods and capability on coarse spatial scales. These climate projections, once downscaled to finer resolution for a region of interest, represent appropriate study cases for climate change impact studies such as the present study.

About two dozen GCMs are used in the global climate modeling community. Recent research indicates that selecting a number larger than four is adequate to sample much of the inter-model variability (Pierce et al., 2009). Of the 16 GCMs for which data were available, six were selected for this project, as shown in Table 2-1. These models provide a broad coverage of the geographically diverse research community associated with climate change research. Further discussion of issues affecting the selection of these models is provided in Appendix A1.

Table 2-1: Selected Global Circulation Models

#	Modeling Group	Model I.D.	Primary Reference
1	U.S. Department of Commerce/NOAA/Geophysical Fluid Dynamics Laboratory (U.S)	GFDL-CM2.0	Delworth *et al.* (2006)
2	Institut Pierre Simon Laplace (France)	IPSL-CM4 (IPSL)	IPSL (2005)
3	Max Planck Institute for Meteorology (Germany)	ECHAM5/MPI-OM (ECHAM5)	Jungclaus *et al.* (2006)
4	Hadley Centre for Climate Prediction and Research/Met Office (U.K.)	UKMO-HadCM3	Gordon *et al.* (2000)
5	Meteorological Research Institute (Japan)	MRI-CGCM2.3.2 (MRI)	Yukimoto *et al.* (2001)
6	U.S. National Aeronautics and Space Agency (NASA)/Goddard Institute for Space Studies (U.S.)	GISS-ER	Russell *et al.* (2000)

Note: Model I.D. = model identification as used by the Intergovernmental Panel on Climate Change

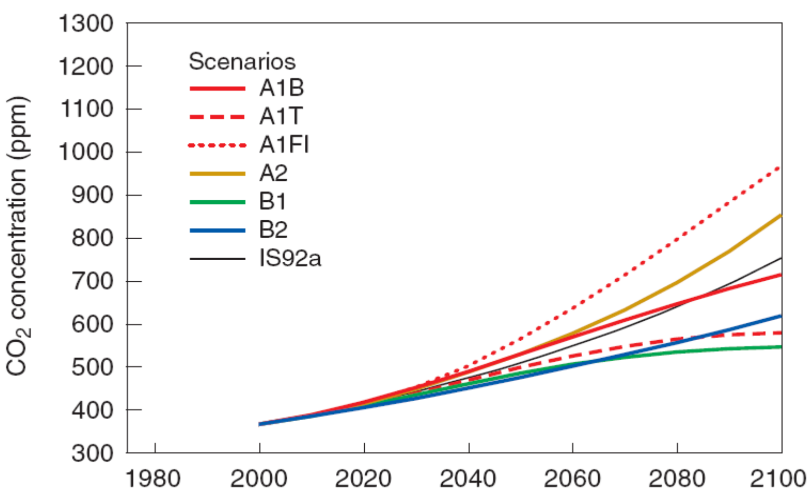
2.1.3 Emissions Scenarios

The IPCC has developed GHG global emissions scenarios that are published in the Special Report on Emissions Scenarios (SRES) (Nakicenovic, N., et al., 2000). Each SRES emissions scenario is built on a "storyline" that relates future GHG emission levels to key driving forces. For this assessment, SRES emissions scenarios A2 and B1 were used and are described in the SRES as follows:

- SRES-A2: Based on a world that is regionally organized economically, in which technological change is fragmented and population growth is high.
- SRES-B1: Describes a world with low population growth and rapid changes in economies toward service and information, with relatively rapid introduction of clean and resource efficient technologies.

A more detailed description of the SRES emissions scenarios is included in the SRESs. Figure 2-1 shows the various SRES emissions scenarios and resulting estimated carbon dioxide (CO_2) concentrations in the atmosphere through the 21st century (IPCC, 2001).

Figure 2-1: IPCC SRES Emissions Scenarios and Atmospheric Carbon Dioxide Concentrations



Source: IPCC, 2001.

As Figure 2-1 shows, each emissions scenario estimates different atmospheric concentrations of GHGs in the future. Scenario B1 is often used to represent the 21st century "best case" scenario (Houghton et al., 2001). Scenario A2 reflects higher GHG concentrations and is the highest emissions scenario for which most modeling groups have completed simulations; however, the A2 scenario is not a "worst case" scenario; CO_2 emissions since the year 2000 have exceeded even the highest IPCC SRES emissions scenario (see Raupach et al., 2007, and updates at The Carbon Project: http://www.globalcarbonproject.org). Because A2 is often the highest emissions scenario studied in regional impact studies (e.g., Maurer, et al., 2009), it was selected to represent the high GHG emissions scenario for this study.

IPCC Emission Scenarios, the Copenhagen Accord and the Cancún Agreements

After the climate change negotiations of Copenhagen in December 2009, Annex I and non-Annex I countries developed pledges for future emission reductions to help achieve a maximum 2°C temperature increase. Modeling of the combined pledges shows that the projected results fall short of the necessary reductions identified by the IPCC to achieve the 2°C goal; therefore, the chance of exceeding an increase of 2°C is high. In the Cancún Agreements, pledged target levels have not changed from Copenhagen, nor are they legally binding; these pledges are still below the level required to limit global warming to a 2^oC increase (Pew Center, 2010).

The most recent information on actual GHG emissions indicates that the global emission pathway exceeds the highest scenario considered by the IPCC in its SRES report. Given recent estimates of actual emissions reductions, GHG emissions, and associated climate impacts, the global community is recognizing a strong need to focus attention to adaptation measures to cope with climate changes (Pew Center, 2010).

2.1.4 Climate Projection Data Inputs and Outputs

Regional climate studies require downscaling of GCM results to regional scales. For this project, downscaled CMIP3 results at 0.5 degree (°) resolution (latitude and longitude) are used (Santa Clara University, 2010; Mauer, et al., 2009). The appropriate subsets were identified and selected to address the geographic regions of Zambia (269 grid cells) and the Kafue River Basin project study area (70 grid cells). Additional information on the Santa Clara University dataset, the downscaling approaches used, and the strengths and limitations of the dataset are provided in Appendix A1.

After data set selection, the CMIP3 data were analyzed to generate gridded temperature and precipitation data sets for Zambia and the Kafue River Basin for the six GCMs and two emissions scenarios, across a base period and three future time periods.

2.2 Climate Change Assessment Findings

This section presents temperature and precipitation findings associated with the climate change projections; additional detail on this portion of the study is provided in Appendix A1.

2.2.1 Temperature

Figure 2-1 shows the projected mean annual temperature for the six GCMs studied, and their mean (black line), for Zambia and for the Kafue River Basin. The Kafue River Basin's mean annual temperature is about 0.5°C cooler than the mean for Zambia. The variation in results among the six models is reasonably small, with all projecting large temperature increases over this century.

As shown in Figure 2-2, in every case, the ECHAM5 projects the highest temperature increases and MRI projects the lowest temperature increases. Trends for Zambia and the Kafue River Basin are similar; basin temperatures are about 0.5°C cooler the Zambian average at any projected time.

The 30-year running means of the temperature projections are shown in Figure 2-3. The plotting position corresponding to a given year (e.g., 2015), represents the mean for the 30 years around that year (e.g., 2000-2029 for 2015). Thus, the plotted lines do not extend to the first 15 years (1950-1964) or the last 14 years (2086-2099).

Figure 2-2: Simulated Annual Time Series of Temperature Spatially Averaged over Zambia (top panels) and the Kafue River Basin (bottom panels), for the B1 (left) and A2 (right) Emission Scenarios

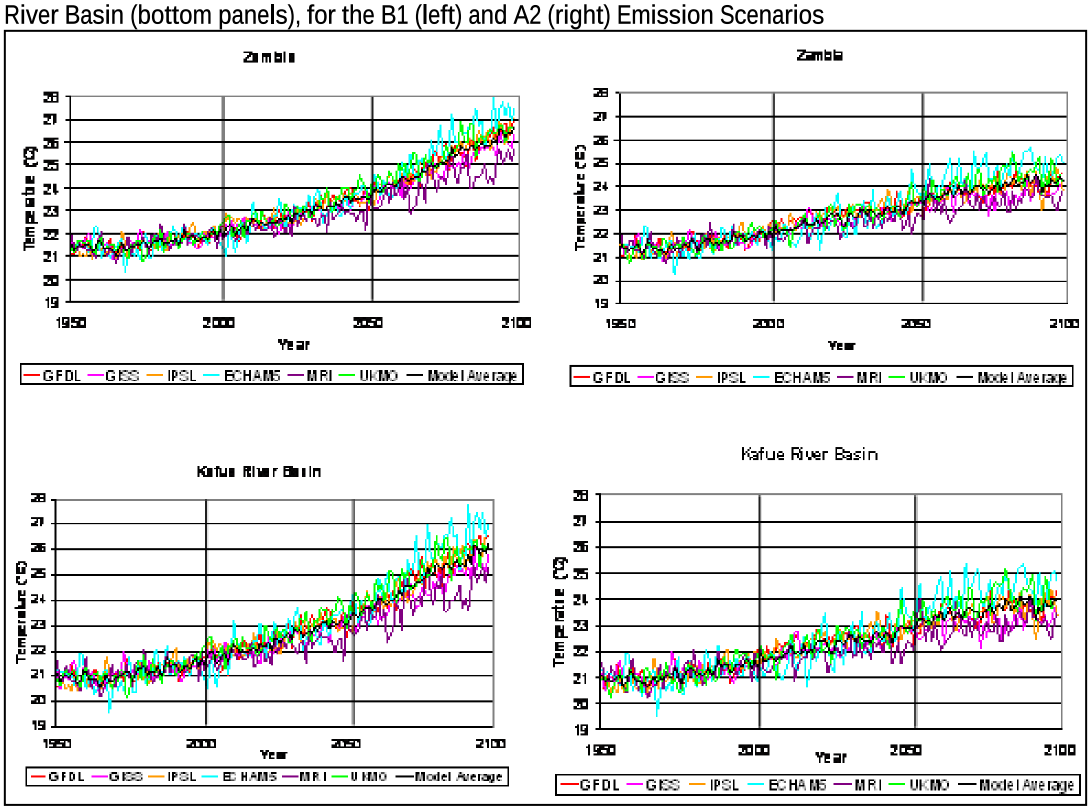
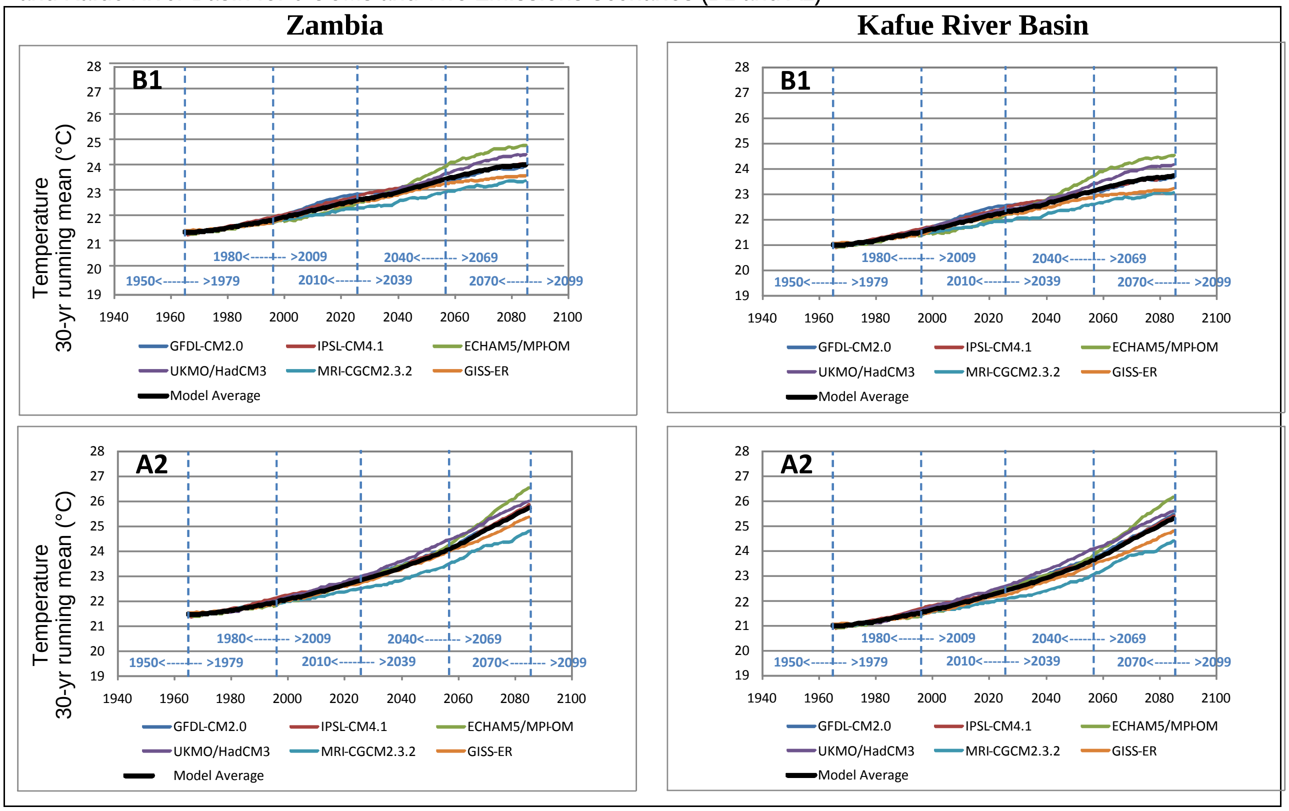


Figure 2-3: 30-Year Running Means of Simulated Annual Time Series of Temperature Spatially Averaged for Zambia and Kafue River Basin for 6 GCMs and Two Emissions Scenarios (B1 and A2)



Notes: This figure shows the 30 year running means of the simulated annual time series of temperature spatially averaged over Zambia (left panels) and the Kafue River Basin (right panels), for the B1 (top) and A2 (bottom) emissions scenarios.

Figure 2-4 shows the simulated seasonal temperatures for the four seasons, for the A2 emissions scenario, spatially averaged over the Kafue River Basin. The projected temperature increase is greatest (about 6°C) for the September to November period. It is least (about 4°C) for the December to February period, which is the principal rainy season.

Figure 2-4: Simulated Seasonal Temperature (for Four Seasons) for the A2 Emissions Scenario Spatially Averaged over the Kafue River Basin

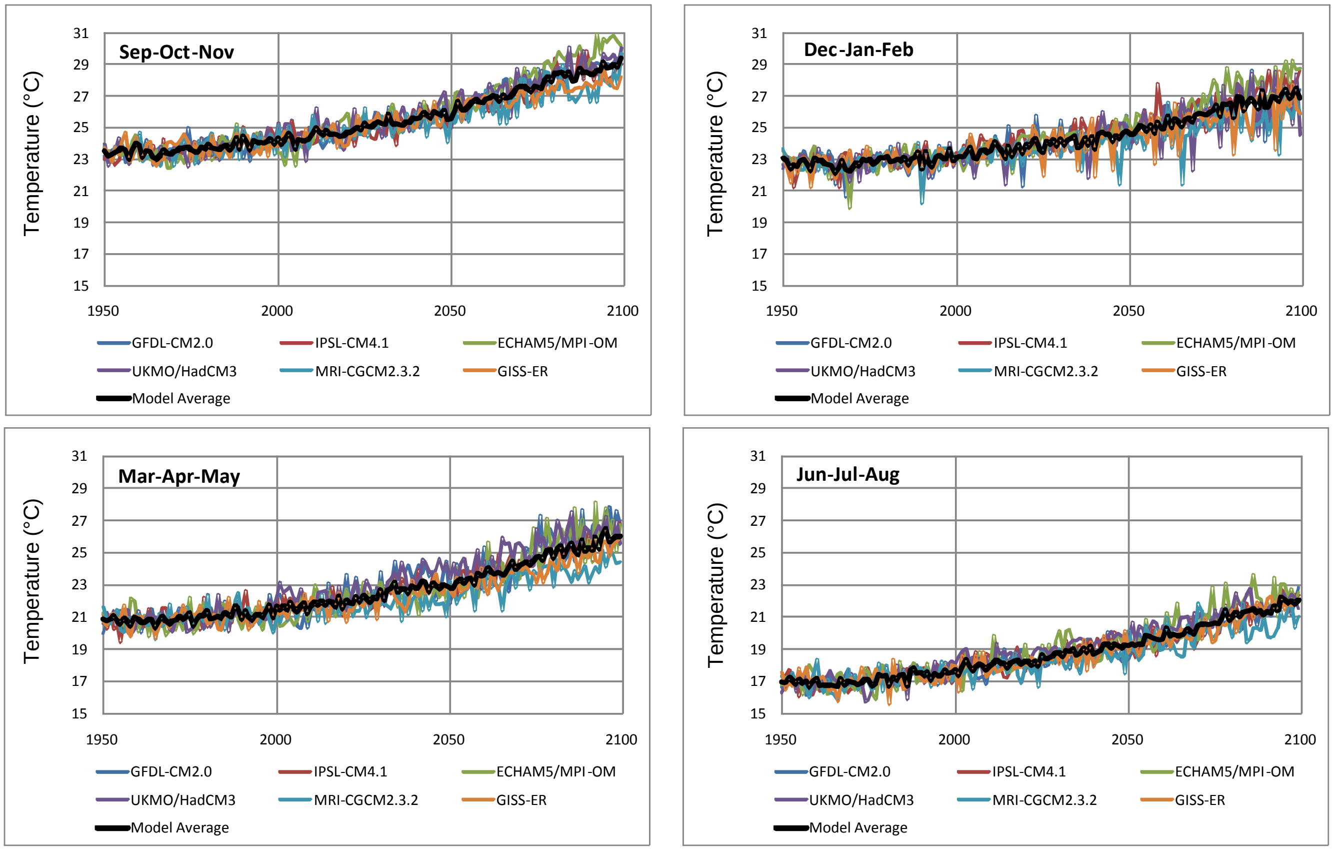


Figure 2-5 shows projected temperature for each of the 12 months, for the end-of-century time horizon, for scenarios B1 and A2 over the Kafue River Basin. The shapes of the temperature curves align for the baseline and projected results. Figure 2-6 shows the range of results for each of the GCMs for the base and late-century periods for both emission scenarios.

Figure 2-5: Simulated Mean Monthly Temperature for the End of Century (2070-2099) and Baseline (1950-1999) Periods, for A2 and B1, Spatially Averaged over the Kafue River Basin

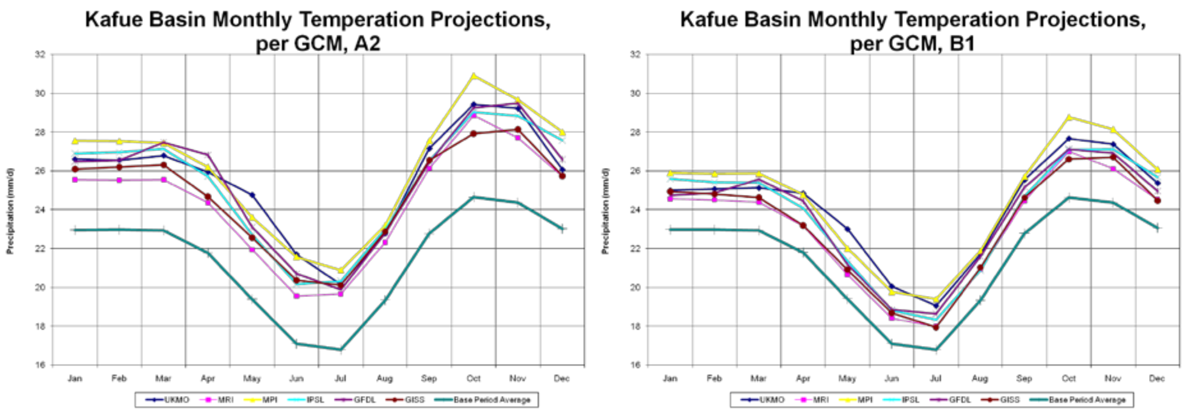
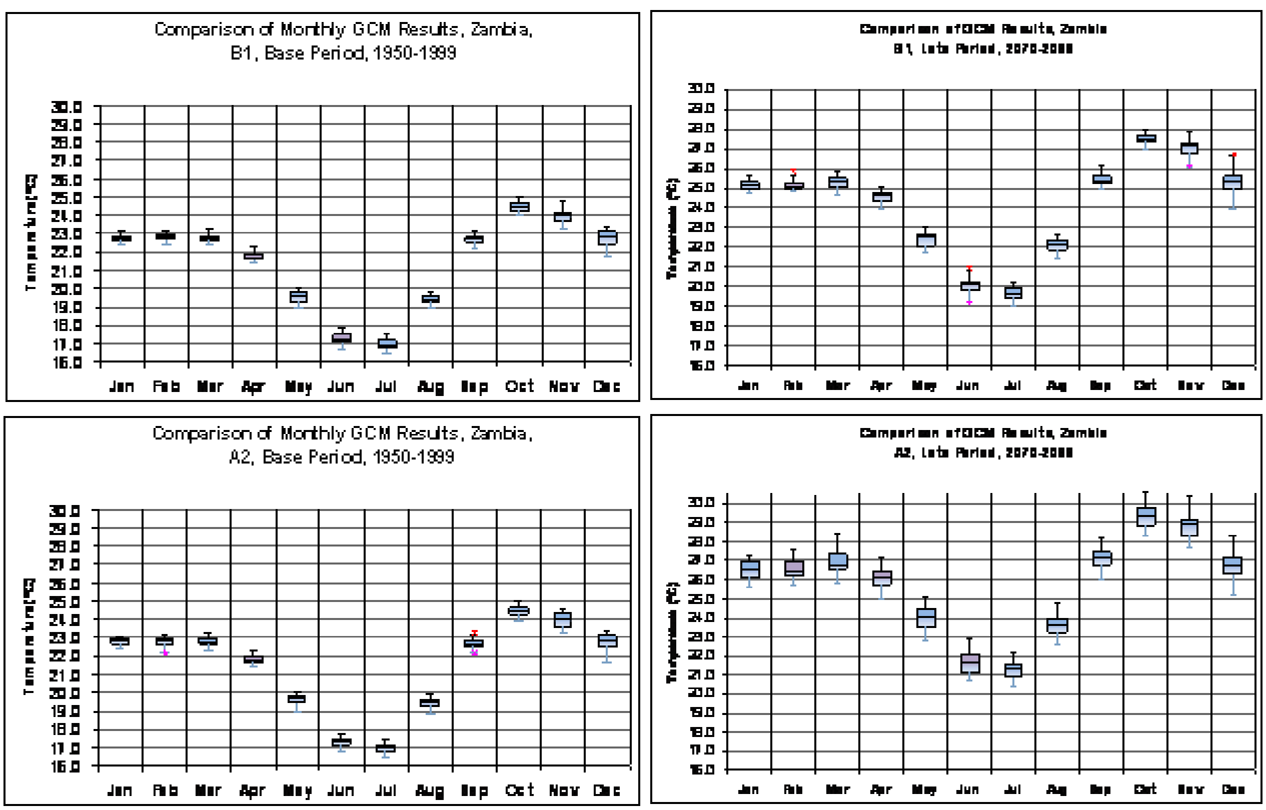


Figure 2-6 shows the range of temperature results for each period from each of the GCMs for each of the months.

Figure 2-6: Summary Statistics for Temperature Projections, per GCM, Zambia, Base and Late Periods B1 and A2



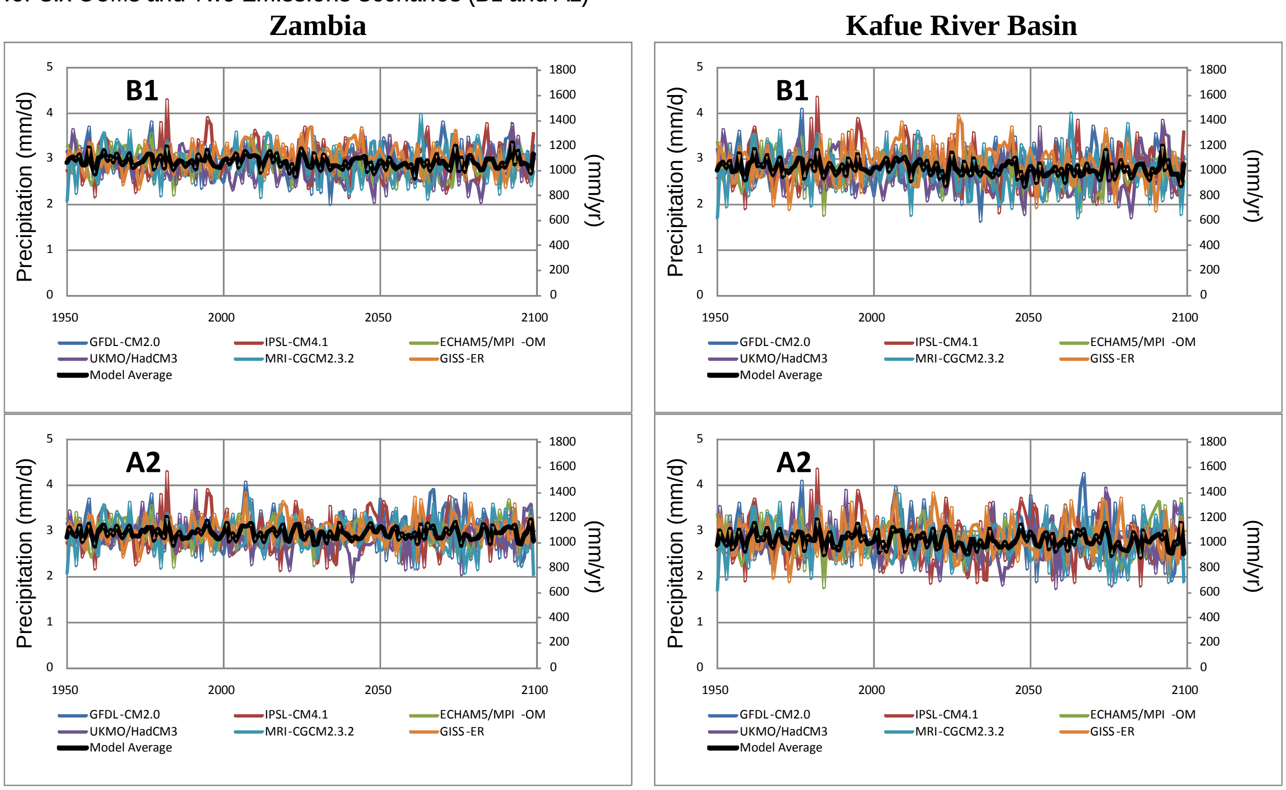
Appendix A1 provides additional analysis, including consideration of the spatial patterns in temperature changes in Zambia and the Kafue River Basin. Spatial patterns differ notably among the models; however, all models show a consistent upward trend in temperature through the end of the century for Zambia and within the Kafue River Basin. The projected temperature increase is similar for Zambia and the Kafue River Basin; the six-model average is about 3°C for emissions scenario B1, and 5°C for A2

(Figure 2-2). Model ECHAM5 projects the highest temperature increases (about 4°C and 6°C for scenarios B1 and A2, respectively).

2.1.2 Precipitation

The mean annual precipitation projected through the end of the century by the six GCMs, and the model average (black line), are shown in Figure 2-7. None of the models projects significant changes in mean annual precipitation, for either emissions scenario B1 or A2.

Figure 2-7: Simulated Annual Time Series of Precipitation Spatially Averaged over Zambia and the Kafue River Basin for Six GCMs and Two Emissions Scenarios (B1 and A2)



The trend of relatively small percentage changes is also evident in the plots of 30-year running means in Figure 2-8, and the plots for monthly projections in Figure 2-9.

Figure 2-8: Thirty-year Running Means of the Simulated Annual Time Series of Precipitation Spatially Averaged over Zambia and the Kafue River Basin for 6 GCMs and Two Emissions Scenarios (B1 and A2)

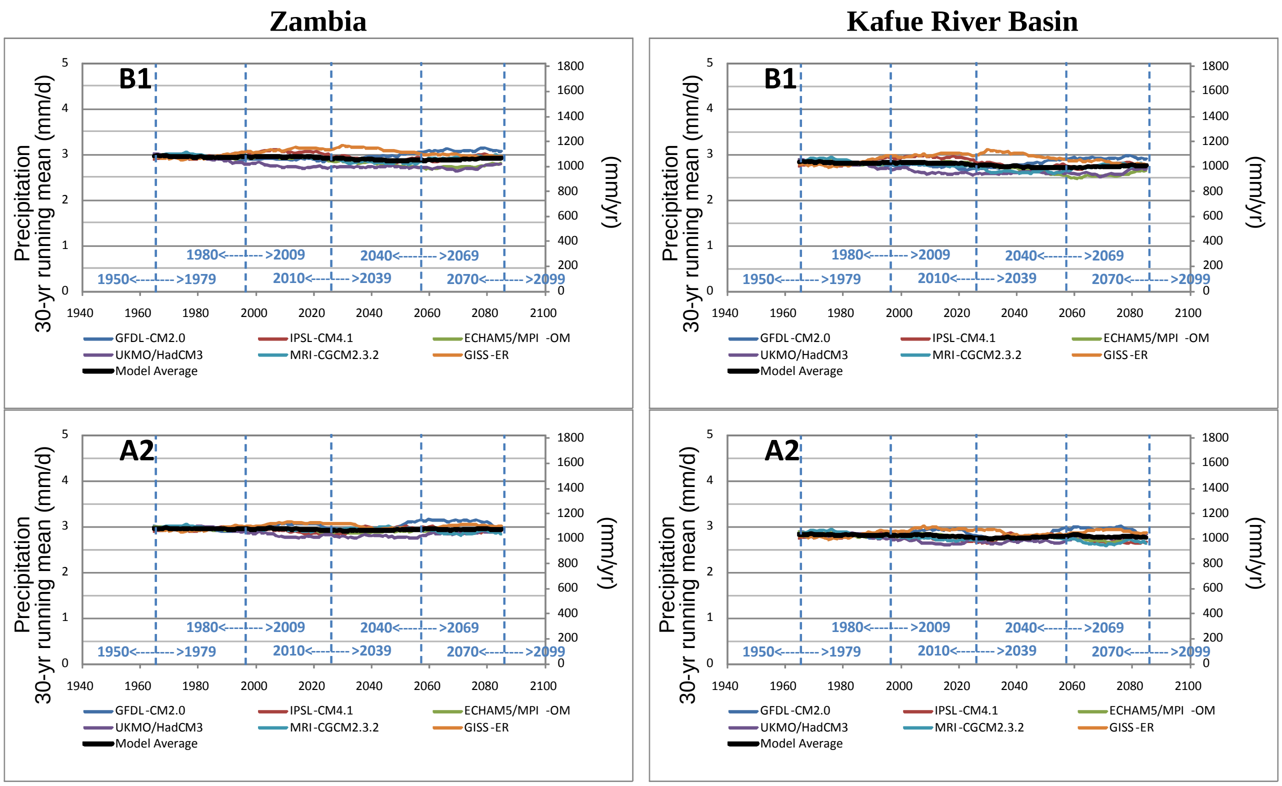


Figure 2-9: Simulated Mean Monthly Precipitation for the Late-Century (2070-2099) and Base (1950-1999) Periods, for A2 and B1, Spatially Averaged over the Kafue River Basin

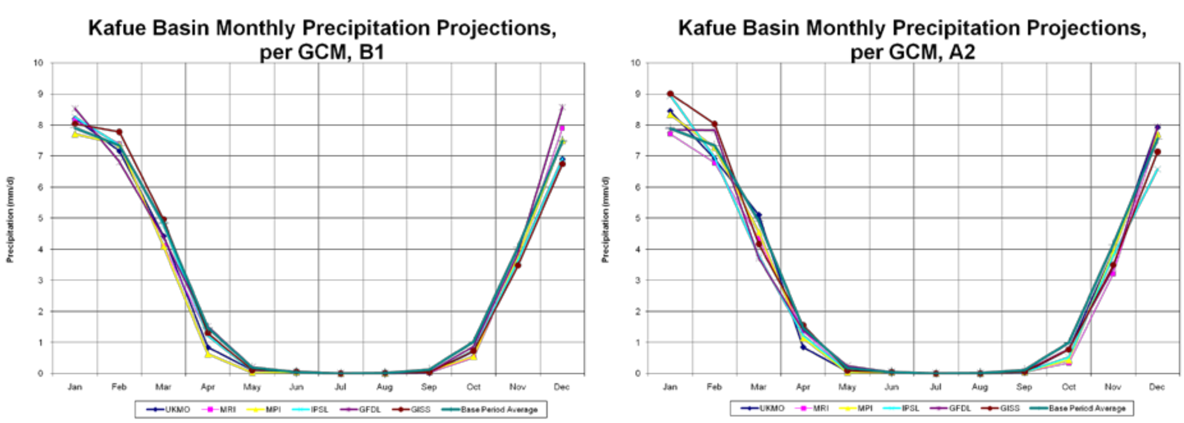
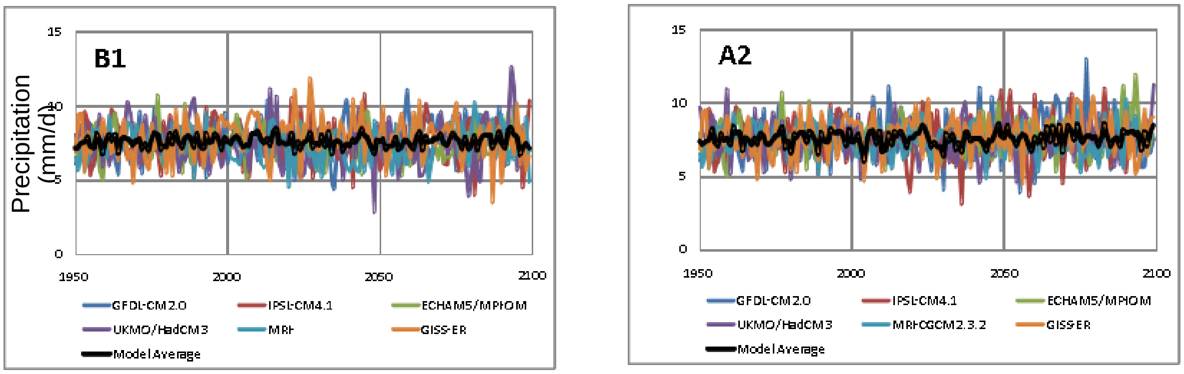


Figure 2-10 shows projections specific to the wet season, which also reflects little change.

Figure 2-10: Simulated Precipitation in Wet Season (December-February), Spatially Averaged over the Kafue River Basin, for Two Emissions Scenarios (B1 and A2)



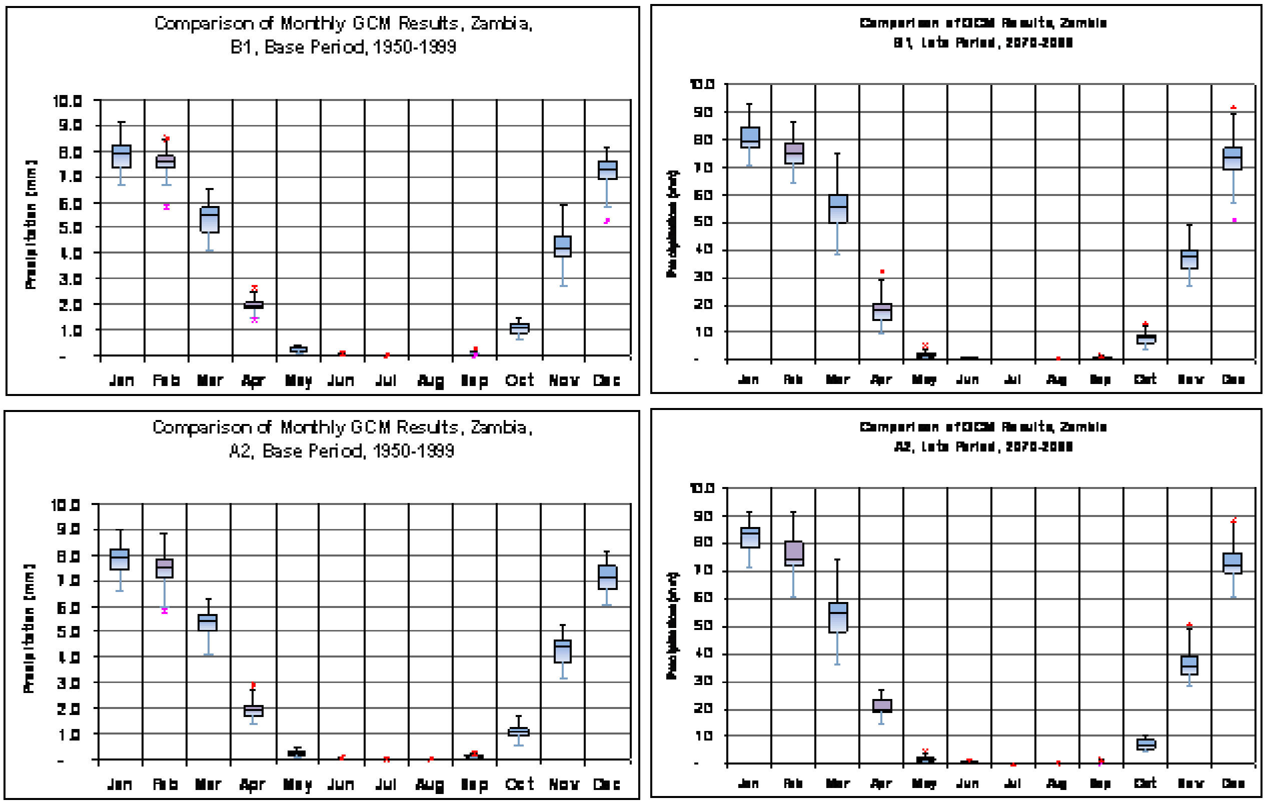
For Zambia and the Kafue River Basin, average annual precipitation changes are not projected to be significant (up to 3% of base period average annual precipitation). For the Kafue River Basin, for the B1 emissions scenario, two GCMs project average annual precipitation increases; four GCMs project decreases. For emissions scenario A2, one GCM projects an average annual precipitation increase; one projects a mix of local increases and decreases; and four project average annual rainfall decreases.

Precipitation changes projected by other GCMs were reviewed and compared to those projected by this study's six selected GCMs. This review indicated that the six GCMs in this study include scenarios that are close to the lowest or "driest" of the 16 GCMs reviewed (e.g., the results for ECHAM5 B1 is close to the ensemble's lowest [being lower than the 20th percentile]); MRI A2 also comes close to the ensemble's lowest. This indicates that while the projected average annual rainfall changes are small, it is not because of the six GCMs selected from the 16 GCMs for which data is available.

Under emissions scenario B1 and A2, GCMs generally predict increases in inter-annual variability for precipitation.

Overall, the projected precipitation changes are relatively small, but are associated with large uncertainty, given that the simulation of precipitation remains one of the principal challenges in global climate modeling. Figure 2-11 shows the monthly results from each of the GCMs for the base- and late-century periods for both emissions scenarios.

Figure 2-11: Summary Statistics for GCM Precipitation Projections by Month for Zambia, for the Base and Late-Century Periods for Scenarios B1 and A2



Appendix A1 provides further information on the data sources, models, approach, findings, and uncertainty associated with the temperature and precipitation projections.

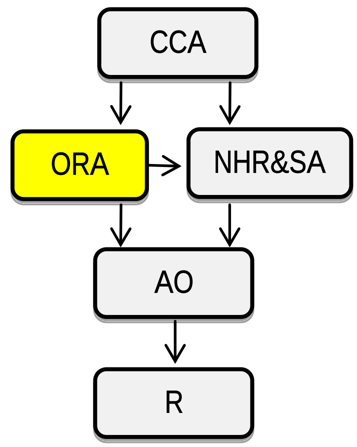
Given the evolving nature of climate change modeling, there is uncertainty associated with GCMs temperature and precipitation projections. This uncertainty increases for longer time periods. In addition, there is greater uncertainty in projecting precipitation changes as compared to temperature changes. A discussion of uncertainty associated with the temperature and precipitation projections provided in this section is included in Section 7.

3. Operational Risk Assessment

This section presents the operational risk assessment of projected temperature and precipitation associated with climate change on the availability of water in the Kafue River. Water availability will impact operation of the KGL power plant, and have corresponding impacts on revenue generated by the KGL power plant.

3.1 Projected Climate Change Impacts on Hydrology (Flow)

A hydrologic model was used to project flow changes associated with the future projections of temperature and precipitation developed in the study's climate change assessment. Three of the six GCMs were selected for further analysis, representing a cross-section of the climate projections for the study area. This section also describes use of a weather generator (WXGEN) to provide additional analysis of two selected scenarios. Additional detail on the hydrologic modeling effort is included as Appendix A2. Uncertainty associated with modeling, data, and findings is discussed in Section 7 and in Appendix A2.



3.1.1 Hydrologic Assessment Approach

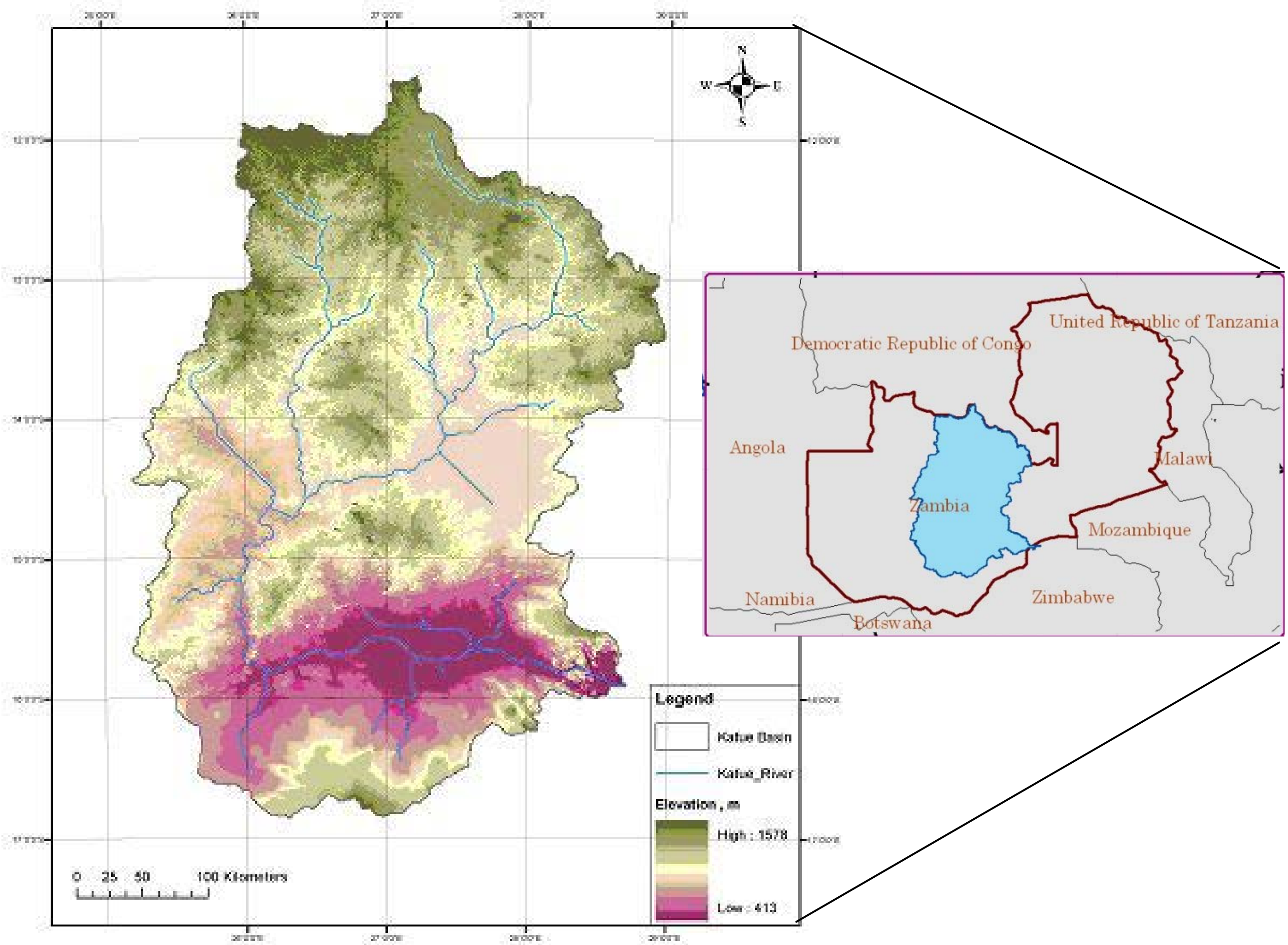
The U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center's (HEC), Hydrologic Modeling System (HMS) (HEC-HMS) tool was selected for the project based on its use for similar applications, public availability, and ability to address a daily time step. This model is widely used for hydrologic modeling and is available at no cost from the USACE. HEC-HMS is designed to simulate the precipitation-runoff processes of dendritic watershed systems. It is applicable across a wide range of geographic areas and can address a wide range of project goals.

HEC tools have been applied in the Kafue River Basin and other basins in Zambia for previous studies. For example, a May 2009 World Bank study (Zambezi River Basin Multi-Sector Investment Opportunities Analysis, Preliminary Report, May 2009) (World Bank, 2009) indicates that the HEC-3, Reservoir System Analysis for Conservation computer program was used at a monthly time step for the SADC 3.0.4 project to investigate joint operation of the Kariba, Kafue, and Cahora Bassa hydropower plants to generate combined system energy estimates. An SEIA prepared for ZESCO used HEC tools to assess potential environmental impacts associated with three development scenarios related to the Kafue River Basin: (1) hydroelectric power, (2) irrigation, and (3) wetlands conservation (SWP, 2003). Another study appears to have used HEC-5 to model water availability for prescribed releases from the Cahora Bassa Dam in Zambia (Beilfuss, 2001).

The HEC-HMS model provides an integrated work environment, including a database, data entry utilities, computation engine, and results reporting tools, with a graphical user interface. Additional information on the model is available at: http://www.hec.usace.army.mil/software/hec-hms/.

Physical representation of the Kafue River Basin incorporates various hydrologic elements (sub basins, river reaches, junctions, and reservoirs), which are connected in a dendritic network to simulate the rainfall-runoff process. Figure 3-1 shows the HEC-HMS schematic representation of the Kafue River Basin. The project model includes 22 sub basins (also called sub catchments), 54 reaches, 28 junction elements, three dams (IT, KGU, and the proposed KGL), and the Kafue Flats. Stream flow gauging stations were incorporated to facilitate model calibration and validation. The model estimates the areal extent of the Kafue River Basin as 154,500 square kilometers (km^2), which aligns with data available in background literature (Imagen Consulting, 2008).

Figure 3-1: Digital Elevation Data used for Delineation of Sub Basins



HEC-HMS allows the user to select from a number of methods to represent catchment characteristics and meteorological data. The methods used for this analysis include:

Basin Model:

- Rainfall Loss and Infiltration: Deficit and Constant Loss
- Rainfall-Runoff Transformation: U.S. Soil Conservation Service (SCS) Unit Hydrograph
- Stream Flow Routing: Muskingum Method
- Base flow Method: Recession Method

Meteorological Model:

- Precipitation: Gauge Weights
- Evapotranspiration: Priestley-Taylor

The model calibration phase included modeling a number of historical events, for which both rainfall and stream flow records were available. To calibrate the model, historical and modeled flows were compared. In water availability studies, emphasis is placed on emulating the peak flow and the volume of water contained in hydrograph. Ideally, a number of flood events can be fitted adequately with only a small range of parameter variation. The calibration process is usually manual, using engineering judgment to iteratively adjust hydrologic parameters and evaluate the fit between the computed and observed hydrographs. After event-based calibration, the model was validated, as discussed in Appendix A2. After calibration and validation, flow modeling was conducted using the climate change projections from the downscaled GCM/emissions data. Based on a review of these data, three GCMs were selected for further analysis of the impact of climate change on basin flows. These were selected to represent a high, median, and low range of outputs. Temperature and precipitation projections for the three GCMs (ECHAM5, MRI, and IPSL) were applied to model flow for both of the emissions scenarios (A2 and B1). Each GCM/emissions scenario combination was modeled for a base period, and the early-, mid-, and late-century time periods using the 70 gridded temperature and precipitation data cells (for the Kafue River Basin study area; gridded data are introduced in Section 2.4). Each scenario was modeled for 30 years at a daily time step. Daily flows were generated for each basin element (sub basins, streams, flows gauges, and reservoirs) of the model. For comparison of the flows across various time horizons, GCMs, and emissions scenarios, average monthly flows were computed from the daily flow data (from each 30 year period of simulated flow). Findings of impacts on flow are summarized in Section 3.1.2, with additional detail provided in Appendix A2.

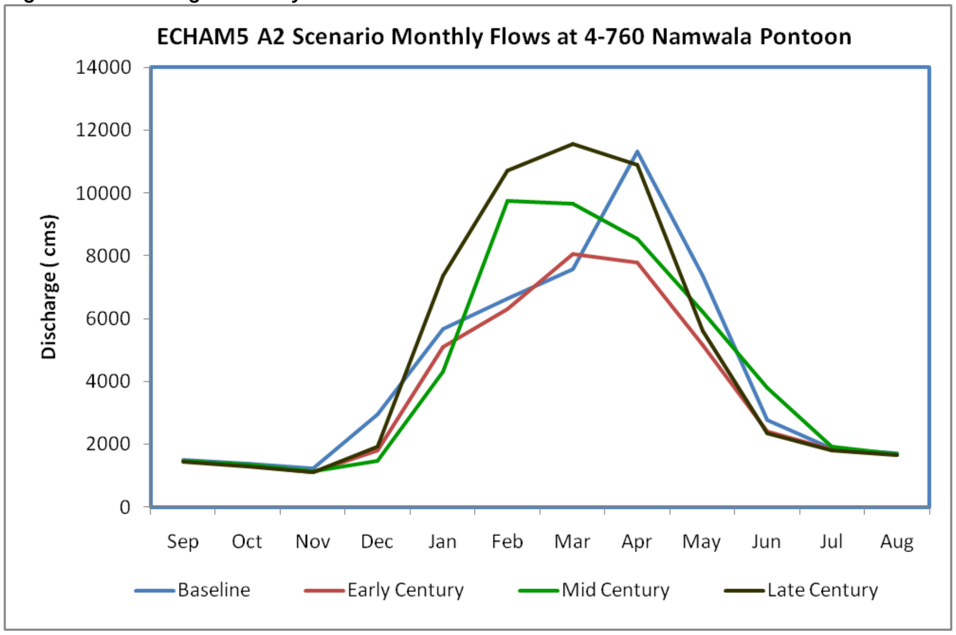
Study recommendations are included in Section 6.0. Models, data, and uncertainty are discussed in Section 7.0. Further information on the application of these methods, data review and use, model strengths and limitations, and uncertainty are included in Appendix A2.

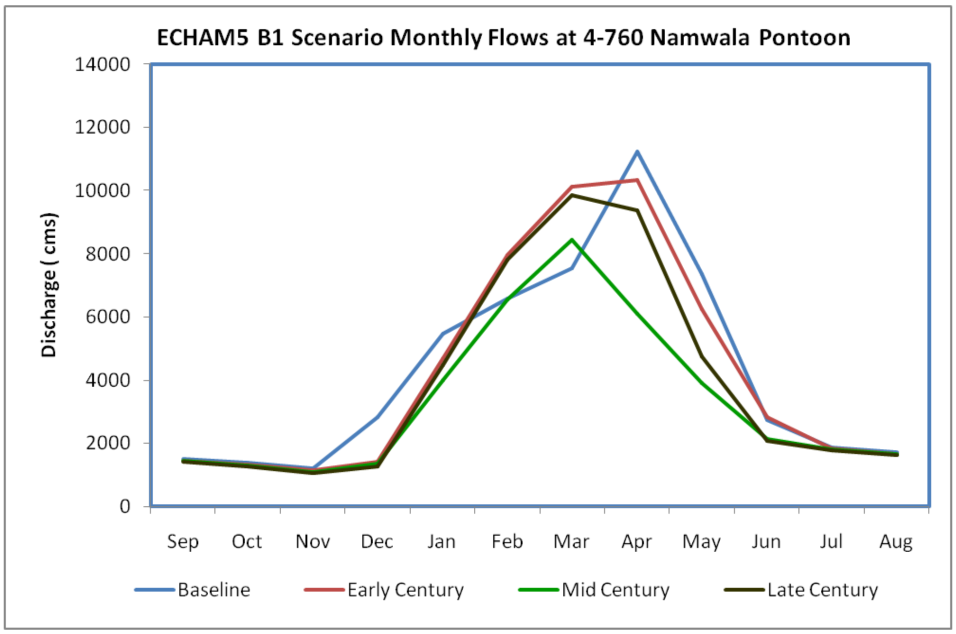
3.1.2 Hydrologic Assessment Findings

This section presents findings for hydrologic modeling of the 24 combinations of GCMs (three), emissions scenarios (two), and time periods (four) on available flow in the Kafue River. It also presents the results of the additional WXGEN analysis of two selected scenarios (i.e., the highest positive and negative flow changes compared to their respective base periods) for the modeled scenarios. Further information on the analysis and findings is provided in Appendix A2.

Daily flows were generated for all system elements (sub-basins, streams, flows gauges, and reservoirs) of the model. For comparison of the flows across various time horizons, GCMs, and emissions scenarios, average monthly flows were generated from the daily flow data (for each 30-year time horizon). As an example, data are presented for the Namwala Pontoon flow gauge station; this flow gauge station is at a critical location in the Kafue River Basin (downstream of the IT reservoir and upstream of the Kafue Flats). Figures 3-2 to 3-4 show the average monthly flows at this station for each GCM model, emissions scenario, and time horizon.

Figure 3-2: Average Monthly Flow for ECHAM5 A2 and B1 Scenarios at Namwala Pontoon

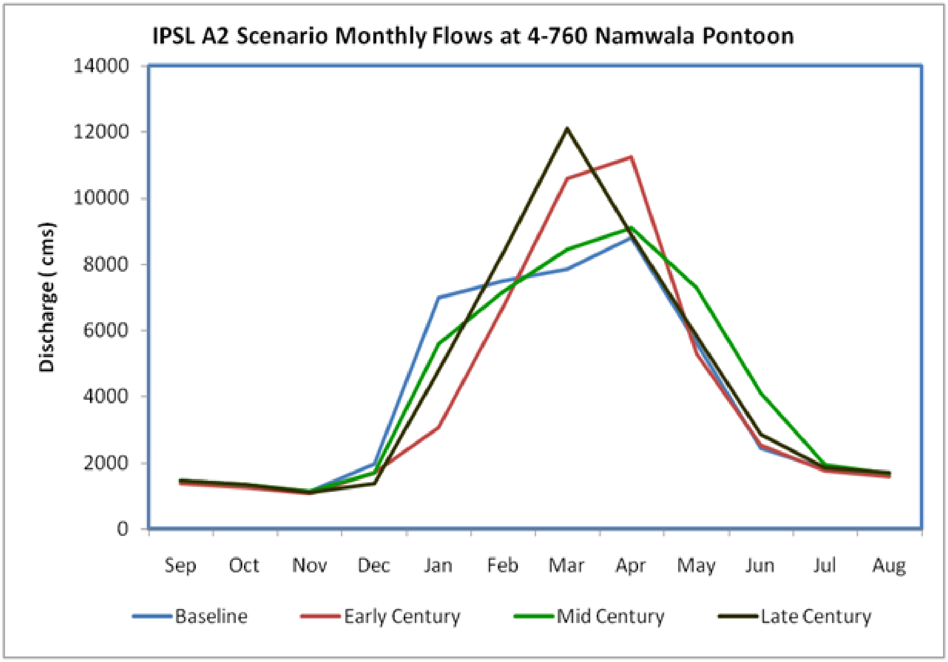


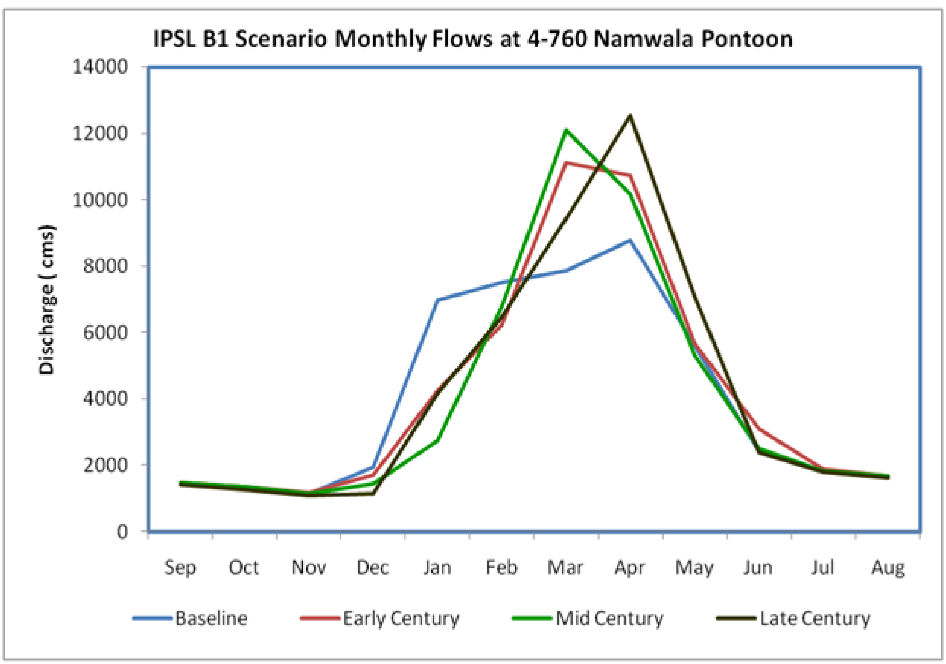


Notes: cms on the y-axis = cms-month.

For the ECHAM5 A2 scenarios (Figure 3-2), the early- and mid-century average monthly flows are lower than the baseline flow, in contrast to a considerable increase in flow during the late-century. For all three future time horizons, peak flow volumes are projected to occur one to two months earlier than for the base period. For ECHAM5 B1 scenarios, a reduction in average monthly flow is observed for all three time periods. There is also a shift in the timing of the maximum average monthly flow (peak flow) during the mid- and late-century compared to baseline peak flow. The potential impacts of these shifts on adjustments to crop cycles and irrigation needs are addressed in Section 4.2.1 (in particular, see Section 4.2.1, Agriculture).

Figure 3-3: Average Monthly Flow for IPSL A2 and B1 Scenarios at Namwala Pontoon

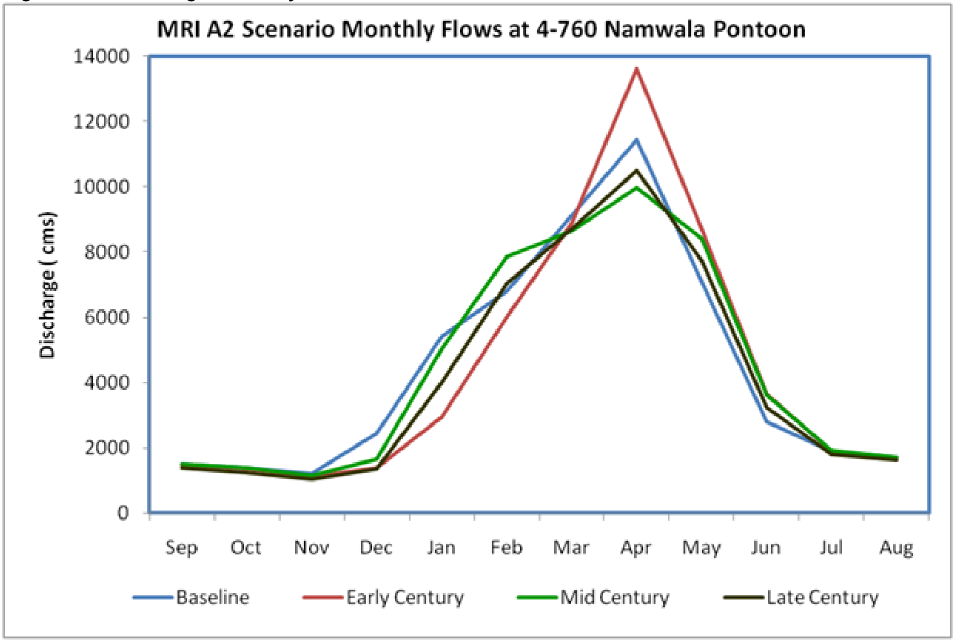


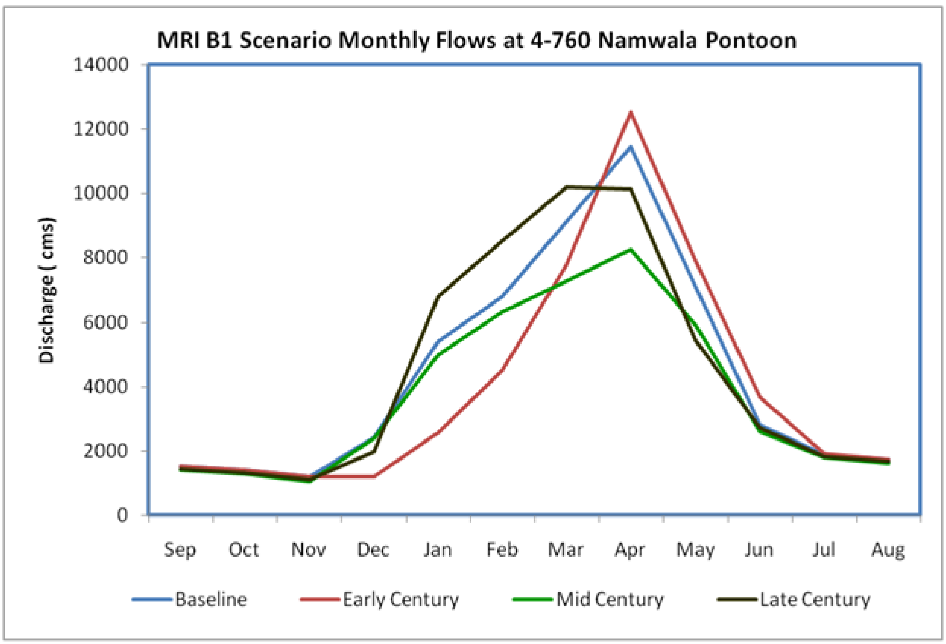


Notes: cms on the y-axis = cms-month.

For the IPSL A2 scenarios (Figure 3-3), the early- and late-century average monthly flows are greater than average monthly flows for the baseline period. In contrast, for the mid-century, average monthly flows are nearly equal to the baseline flow. During the late-century, a shift in the timing of the maximum average monthly flow is observed compared to the baseline flow. For the IPSL B1 scenario, an increase in maximum average monthly flow is observed compared to the baseline flow for all three future time horizons. There is a shift in the maximum average monthly flow (peak flow) during all of the future time periods compared to base period..

Figure 3-4: Average Monthly Flow for MRI A2 and B1 Scenarios at Namwala Pontoon





Note: cms on the y-axis = cms-month.

The MRI A2 scenario results are shown in Figure 3-4. For the early-century projections, the high-flow months show average monthly flows that are higher than the baseline period. In the mid- and late-century periods, average monthly flows are lower than the baseline flows. There is no shift in the timing of peak flows for this scenario compared with the baseline. For the MRI B1 scenarios, average monthly flows increase over the baseline during the early-century. In the mid- and late-century, there is a reduction in the average monthly flows compared to baseline flows. There is also a shift in the timing of the peak flows during the late-century compared to the baseline peak flow.

After evaluating impacts on flow for each GCM/emissions scenario combinations across future time horizons, two scenarios were selected for further analysis using WXGEN. To screen for the highest positive and negative changes in flows across the GCMs, emissions scenarios, and time horizons, the average annual flow at Namwala Pontoon flow gauge station was evaluated. Average annual flows are shown in Tables 3-1 and 3-2, respectively. The percent change in the average annual flows with respect to the baseline flows of the corresponding GCM/emissions scenario were computed and compared. These percent changes are shown in Tables 3-3 and 3-4 for the A2 and B1 emissions scenarios, respectively.

Table 3-1: Average Annual Flow at Namwala Pontoon for Emissions Scenario A2

GCM	Baseline (1961-1990)	Early 21st Century (2010-2039)	Mid 21st Century (2040-2069)	Late 21st Century (2070-2099)
ECHAM5	51,963	44,053	51,361	57,751
MRI	52,780	52,714	52,868	49,649
IPSL	48,575	48,186	50,982	51,724

Notes: Results are presented in cms-year.

Table 3-2: Average Annual Flow at Namwala Pontoon for Emissions Scenario B1

GCM	Baseline (1961-1990)	Early 21st Century (2010-2039)	Mid 21st Century (2040-2069)	Late 21st Century (2070-2099)
ECHAM5	51,461	51,048	39,766	46,758
MRI	52,780	47,935	44,909	53,048
IPSL	48,548	50,378	48,587	50,444

Notes: Results are presented in cms-year.

Tables 3-3 and 3-4 show the percent changes in average annual flow compared to each respective baseline period for the A2 and B1 scenarios, respectively.

Table 3-3: Percent Change from Baseline in Average Annual Flow at Namwala Pontoon for Emissions Scenario A2

GCM	Baseline (1961-1990)	Early 21st Century (2010-2039)	Mid 21st Century (2040-2069)	Late 21st Century (2070-2099)
ECHAM5	-	-15%	-1%	11%
MRI	-	0%	0%	-6%
IPSL	-	-1%	5%	6%

Notes: "-" indicates not applicable; there is no change from the baseline.

Table 3-4: Percent Change from Baseline in Average Annual Flow at Namwala Pontoon for Emissions Scenario B1

GCM	Baseline (1961-1990)	Early 21st Century (2010-2039)	Mid 21st Century (2040-2069)	Late 21st Century (2070-2099)
ECHAM5	-	-1%	-23%	-9%
MRI	-	-9%	-15%	1%
IPSL	-	4%	0%	4%

Notes: "-" indicates not applicable; there is no change from the baseline.

Changes in flow were analyzed for each emissions scenario for each GCM, with future projected flows compared to the respective baseline flow. For the A2 emissions scenario (Table 3-3), flow changes are

-15% in the early-century, -1% in the mid-century, and +11% in the late-century for ECHAM5. The MRI model indicates that there is no change in the early and mid-century, but flows are decreasing by 6% in the late-century. For IPSL, flows decrease by 1% in the early-century with flows increasing during mid (5%) and late-century (6%).

For the B1 emissions scenario (Table 3-4), flows changes are -1 % in the early-century, -23% in the mid-century, and -9 % in the late-century for ECHAM5. For MRI, flows changes are -9% in the early-century, -15% in the mid-century, and +1% in the late-century. For IPSL, there is no change in mid-century, but flows increase by 4% in the early and late-century compared to the baseline.

3.1.3 WXGEN Analysis Approach

Based on the results of the HEC-HMS modeling, two future flow scenarios were selected for further simulation using the weather generator. These two scenarios are the combination of GCM/emissions scenario/future time period that yielded HEC-HMS results with the (1) the highest positive flow change compared to the respective base period, and (2) the highest negative flow change compared to the respective base period. These scenario combinations are ECHAM5 A2 late-century period (greatest positive change) and ECHAM5 B1 mid-century period (greatest negative change). The purpose of this additional simulation with WXGEN is to provide two examples of alternative climate projections that may characterize extreme weather events better than the GCM model results due to the WXGEN's ability to perform a greater number of simulations than is usually possible with GCM models.

A stochastic weather generator tool produces synthetic time series of weather data of infinite length for a location based on the statistical characteristics of observed weather at that location. It is worth noting that a weather generator is not a predictive tool that can be used in weather forecasting, but is simply a means of generating time-series of synthetic weather statistically "identical" to observed data. Applications of weather generator approaches can support areas where meteorological data is scarce and can support climate change studies.

The selected tool for this study, WXGEN, is the Richardson model. This tool was developed at the U.S. Department of Agriculture, Agriculture Research Service (USDA/ARS), Grassland Soil and Water Research Laboratory and is based on the techniques described in the literature (Richardson, 1981). The WXGEN tool can be accessed at: http://epicapex.brc.tamus.edu/downloads/model-executables/wxgn-v3020.

This tool was applied to generate a long-term synthetic weather series simulation (200 years) of the key climate outputs (e.g., temperature and precipitation) of the two target scenario combinations (ECHAM5 A2 late, and ECHAM5 B1 mid) to provide improve estimates of the magnitude and frequency of extreme events on flow across 200 years of simulated weather data. The WXGEN tool is particularly advantageous for evaluating rarely occurring (extreme) events, such as drought and flood, the probabilities of which may be estimated from these longer time periods with a smaller uncertainty than from short runs and/or observed weather series. The application of this tool and the calibration process are discussed in Appendix A2.

The HEC-HMS model was then run using the output of the two WXGEN scenarios. Similar to other runs, daily flows were generated for all the model elements (sub basins, streams, flows gauges, and reservoirs). The findings are summarized in Section 3.1.4 and discussed further in Appendix A3.

3.1.4 WXGEN Analysis Findings

For the WXGEN high flow scenario (ECHAM5 A2 late-century period, the simulated flows are higher than for the ECHAM5 A2 late-century results. For the WXGEN low flow scenario (ECHAM5 B1 mid-century period), flows are nearly equal to the ECHAM5 B1 mid-century period flow.

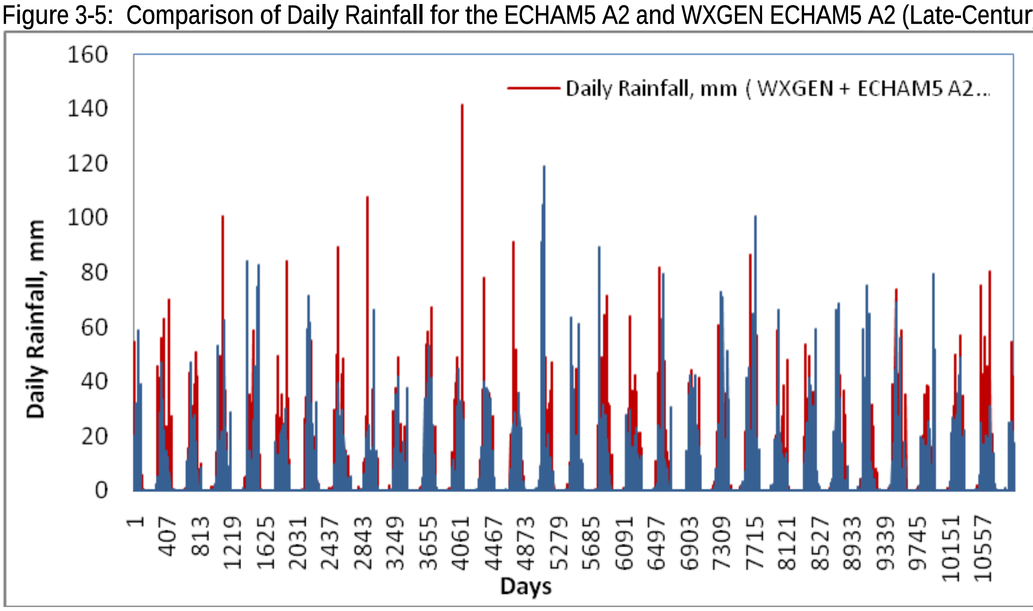
Table 3-5 compares the late-century period results for both ECHAM5 A2 and WXGEN for key 1-day rainfall parameters: maximum, average, minimum, and the standard deviation. The comparison shows that the WXGEN analysis provides higher values for maximum, minimum, and average of annual maximum 1-day precipitation, while the standard deviations are almost equal. The plot (Figure 3-5) of daily rainfall data with and without WXGEN analysis also shows that the WXGEN results have a greater number of extreme events. Figure 3-6 shows that the flows also are higher using WXGEN outputs than the flows based on the GCM/emissions scenarios data.

Table 3-5: Comparison of 1-day Precipitation Results ECHAM5 A2 and WXGEN Analysis of ECHAM5 A2 (Late Century)

Comparison Parameter	ECHAM5 A2 Late-century	WXGEN Late-century
Maximum (mm)	119	144
Average (mm)	60	65
Minimum (mm)	24	28
Standard Deviation (%)	23	22

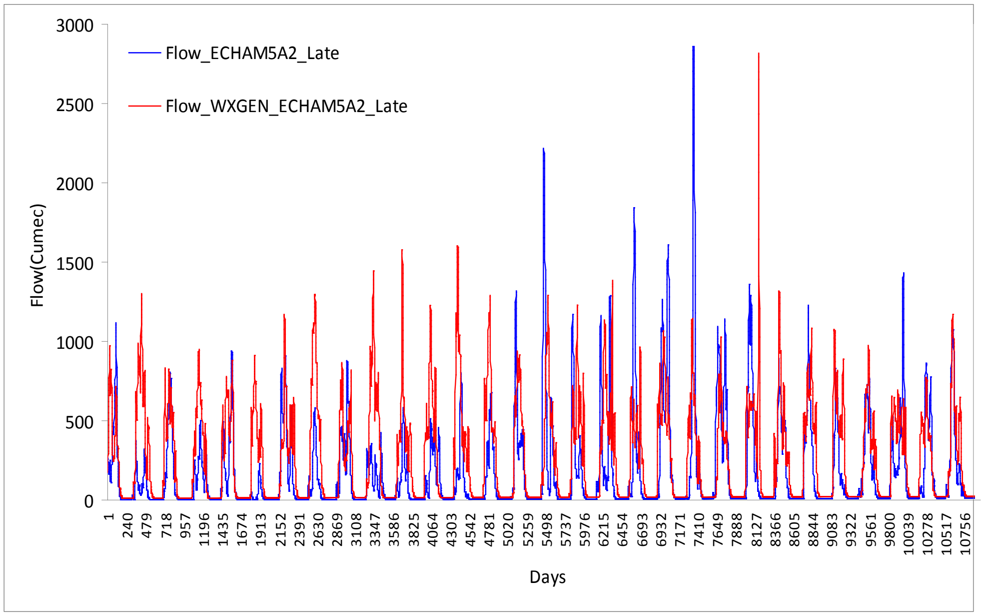
Notes: mm= millimeter.

Figure 3-5: Comparison of Daily Rainfall for the ECHAM5 A2 and WXGEN ECHAM5 A2 (Late-Century)



Notes: mm = millimeter. Blue indicates ECHAM5 A2 data; red indicates WXGEN analysis of ECHAM5 A2 data.

Figure 3-6: Comparison of Daily Flow from the ECHAM5 and WXGEN ECHAM5 A2 (Late-Century)



Notes: Cumec = cubic meters per second.

For the WXGEN ECHAM5 A2 late-century period (high positive flow change) scenario, the flows are higher than for the ECHAM5 A2 base period flow. For the WXGEN ECHAM5 B1 mid-century period (greatest negative flow change scenario), flows are nearly equal to the ECAHM5 B1 mid-century period flow.

Mean flows for the WXGEN ECHAM5 B1 mid-century period analysis are greater than those of the ECHAM5 B1 mid-century run. This result may occur because of the following limitations of WXGEN: (1) the WXGEN does not accurately reproduce the temporal auto-correlation of the annual precipitation; and (2) the WXGEN cannot generate multiple correlated precipitation inputs (i.e., implies zero spatial correlation of precipitation). These weather generator observations have been noted elsewhere (Carney et al., 2008). Since the HEC-HMS model received input data from various station locations, this significantly impacts the frequency distribution of flows. Further information about the WXGEN analysis is provided in Appendix A2.

3.1.5 RCLIMDEX Approach

The relationship between climate change and river flow was further assessed using RClimDex, a statistical analysis and graphics package used by researchers in the analysis of key climate change indices related to precipitation.

Estimating the impact of climate change on the hydrology of the watershed is a major challenge due to complex hydrological processes and the combined, interrelated impacts of various physical and meteorological parameters. These parameters include spatial and temporal distributions of rainfall, evapotranspiration, temperature, solar radiation, hours of sunshine, relative humidity, and wind speed.

Various researchers have noted the interrelationships between these parameters and subsequent impacts on flows. For example, a rainfall pattern where high rainfall tends to occur in continuous sequences is likely to result in higher runoff than similar rainfall values which are distributed more randomly or evenly. This increased runoff occurs because of catchment wetness (Mansell, 1997). Studies of the response of runoff to climate change suggest that the annual runoff volume is more sensitive to changes in precipitation than to changes in potential evapotranspiration. In addition, studies show that for a given percentage change in precipitation, a greater percentage change in runoff can result (Najjar, 1999), with arid catchments showing a greater sensitivity than humid ones (Gordon and Famiglietti, 2004). An increase in annual precipitation of 10% is enough to offset the higher evaporation associated with a 2°C temperature rise (http://www.libraryindex.com/pages/3394/Rivers-Impacts-Climate-Change.html). Warmer average global temperatures also result in greater evaporation, with a warmer atmosphere able to hold more moisture that can fall as precipitation, increasing the potential for flooding (Water Aid, undated).

Riverine stream flow is a function of hydrologic inputs in the form of rainfall, rainfall distribution, and physical and climatic characteristics (Mutreja, 1986). Since the amount of rainfall and the temporal distribution of rainfall are the greatest drivers for modeled flow generation, these variables were studied in detail to evaluate the changes in the flows across the three GCMs, two emissions scenarios, and future time horizons.

3.1.6 RCLIMDEX Findings

Precipitation Intensity Comparison Among GCMs

To quantify the impact of precipitation changes more precisely in terms of rainfall intensity, the daily average rainfall over the Kafue River Basin (for the three GCMs and two emissions scenarios) was analyzed. Various extreme precipitation indices were estimated using RClimDex (Zhang and Yang, 2004). These indices included consecutive wet days (greater than 1 mm of rainfall), consecutive dry days (less than 1 mm of rainfall), maximum 1-day precipitation (Rx1Day), maximum 5-day precipitation (Rx5Day), total annual precipitation (PRECPTOT), and simple daily intensity index (SDII, the annual total precipitation divided by the number of wet days in the year). The findings of these analyses are provided for each of the three GCMs in this sub-section.

Tables 3-6 to 3-9 present the long term annual average rainfall amounts and percent changes with respect to the baseline period for the three GCMs and two emissions scenarios (A2, Tables 3-6 and 3-7 and B2, Table 3-8 and 3-9). Table 3-6 presents the average annual rainfall in millimeters (mm) for the GCMs, A2 emissions scenario, and time horizons.

Table 3-6: Average Annual Rainfall - A2 Emissions Scenario

GCM	Baseline (1961-1990)	Early 21st Century (2010-2039)	Mid 21st Century (2040-2069)	Late 21st Century (2070-2099)
ECHAM5	1,048	999	1,023	1,027
IPSL	1,029	982	1,018	982
MRI	1,077	999	1,016	969

Notes: Average annual rainfall is presented in millimeters (mm).

Table 3-7 shows the percent change in average annual rainfall associated with the Table 3-6 changes.

Table 3-7: Percent Change in Average Annual Rainfall from Baseline Period - A2 Emissions Scenario

	Percent Change from Baseline			
GCM	Baseline (1961-1990)	Early 21st Century (2010-2039)	Mid 21st Century (2040-2069)	Late 21st Century (2070-2099)
ECHAM5	-	-5%	-2%	-2%
IPSL	-	-5%	-1%	-5%
MRI	-	-7%	-6%	-10%

Notes: "-" indicates not applicable; there is no change from the baseline.

Tables 3-8 and 3-9 provide the average annual rainfall and percentage changes in rainfall for the three GCMs for the B1 emissions scenario across the four time periods studied.

Table 3-8: Average Annual Rainfall - B1 Emissions Scenario

GCM	Baseline (1961-1990)	Early 21st Century (2010-2039)	Mid 21st Century (2040-2069)	Late 21st Century (2070-2099)
ECHAM5	1,048	1,018	947	971
IPSL	1,029	1,058	1,010	1,014
MRI	1,077	1,003	957	1,016

Notes: Average annual rainfall is indicated in millimeters (mm).

Table 3-9 presents the percent change in rainfall over time for the B1 emissions scenario.

Table 3-9: Percent Change in Average Annual Rainfall from Baseline Period - B1 Emissions Scenario

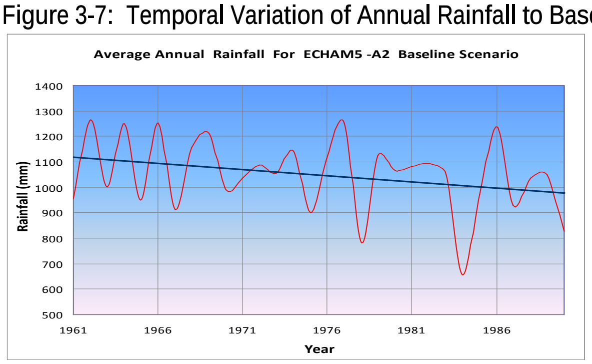
	Percent Change from Baseline			
GCM	Baseline (1961-1990)	Early 21st Century (2010-2039)	Mid 21st Century (2040-2069)	Late 21st Century (2070-2099)
ECHAM5	-	-3%	-10%	-7%
IPSL	-	3%	-2%	-1%
MRI	-	-7%	-11%	-6%

Notes: "-" indicates not applicable; there is no change from the baseline.

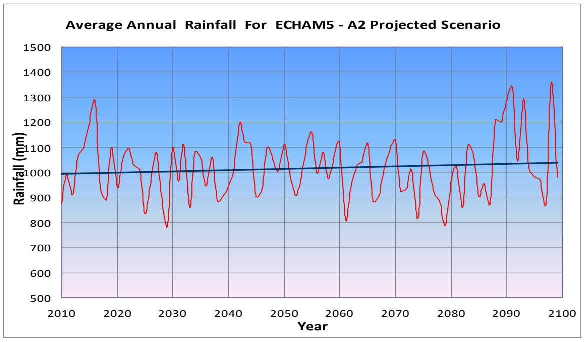
Precipitation Variability for ECHAM5

Figure 3-7 (a-c) shows the temporal variation in average annual rainfall for the baseline, A2 emissions scenario, and B1 emissions scenario for the ECHAM5 GCM. Average annual rainfall shows a more or less constant trend for the A2 emissions scenario, with significant increases in the last decade of the late 21st century period and a decreasing trend in the B1 emissions scenario. As shown in Tables 3-7 and 3-9, the long term average annual rainfall changes are about -5% (early-century) and -2 % (mid- and late-century) for the A2 emissions scenario and are -3% (early), -10% (mid), and -7% (late) respectively, for the B1 emissions scenario.

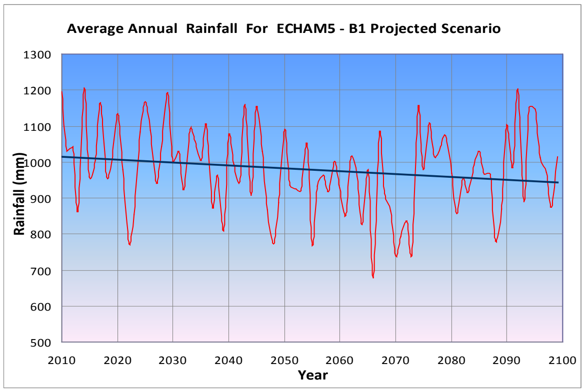
Figure 3-7: Temporal Variation of Annual Rainfall to Baseline - ECHAM5 A2



3-7(a): ECHAM5 - Baseline Average Annual Rainfall



3-7(b): ECHAM5 A2 - Average Annual Rainfall



3-7(c): ECHAM5 B1 - Average Annual Rainfall

Impacts of Precipitation Variability on Flows

For the ECHAM5 A2 emissions scenario, spatial and temporal changes in the long term average annual rainfall correspond to the mixed changes in the long term average annual projected flows (Tables 3-1 and 3-3).

The decrease in flows is much more significant than the decrease in rainfall during the early-century period: an approximate -15% change in flows compared to an estimated -5% change in rainfall for the temporal variation and -5 to -11% changes for the spatial variation. Based on a review of the data and various indices, this greater decrease in flow appears to be attributable to the significant decrease in the 1-day maximum rainfall during the early-century period (see Figure 3-8 (a)).

During the mid-century period, there is no significant change in the average annual rainfall (an estimated -2% change) and similar results are observed for flows (an estimated -1% change).

During the late-century, the -2% change in rainfall temporally and the +1 to -13% change in rainfall spatially results in a positive change of +11% in the flows. In this period, the maximum 1-day rainfall (Figure 3-8(a)) and annual rainfall (Figure 3-8(b)) (particularly for the last 8-10 years) are increasing compared to baseline period. Table 3-10 summarizes key statistics comparing the base period and the late-century period.

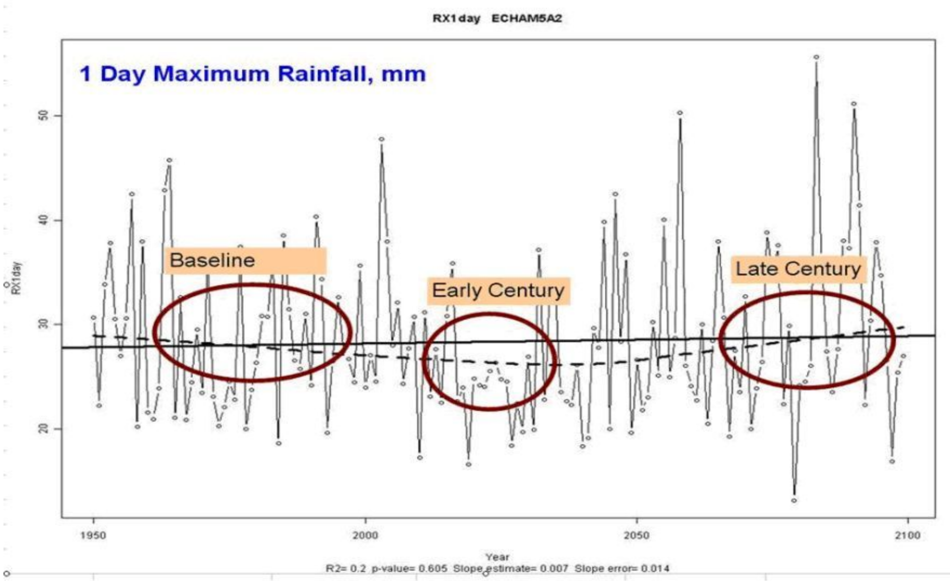
Table 3-10: Comparison of Rainfall for the Base and End of Late-century Periods for ECHAM5 A2

	Daily Average (mm)		Annual Average (mm)	
Parameter	Base Period	Late-century Period	Base Period	Late-century Period
Minimum	19	13	619	848
Average	27	31	1,020	1,065
Maximum	46	56	1,233	1,341
St. Deviation	7.1	9.3	149	164

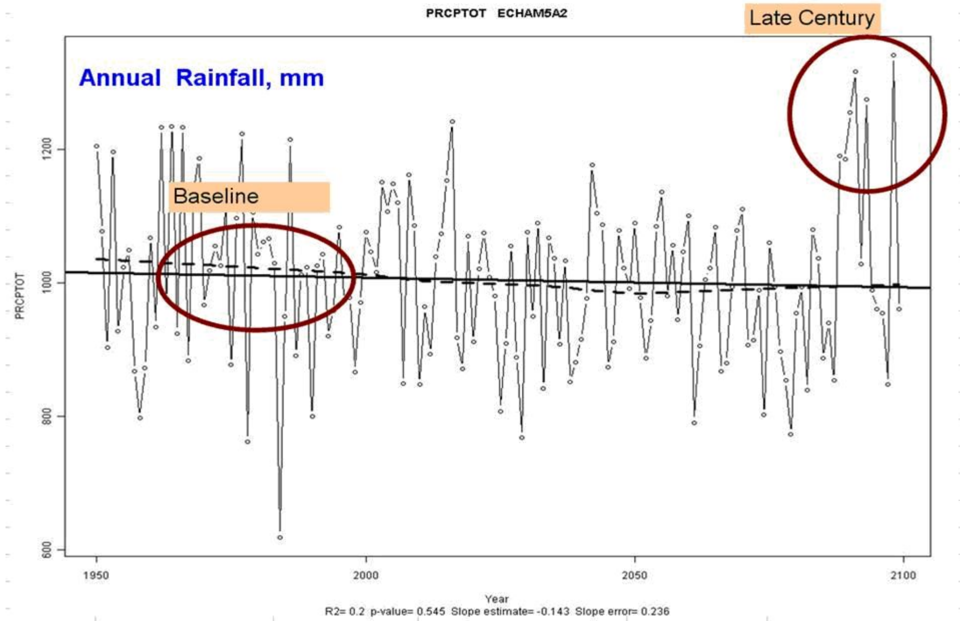
Notes: mm = millimeter.

As a result, the rainfall intensity (Figure 3-8(c)) is greater than in the baseline period (also showing a considerable increase in the last 8-10 years of the period). These combined factors, including the greater rainfall intensity, result in increased flows (a positive 11% change), compared to the baseline period. The potential impacts of changes in the annual amount, variability, and intensity of rainfall patterns are discussed in Sections 4.0 (Natural Hazard Risk and Sector Assessments) and 5.0 (Adaptation Options).

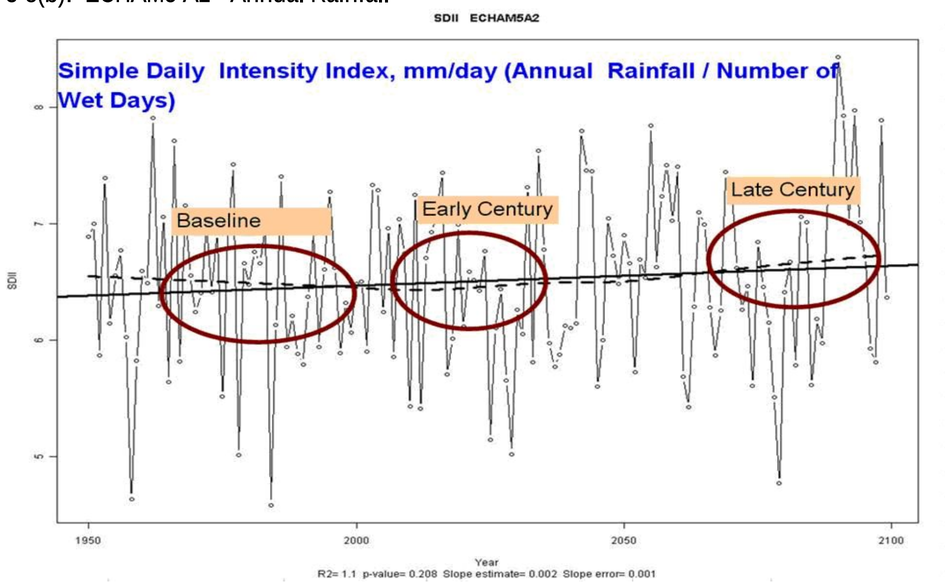
Figure 3-8: Variations in Extreme Rainfall Indices (ECHAM5 A2 Emissions Scenario)



3-8(a): ECHAM5 A2 - 1-Day Maximum Rainfall



3-8(b): ECHAM5 A2 - Annual Rainfall



3-8(c): ECHAM5 A2 - Rainfall Intensity

For the B1 emissions scenario, the spatial and temporal changes in long term average annual rainfall correspond to the change in the long term average annual flows (Tables 3-2 and 3-4). During the early-century period, there is no significant change in the rainfall (an estimated -3% change) and similarly, there is no significant change in flows (an estimated -1% change). During the mid-century period, however, the decrease in flows is much more significant than the decrease in rainfall. Flows change by an estimated -23% compared to a -10% change in rainfall (long term temporal variation) and a -9 to -16% change in rainfall (spatial variation). This result may be attributed to decreases in the maximum 1-day rainfall (Figure 3-9(a)), the annual total rainfall (Figure 3-9(b)), and the rainfall intensity (simple daily intensity index) (Figure 3-9(c)). During the late-century, the change of -7 % rainfall temporally and -6.5 to -14 % rainfall spatially results in changes of -9% in Kafue River Basin flows. During this period, maximum 1-day rainfall and average annual rainfall are increasing compared to the mid-century period, but decreasing compared to baseline period. Table 3-11 summarizes key statistics comparing the base period and the late-century period.

Table 3-11: Comparison of Rainfall for the Base and End of Late-century Periods for ECHAM5 B1

	Daily Average (mm)		Annual Average (mm)	
Parameter	Baseline Period	Late-century Period	Baseline Period	Late-century Period
Minimum	19	17	619	646
Average	27	24	1020	923
Maximum	46	40	1233	1134
St. Deviation	7.1	5.3	149	111

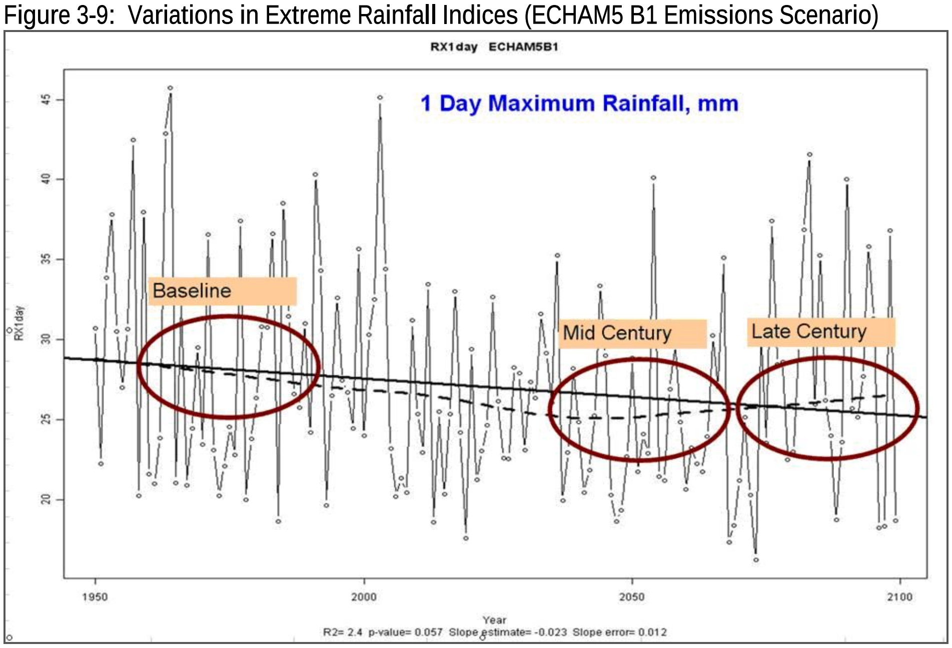
Notes: mm = millimeter.

As a result, the rainfall intensity is greater in the late-century than in the mid-century period, but still lower than the baseline period; this results in a reduction in flows (-9% change) compared to the mid-century period.

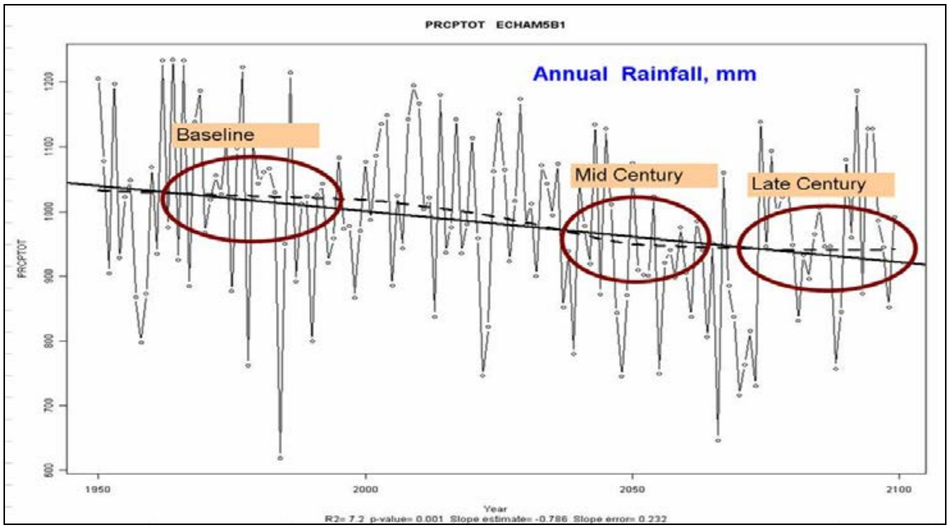
There are several factors (including, but not limited to, the evapotranspiration, temperature, solar radiation, sunshine hours, relative humidity, and wind speed) besides spatial and temporal distribution of rainfall that also govern the hydrological processes of the watershed. To study the combined and interrelated impact of all of these parameters, a detailed distributed hydrological model such as SWAT (Soil and Water Assessment Tool) can be employed. While the complexity of SWAT has some advantages, the less complex HEC-HMS provides more calibration parameters, has higher run time efficiency and uses input and output data formats (DSS) that are interchangeable with other HEC software, such as HEC ResSim (Haberlandt, 2010).

Further analysis of precipitation, which is the most influential factor affecting flow (Mutreja, 1986) was conducted to estimate spatial and temporal variability and its impacts on the flow regime of the Kafue River Basin. The analysis above shows that rainfall intensity and variability have considerable impact on the changes in the flow regime of the watershed associated with the projected climate change scenarios.

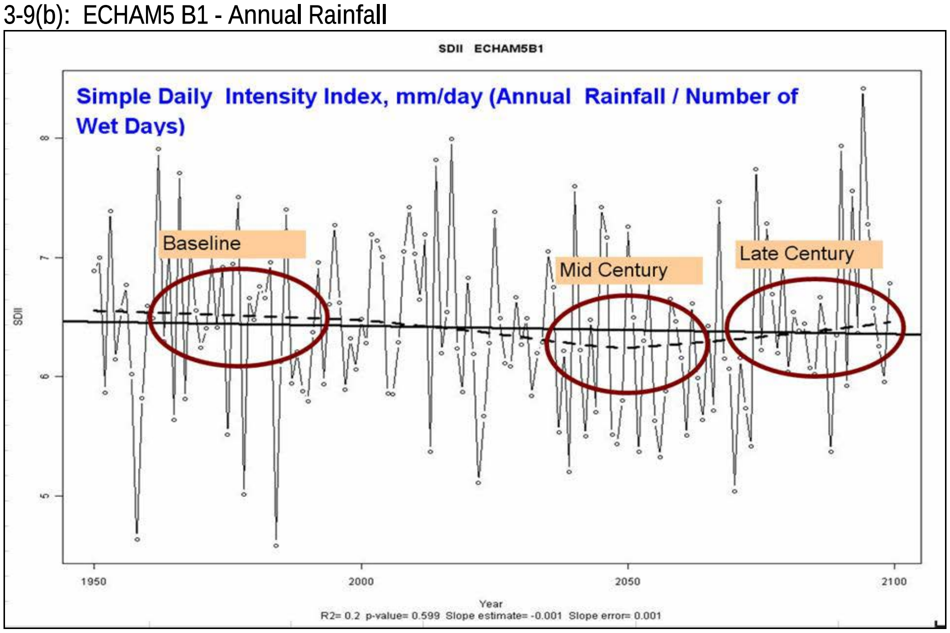
Figure 3-9: Variations in Extreme Rainfall Indices (ECHAM5 B1 Emissions Scenario)



3-9(a): ECHAM5 B1 - 1-Day Maximum Rainfall



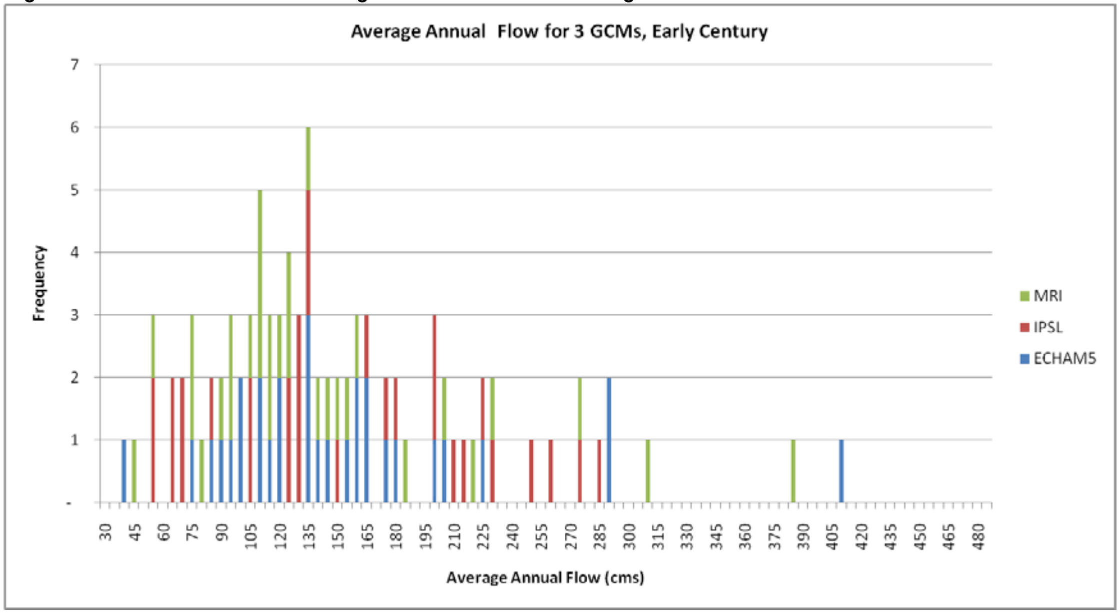
3-9(b): ECHAM5 B1 - Annual Rainfall



3-9(c): ECHAM5 B1 - Rainfall Intensity

The results for the A2 and B1 scenarios for each of the GCMs can also be visualized in terms of the distribution of their volume projections. As an example, the average annual flow at a point downstream of the IT dam is shown in Figure 3-10.

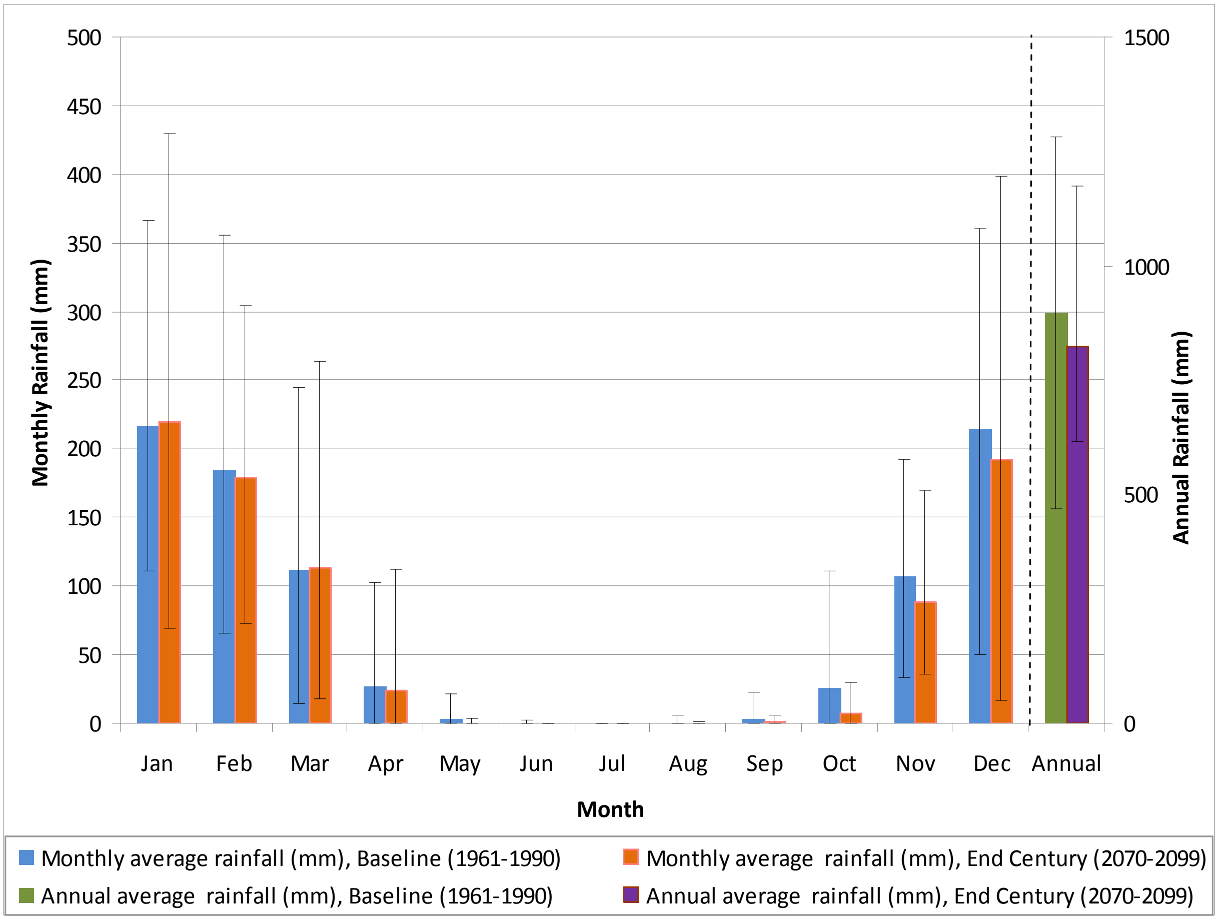
Figure 3-10: Distribution of Average Annual Flows Resulting from Three GCMs



Notes: cms = cubic meters per second.

These projected flow changes associated with increased variability in precipitation also forecast a challenge that other water-dependent sectors, such as agriculture, will encounter over the next century. As shown in Figure 3-11, the relatively small changes in annual average precipitation levels between the base period and the late-century period are not equally distributed within a year. The five months ranging from May to September have historically received little to no rainfall. In the presence of climate change, the months of October, November and December are projected to experience reductions in average precipitation levels.

Figure 3-11: ECHAM5 A2 Comparison of Base Period and Late-century Average Monthly and Total Annual Rainfall



Notes: mm= millimeter
Comparison of monthly (y-axis, left) and annual average rainfall (y-axis, right) for the base- and late-century periods for ECHAM5 A2 Scenario at GCM Grid Point #46 (near the IT dam). The lines for each column show the high and low ranges of values.

These projected precipitation changes will occur in conjunction with temperature changes. Figure 3-12 illustrates the intra-annual temperature shifts compared to the base period. For the purpose of this example, the temperature range of the base period is divided into three relative temperature categories of equal temperature ranges. For the future periods, values in excess of the base period range define a new, fourth temperature category. The values and duration that temperatures exceed the temperature associated with this new category will likely require adaptation responses for humans, plants, and animals.

Figure 3-12: Illustration of Projected Temperature Changes for Zambia, A2 and B1

B1 Projected Temperatures	Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Legend: Number of Months per Temperature Category: Cool	Warm	Hot	Exceeds Historical Experience
Period	Base	22.8	22.8	22.7	21.7	19.6	17.3	16.9	19.4	22.7	24.5	24.0	22.9	3	2	7	0
	Early	23.8	23.8	23.9	23.0	21.0	18.4	18.2	20.6	24.1	25.8	25.5	24.0	2	2	6	2
	Mid	24.5	24.5	24.7	24.0	21.9	19.4	19.2	21.3	24.6	26.8	26.4	24.6	2	1	4	5
	Late	25.1	25.1	25.3	24.7	22.6	20.1	19.7	22.2	25.4	27.5	27.1	25.3	0	2	2	8

A2 Projected Temperatures	Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Legend: Number of Months per Temperature Category: Cool	Warm	Hot	Exceeds Historical Experience
Period	Base	22.8	22.8	22.8	21.8	19.6	17.3	17.0	19.4	22.7	24.5	24.0	22.8	3	2	7	0
	Early	24.0	24.0	23.9	23.1	21.0	18.7	18.5	20.8	24.0	25.9	25.6	24.0	2	2	6	2
	Mid	25.0	24.9	25.2	24.2	22.1	19.9	19.5	21.9	25.4	27.5	26.8	24.9	0	3	2	7
	Late	26.5	26.5	26.7	26.1	24.1	21.7	21.3	23.6	27.2	29.4	29.0	26.8	0	2	2	8

Such changes in seasonality will cause phenological changes to a number of species. This will be particularly relevant to agriculture, where planting and harvest dates will need to adjust to the shifting seasons; agricultural impacts may be aggravated by a potential mismatch in the temporal combination of key climatic conditions, such as temperature and precipitation.

In a larger environmental context, different phenological responses to the changing climate may disrupt coordination and interaction between species and their life cycles (e.g., plants and their pollinators, predators and their prey, insects and their host plants, etc.), and have cascading impacts on the food chain. Analyses of these interactions and climate impacts, and consequences for the Kafue context are beyond the scope of this study, but merit attention in the future.

3.2 Reservoir (Energy) Model

This section provides an overview of reservoir (energy) model selection, development, and implementation. Additional detail on the model development, data sources, and information strengths and limitations is included in Appendix A3. Uncertainty associated with modeling, data, and findings is discussed in Section 7 and Appendix A3.

3.2.1 Reservoir (Energy) Modeling Approach

This section describes the approach for the reservoir (energy) modeling.

3.2.1.1 Reservoir (Energy) Model

The HEC ResSim model was selected and adapted for the KGL project using information from a variety of sources, including: operating data provided by ZESCO, background documents provided by IFC and ZESCO, recent studies and publicly available information. This section describes background information on the reservoir system, followed by summaries of the steps taken to support HEC ResSim modeling. Additional detail is provided in Appendix A3.

Background information indicates that the Kafue River Basin dam and reservoir system were built to support hydropower production, while also accommodating the natural rainy and dry seasons in this area of Zambia. The topography around the KGU dam location does not allow for sufficient reservoir storage for the desired level of power generation and therefore, the IT reservoir was designed to provide primary storage for precipitation collected during the rainy season. The IT reservoir provides a capacity sufficient to allow steady flow releases to the KGU hydropower plant (located over 260 km downstream) across the entire year.

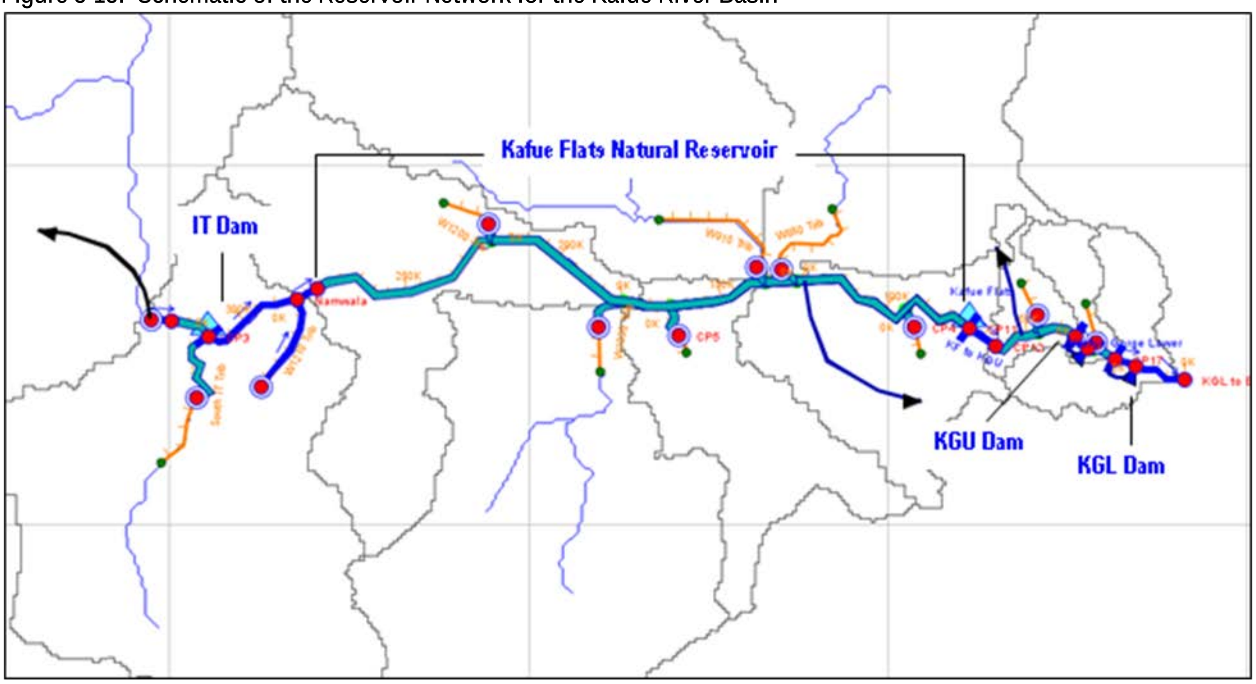
The Kafue River Basin dam and release system disrupts the natural seasonal flooding that previously occurred in the Kafue Flats, an area located downstream of IT and upstream of KGU. In developing the hydropower system in the 1970s, the designers attempted to address natural ecological needs and added capacity in the IT reservoir sufficient to allow flood releases that mimic the natural flood regime. The capacity was designed to allow sufficient storage to open the IT floodgates for all of March to release a flow of 300 cms to flood the Kafue Flats (also called a freshet release). At the time, considering ecological needs and impacts of dams was not a common practice. Adding the additional storage capacity to the IT reservoir increased initial capital costs for the reservoir and dam by 15%; the additional cost was funded based on the recognized natural value of the Flats and a determination to maintain this ecological area to the degree possible (Beilfuss, 2001; World Bank, 2009).

Data indicate that freshet releases and/or natural overflow of the basin have occurred in recent years, although not each year. For example, U.S. National Aeronautics and Space Administration (NASA) images and data indicate that the 2003 and 2004 rainy seasons were particularly wet in Zambia and that the Kafue Flats were flooded (NASA, Undated). ZESCO operational data for recent years also indicate freshet releases in the February through April timeframe. During times of high rainfall (such as 2007), releases also may occur through a gated spillway of the IT dam, when pool elevations exceed ZESCO's parameters for the IT reservoir. Alternately, operator decisions regarding release needs for ecological, operational, and structural reasons can initiate the flow.

Ecological impacts from development of the IT dam have been studied for years and continue to be a priority as further development and use of the hydropower regime is implemented. For example, the WWF has worked with government partners and the utility company to develop an integrated water management approach (Nsongela, 2004).

Geographic information system (GIS) data for basins, streams, gauge and dam locations, and land elevation were developed for implementation of the hydrologic model and were integrated into the HEC ResSim model. Specific dam and reservoir locations and inflows/outflows (through river flows, irrigation assumptions, and tributary flows) were established using this background information. Data were confirmed and refined using other background documents and on-line resources. Figure 3-13 provides a schematic of the reservoir network developed for the assessment.

Figure 3-13: Schematic of the Reservoir Network for the Kafue River Basin



Physical parameters were entered for the three dams and reservoirs (IT, KGU, and KGL). The reservoirs were established as pools with controlled outlets. Table 3-12 summarizes some of the physical parameters included for dams, reservoirs, and existing/planned power stations.

Table 3-13 summarizes some of the operating assumptions established for the power stations based on available background information and research. HEC ResSim can simulate using time steps ranging from minutes to a day. For all time periods, including the base period, all three power stations were assumed to be operating.

Table 3-12: Physical Parameters for Dams, Reservoirs, and Power Stations

Dam	Dam Parameters			Generating Capacity (MW)	Combined Efficiency (turbine and generator)	Structural Features/Notes
	Top of dam elev. (m)	Length (m)	Storage (mcm)			
IT	1035	1800	6,008 @ 1030.5m	120	88%	3 spillway gates (4,425 cms @1030.5m), low level outlet for power releases
KGU	980	300	1,178 @ 977m	990	91%	4 spillway gates (3,660 cms @ 978m) 11 Km tailrace tunnel, 400 m head
KGL	586	300	80 @ 580m	750	88%	3 spillway gates (3,959 cms @ 582 m), 7 km tailrace tunnel, 200 m head

Notes: Physical parameters were developed for this analysis during 2008 using background information, research, input from ZESCO, and professional experience. Though the IT and KGL power generating units were not in place, they were modeled as operating units for this study. Expectations for the design of these units have varied over time; final construction may be different from the modeled parameters.
Acronyms: elev. = elevation; m = meters; mcm = million cubic meters; MW = Megawatt; km = kilometer; and cms = cubic meters per second.

Table 3-13: Operating Assumptions for Power Stations

Unit	Overflow Mechanisms	Power Operation	Minimum Releases
IT	Guide Curve Operation, Spillway with radial gates	Peak (9 hours) Base (15 hours) 7 days/week	Minimum Flow for Uses Below IT (40 cms)
KGU	Guide Curve Operation, Spillway with radial gates	Peak (6 hours) 7 days/week	Minimum Flow to River (7.2 cms)
KGL	Power Pool (582 to 578 m), Spillway with radial gates	Peak (4 hours) 7 days/week	Minimum Flow to River (7.2 cms)

Notes: Acronyms: m = meters; cms = cubic meters per second.

After establishing the model, various runs were implemented to check the model outputs compared to observed flow and elevation data for the IT reservoir. The primary focus of calibration was to refine the IT hydropower rules to provide sufficient releases to support power production at KGU and KGL, without exhausting the IT reservoir during the P-1 scenario. The model was then refined before the remainder of flow inputs were entered from the hydrologic modeling runs. Appendix A3 provides additional information on the model development process, data sources used, and strengths and limitations of the approaches and data used. Findings are presented in Section 3.2.2.

3.2.1.2 Development/Conservation Scenarios

This section presents the modeling efforts implemented to estimate energy generation for climate change (selected GCM/emissions scenarios and two selected scenarios for WXGEN simulation). It also provides an overview of additional modeling of climate change scenarios combined with select conservation or development scenarios.

As illustrated in Figure 1-2, several conservation and development scenarios were included based on data available in the background documents (SWP, 2003). The conservation scenarios are representative of the quantities of water needed to sustain and possibly improve the ecological status of the Kafue Flats. The development scenarios represent the potential impacts of varying levels of economic growth on

power generation through the end of the century. The expected levels of economic growth suggest that the I-3, I-6, and I-9 scenarios may not be large enough to reflect mid- and late-century development; therefore, the I-10 scenario was added to provide a larger withdrawal during those periods.
The P-1 scenario was modeled to establish baseline energy for the climate change scenarios. The baseline flow for P-1 includes assumptions regarding present flows and withdrawals, including 15 cms (for other users between IT and KGU) and 25 cms (for base flow maintenance) for a total of 40 cms of minimum required flow from IT (SWP, 2003). In addition, mid- and upper-basin water withdrawals for domestic, mining, and industry (DMI) are included, for a combined impact of 6.6 cms above IT. A withdrawal of 11.1 cms for DMI is included below IT and above the Kafue Flats. A 5.7 cms withdrawal is included below the Kafue Flats and above KGU for local domestic uses. Below IT, a baseline abstraction of 7.2 cms for minimum flow requirements in the stream around the tailraces is maintained; this amount is withdrawn from both the KGU and KGL reservoirs, but represents a non-consumptive use. Any withdrawals or uses below KGL were not modeled because they would not affect power generation in the system. These assumptions are summarized in Table 3-14.

In addition to the P-1 scenario, three conservation scenarios were modeled to evaluate the impact of freshet releases above the baseline flow of 40 cms as follows: (1) C-1 provides 300 cms during March; (2) C-2 provides 300 cms during March and April; and (3) C-3 provides 400 cms during February and 600 cms during March and April (SWP, 2003). These are “non-consumptive” uses of water in that they impact timing of water releases, but the water stays in the river system, allowing for power generation downstream. These scenarios are identical to the P-1 scenario in terms of water abstraction for agriculture and DMI.

Additionally, four development scenarios were modeled to evaluate the impact of future expansion of irrigation and DMI demand above the IT and from the Kafue Flats areas. These consumptive uses were compared to the P-1 scenario and modeled separately from the conservation scenarios for this study. Scenarios I-3, I-6, and I-9 were based upon those used in the 2003 SEIA; an additional scenario, I-10, was added to address likely additional withdrawals for anticipated irrigation and DMI in the mid- and late-century periods.   The development-driven scenarios include: (1) I-3, an irrigation withdrawal equivalent to an additional 20,000 hectare (ha) of irrigated land in the Upper Kafue Basin (above IT); (2) I-6, equivalent to an additional 20,000 ha in the Middle Kafue Basin (in the flats); (3) I-9 equivalent to an additional 20,000 ha in the Upper Kafue Basin and 10,000 ha in the Kafue Flats; and (4) I-10 equivalent to additional 60,000 ha in the Middle Basin (above IT) and 40,000 ha in the Kafue Flats.

An estimated future DMI of 9.1 cms for all scenarios and time periods; the water abstractions for all scenarios are summarized in Table 3-14.

To evaluate the combined impacts of conservation and other demands, a combination of the conservation and development scenarios was modeled: C-3 and I-9 for the early-century time period, and C-3 and I-10 for the mid- and late-century time periods. These combined scenarios were run for the ECHAM5 GCM, for both emissions scenarios (A2 and B1).

Table 3-14: Water Withdrawals for P-1 (Maximum Power), Development, and Conservation Scenarios

Scenario	Above IT Dam		Below IT Dam to KGU Dam (Kafue Flats Area)		Total Abstractions			Total Conservation Releases (cms [Months])
	New Ag (ha/cms)	Total Req (cms)	New Ag (ha/cms)	Total Req (cms)	Total Ag (cms)	Total DMI (cms)	Total Req (cms)*	
P-1	0	6.6	0	16.8	14.3	9.1	23.4	0
C-1	0	6.6	0	16.8	14.3	9.1	23.4	300 [Mar]
C-2	0	6.6	0	16.8	14.3	9.1	23.4	300 [Mar-Apr]
C-3	0	6.6	0	16.8	14.3	9.1	23.4	400 [Feb] 600 [Mar-Apr]
I-3	20,000/5.3	11.9	0	16.8	19.6	9.1	28.7	0
I-6	0	6.6	20,000/11.4	28.2	11.1	9.1	34.8	0
I-9	20,000/5.3	11.9	10,000/5.7	22.5	11.0	9.1	34.4	0
I-10	60,000/17.2	23.8	40,000/26.9	43.7	58.4	9.1	67.5	0

Notes: Based on information in the 2003 SEIA (SWP, 2003). Acronyms: cms = cubic meters per second; Ag = agriculture; DMI = domestic, mining, industry; ha = hectare; Req = required.

3.2.2 Reservoir (Energy) Modeling Findings

This section discusses findings for energy generation for (1) the climate change scenarios and (2) climate change with conservation or development scenarios. The results for ECHAM5 are presented here; the corresponding information for the IPSL and MRI GCMs can be found in Appendix 3.

3.2.2.1 Projected Climate Change Impacts and Energy Production

Power generation projections for the target power generation unit (KGL) are presented in this section; combined results for power at IT, KGU, and KGL were also modeled and are presented in Appendix A3. Results include the base period and climate change projections associated with the three GCMs, two emissions scenarios, and four time horizons. The two additional WXGEN simulations are also presented.

Table 3-15 provides a summary of the energy availability at KGL power plant for the three GCMs and two emissions scenarios across four time horizons. The energy results reflect changes in flow associated with the variable precipitation levels that were discussed in Section 3.1.

Table 3-15: KGL Energy Production for ECHAM5 Scenarios

KGL 750MW Capacity Unit – Annual Energy Production (GWh/Yr)									
GCM	SRES	Development Scenario	Base Period	Early-century Period	% Change from Base	Mid-century Period	% Change from Base	Late-century Period	% Change from Base
ECHAM5	A2	P-1	2,227	1,847	-17.1%	2,182	-2.0%	2,487	11.7%
ECHAM5	B1	P-1	2,160	2,099	-2.8%	1,682	-22.1%	1,970	-8.8%

Notes: GWh/Yr = Gigawatt-hour per year; MW = Megawatt.

As shown in Table 3-15, energy production decreases in the early- period for both the A2 and B1 scenarios, but rebounds for A2 due to higher flows in the mid- and late-century periods. For ECHAM5, B1, energy production at KGL decreases in the mid- and late-century, compared to the base period. These results are for the P-1 scenario. Results for the development scenarios are discussed in Section 3.2.2.2.

Select increased and decreased flow scenarios were studied further using the WXGEN. The WXGEN scenarios simulated 200 years for the ECHAM5, A2, late-century results (highest increase in flow from its respective base period) and the ECHAM5, B1, mid-century results (highest decrease in flow from its respective base period). Table 3-16 presents these results for the KGL power plant; a significant increase in power results for the A2 scenario; little change is observed for the B1 scenario.

Table 3-16: KGL Energy Production for WXGEN Scenarios (GWh/yr)

GCM	SRES and Period	Use Scenario	Base Period Power	WXGEN Simulation Power	% Change from Base
ECHAM5	A2-Late	P-1	2,227	3,328	49.4%
ECHAM5	B1-Mid	P-1	2,160	2,189	1.3%

Notes: GWh/Yr = Gigawatt-hour per year.

3.2.2.2 Development/Conservation Scenarios

The impacts of the development and conservation scenarios on power are shown for KGL are summarized in this section; these impacts for total system generation (for IT, KGU, and KGL) are provided in Appendix A3.

The SEIA found that power generation would be reduced by up to 7% for the highest withdrawal scenario (impacted most by withdrawals above the IT). However, additional agriculture development is expected in the Kafue River Basin (SWP, 2003). Tables 3-17 and 3-18 show KGL power generation estimates for development scenarios for the ECHAM5 A2 and B1 emissions scenarios for the early-, mid-, and late-century time periods.

Table 3-17 shows energy production at KGL for the development scenarios for the ECHAM5 A2 scenario. This table illustrates that the water abstractions from the various development scenarios are projected to reduce projected power generation between 2% and 16% in all four periods (base-, early-, mid-, and late-century). Therefore, development exacerbates the effects of power reductions and reduces the effects of the power increases shown in the P-1 scenario for this climate change scenario.

Table 3-17: Energy Production for KGL for Development Scenarios: ECHAM5 A2

Annual Energy Production (GWh/Yr)								
Use Scenario	Base Period Power	Change from Base P-1	Early-century Power	Change from Base P-1	Mid-century Power	Change from Base P-1	Late-century Power	Change from Base P-1
P-1	2,227	0.0%	1,847	-17.0%	2,182	-2.0%	2,487	11.9%
I-3	2,183	-2.0%	1,806	-18.9%	2,142	-3.8%	2,447	9.9%
I-6	2,057	-7.6%	1,678	-24.7%	2,102	-5.6%	2,319	4.1%
I-9	2,098	-5.8%	1,721	-22.7%	N/A	N/A	N/A	N/A
I-10	1,865	-16.3%	N/A	N/A	1,815	-18.5%	2,126	-4.5%

Notes: GWh/Yr = Gigawatt-hour per year; N/A = not applicable.

Table 3-18 shows energy production at KGL for the development scenarios for the ECHAM5 B1 scenario. This table reflects results that are similar to those shown in the previous table for the ECHAM5A2 scenario.

Table 3-18: Energy Production for KGL for Development Scenarios: ECHAM5 B1

Annual Energy Production (GWh/Yr)								
Use Scenario	Base Period Power	Change from Base P-1	Early-century Power	Change from Base P-1	Mid-century Power	Change from Base P-1	Late-century Power	Change from Base P-1
P-1	2,160	0.0%	2,099	-2.8%	1,682	-22.1%	1,970	-8.8%
I-3	2,172	0.6%	2,058	-4.7%	1,643	-23.9%	1,933	-10.5%
I-6	2,044	-5.4%	1,928	-10.7%	1,512	-30.0%	1,801	-16.6%
I-9	2,087	-3.4%	1,974	-8.6%	N/A	N/A	N/A	N/A
I-10	1,850	-14.4%	N/A	N/A	1,142	-47.2%	1,608	-25.6%

Notes: GWh/Yr = Gigawatt-hour per year; N/A = not applicable.

Appendix A3 provides additional information on the impacts at each power station across the various time periods and development scenarios, including combined system power generation.

Table 3-19 shows KGL power generation for the base and each of the conservation scenarios over time compared to the respective base period.

Table 3-19: KGL Energy Production Conservation Scenarios: ECHAM5 A2 and B1

Projected Annual Energy Production (GWh/Yr)										
GCM	SRES	Scenario	Base Period Power	% Change	Early-century Power	% Change from Base P-1	Mid-century Power	% Change from Base P1	Late-century Power	% Change from Base P1
ECHAM5	A2	P-1	2,246	0.0	1,847	-17.8	2,182	-2.8	2,487	10.7
ECHAM5	A2	C-1	2,216	-1.3	1,866	-16.9	2,192	-2.4	2,496	11.1
ECHAM5	A2	C-2	2,224	-1.0	1,823	-18.8	2,202	-2.0	2,502	11.4
ECHAM5	A2	C-3	2,241	-0.2	1,892	-15.8	2,217	-1.3	2,501	11.4
ECHAM5	B1	P-1	2,160	0.0	2,099	-2.8	1,682	-22.1	1,970	-8.8
ECHAM5	B1	C-1	2,164	0.2	2,113	-2.2	1,687	-21.9	1,986	-8.1
ECHAM5	B1	C-2	2,170	0.5	2,125	-1.6	1,705	-21.1	1,998	-7.5
ECHAM5	B1	C-3	2,187	1.3	2,140	-0.9	1,721	-20.3	2,010	-6.9

Notes: GWh/Yr = Gigawatt-hour per year.

Table 3-19 indicates that the conservation scenarios do not have a significant impact on average annual power generation at KGL. However, further analysis revealed that the modeled power outputs do not reflect the full impact of higher conservation releases (C-2 and C-3). Operating rules established based on ZESCO information include pre-established withdrawal limits for water depth in the IT reservoir. These operating rules prevent the full volume of water for the C-2 and C-3 scenarios from being released. Therefore, the flow of water and generation of energy for the C-2 and C-3 conservation scenarios are similar to those for the maximum power scenario. This results because the model allows the additional release of water for conservation only to the point where the water levels at the IT dam reach a lower limit established by the operating rules as being the minimum necessary to generate power. Therefore, the modeling results do not fully reflect the power impacts associated with full C-2 and C-3 releases. This also indicates that the C-2 and C-3 conservation releases, if fully implemented, may conflict with power generation goals, as reflected in the operating rules implemented by ZESCO.

This study included modeling runs to determine the combined impacts of development and conservation scenarios. The ECHAM5 GCM, A2 and B1 scenarios were used for this analysis. To model these combined impacts, C-3 was run in conjunction with I-9 for the base- and early-century periods and in combination with I-10 for the mid- and late-century periods. The results from these modeling runs were similar to those presented for the higher development runs alone. For example, the results from combining the C-3 scenario with the I-9 or the I-10 scenarios were not significantly different from the I-9 or I-10 scenarios, which are presented in Tables 3-17 and 3-18. As discussed above for the conservation scenarios (C-2 and C-3), further analysis of the modeling results for the combined conservation release/development scenarios revealed that modeled power outputs do not reflect the full impact of these conservation releases. Operating rules established based on ZESCO information include minimum withdrawal levels for water depth in the IT reservoir. These operating rules in the HEC ResSim model prevent the full volume of water for the C-2 and C-3 scenarios from being released. Therefore, the results of the modeling do not fully reflect the impacts on power that would result from requiring the releases of water prescribed by the C-2 and C-3 conservation scenarios. This indicates that the higher conservation releases (C-2 and C-3), with or without additional development withdrawals would conflict with power generation goals reflected in currently established operating rules implemented by ZESCO.

This study's analysis of climate change, conservation release, and development scenario impacts on the hydropower system at KGL indicate this power plant operates with positive power outputs for the P-1 water abstraction scenario (which assumes a 30 percent increase in future agricultural and DMI demands). The extra capacity which was added at IT reservoir during development (World Bank, 2009 and Beilfuss, 2001), helps to provide additional storage that supports productive management of the power plant, even given rainfall variability and potential precipitation decreases projected by some climate change scenarios evaluated. However, negative power generation impacts compared to the base period are observed for some time future periods for the ECHAM A2 and B1 scenarios (as discussed in subsection 3.3.2.1) (even without additional development or conservation withdrawals assumed).

When development scenarios are considered, some negative impacts on power generation are observed compared to the P-1 scenario for various time periods. Negative changes in energy production compared to the P-1 baseline period are seen for some future periods for the low to moderate development scenarios (I-3, I-6, and I-9). In addition, significant negative energy production impacts are seen for all scenarios and time periods compared to the baseline P-1 period for the highest development scenario (I-10). These negative impacts highlight the need to view hydropower operations in a systemic manner within the Kafue River Basin, considering the projected climate change impacts, in combination with continued development and population growth. In addition, it is important to note that reductions in flows through the Kafue Flats will not only result in the above-mentioned reductions in power, but could also increase water pollution by reducing the availability of water to dilute contaminants and adjust temperature gradients in current and future industrial and municipal discharges. In addition, while not estimated in this report, project air temperature increases projected by the GCMs and emissions scenarios will increase water temperatures in the Kafue Flats (IFC 2010). These water temperature increases, as well as potential impacts of increasing industrial discharge and changes in water-borne diseases were not modeled as part of the study, but may merit further study from an ecological and environmental perspective.

Table 3-19 shows that for the KGL operating scenario, conservation releases do not have a significant impact on average annual power generation compared to the P-1 scenario. However, further analyses of the modeling results for the conservation release scenarios revealed that the models did not reflect the full releases of water required to fulfill the assumptions of the C-2 and C-3 scenarios. This analysis reflects that the volume of water desired for C-2 and C-3 would violate historic operating rules established by ZESCO to generate power. Therefore, these types of conservation releases would require ZESCO and stakeholders to agree on feasible conservation release regimes in light of climate change impacts on flow and variability of flow, base power demand, other water uses, and conservation needs.

Later sections provide additional analysis of climate change, conservation, agriculture, and other sector development scenarios and their impacts on water demands (see Agriculture, Conservation, and Other Sectors in Section 4.2). These analyses assist in providing an independent evaluation of the reasonableness of the abstractions modeled in this section. Natural hazard impacts are also considered in Section 4.1. The combination of all of these factors points to the need to plan for proper operation and management of the KGL plant, the overall hydropower system, and other regional water demands and needs impacted by climate change and ongoing development. Adaptation options are presented in Section 5.0.

3.3 Financial Modeling

The financial assessment for this study provides additional perspectives on KGL performance in light of potential future operational and market outcomes based on the climate change scenarios developed for this project. This financial assessment is not intended to establish or reevaluate the financial viability of the KGL project (those types of investment analyses have been undertaken by others, including IFC). Previous financial and technical analyses have assessed the financial impacts of a range of factors on the KGL project's ability to generate a positive cash flow; these analyses applied traditional engineering cost/financial analysis to characterize construction and operational costs (e.g., size and location of the project) and future trends that could affect project revenues (e.g., changing demand, new supply, and economic drivers affecting the price of electricity). This financial assessment, in contrast, evaluates potential power generation and associated revenue changes associated with climate change and development scenarios evaluated as part of this project.

Each stage of modeling for this study is completed using tools that are in the public domain. This will facilitate further use of the project outputs and tested approaches over time, if so desired by project stakeholders or others. This project's financial assessment was completed using the Renewable Energy Technology Screening Tool (RETScreen). RETScreen was developed to "screen" the financial viability of new renewable energy technology projects from around the world. RETScreen was developed with multilateral funding and data from Global Environment Fund (GEF), NASA, and others; this spreadsheet-based tool is available in 37 languages and includes modules that can capture: (1) major macroeconomic factors; (2) project-specific costs, financing, and energy production inputs; and (3) project cash flow considering plant operations and potential carbon markets.

As a key potential lender for development of the KGL project, the IFC has supported numerous engineering, economic and environmental studies to evaluate project costs and revenues, to assess project viability (that is, KGL's ability to produce a positive cash flow and support loan payment within the required payback period). This information was captured in an IFC financial analysis that was provided as a financial reference for this project. The IFC financial analysis was used as the source of financial inputs parameters for RETScreen to establish the financial performance for the project in the absence of climate change. Uncertainty associated with modeling, data, and findings is discussed in Section 7 and Appendix A4.

3.3.1 Financial Modeling Approach

RETScreen was used to evaluate (1) future time periods, (2) development scenarios, and (3) climate change impacts as explained below.

- Time periods: The early-century period was used to evaluate financial returns to investors.

- Development scenarios: The financial analysis for focuses on the P-1 (maximum power) and I-9 (maximum development) scenarios. Because the conservation scenarios (particularly C-2 and C-3) violate KGL operating rules, they are excluded from this financial analysis. The financial assessment considered the impacts the I-9 to show the impacts of the most aggressive level of water withdrawals for near-term irrigation needs.

- Climate change: Two climate scenarios, ECHAM5 A5 and ECAHM5 B1, were evaluated to illustrate the potential impact of climate on the financial analysis of the KGL project.

The financial effects of these flow impacts are evaluated using RETScreen to support this project's assessment of the potential financial impacts of climate change on KGL.

The RETScreen assessment of KGL began with a two-stage calibration process. First, the RETScreen Energy Module was calibrated by using the flow-exceedence curves for target scenarios and comparing electricity estimates generated by RETScreen to those of HEC ResSim. Once calibrated for energy production, RETScreen was then calibrated against the IFC financial analysis of KGL operation. Energy and financial calibration efforts are discussed in the following sub-sections.

HEC ResSim modeling inputs (discussed in Section 3.2.1) incorporate flow estimates and operational parameters to estimate energy generation. Similarly, RETScreen uses flow inputs and assumed operational characteristics to estimate energy generation and associated financial impacts. The RETScreen energy functions were calibrated against the HEC ResSim modeling results to build upon, and ensure compatibility with, the analytic elements already described. Table 3-20 shows the KGL plant features used for the analysis. Table 3-21 shows the resulting calculated operational parameters.

Table 3-20: RETScreen Energy Module Calibration Inputs

Factor	Project Information
Proposed project type	Reservoir
Gross head	200.0 m
Maximum tailwater effect	384.70 m
Residual flow	7.20 cms
Percent time firm flow available	90.0%
Hydro Turbine Features	
Design flow	464.0 cms
Turbine type	Francis
Turbine efficiency	Standard
Number of turbines	4
Efficiency adjustment	0.0%

Notes: m = meters; cms = cubic meters per second.

Table 3-21: Plant Operational Parameters Calculated by RETScreen

Parameter	Value
Firm flow	124.80 cms
Turbine peak efficiency	92.6%
Flow at peak efficiency	365.3 cms
Turbine efficiency at design flow	89.5%

Notes: cms = cubic meters per second.

Other plant operational features were also entered, consistent with parameters used in the HEC ResSim analysis, including: maximum hydraulic losses for the plant (1.2%), miscellaneous losses (2.0%), generator efficiency (95%), availability (99%), and the available flow adjustment factor (1.0). With these inputs, the Energy Module produces flow-duration and power curves and calculates the power capacity of the KGL plant as 749.5 MW.

In the next section of the RETScreen Energy Module, flow-exceedence information for KGL was entered. The flow-exceedence curve for KGL reflects the baseline scenario from the flow analysis previously discussed (performed in HEC-HMS). When calibrated against the HEC ResSim model, the RETScreen Energy Module yields annual electricity production for KGL of 2,226 GWh/yr, compared to 2,227 GWh/yr for the HEC ResSim baseline period results for the ECHAM5 A2 emissions scenario.

Both the A2 and B1 climate change scenarios were evaluated for the early-century period using results from the ECHAM5 GCM. The financial impacts of both the P-1 (maximum power) and I-9 (maximum development, early-century period) scenarios were evaluated.

As a potential lender for the KGL project, IFC has supported numerous engineering, economic, and environmental studies to evaluate the project's potential technical and financial viability. Financial analysis has considered costs and revenues to evaluate whether the project will produce a positive cash flow and support loan payment within the required payback period. IFC financial information was used to identify financial parameters for the RETScreen Financial Module and to calibrate the financial component of the analysis. The results of the IFC financial analysis were used as a baseline ("without climate change") projection of financial performance for the KGL project. Appendix A4 provides additional background information on RETScreen and its use in this study. The text below provides information on assumed KGL project costs, other financial impacts, and financial results.

The IFC's financial analysis uses power generation and project cost information from previous technical and economic analysis (MWH, 2009). Table 3-22 presents the construction costs used for the IFC financial analysis. These values were entered into the Cost Module of RETScreen.

Table 3-22: Project Cost for 750 MW KGL Plant

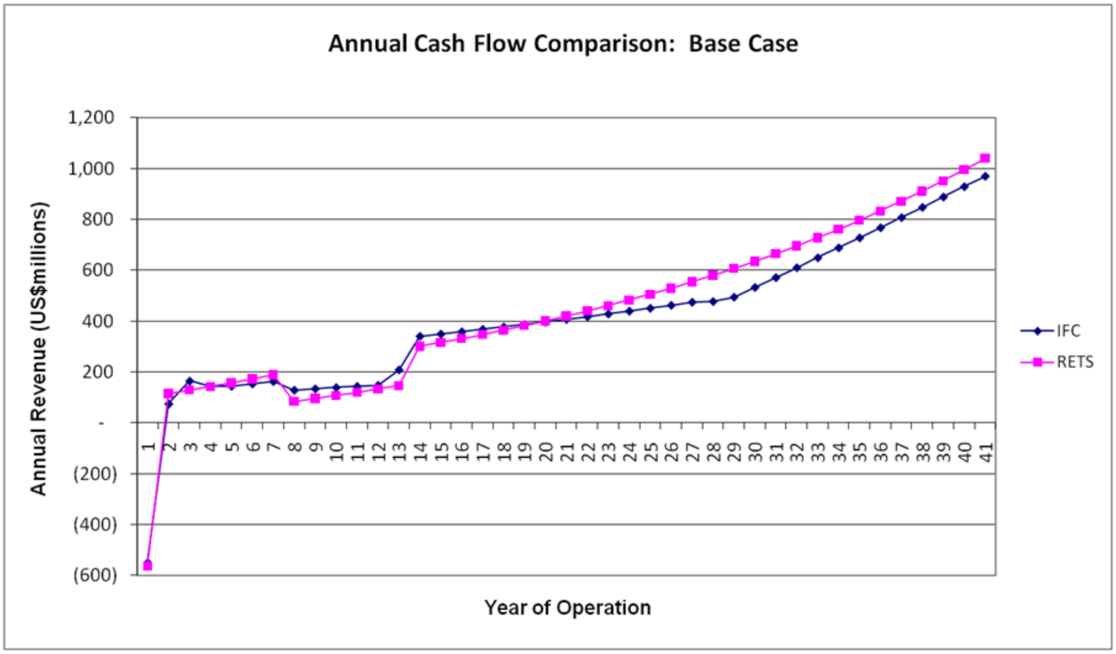
Cost Category	USD (millions)
Civil Works	$422.5
Engineering & Maintenance (E&M) Works	$463.5
Total Civil and E&M Works	$886.0
Civil Works	
Unmeasured	$84.5
Contingency	$63.4
	$147.9
E&M Works	
Unmeasured	$69.5
Contingency	$46.4
	$115.9
Engineering/Administration	$138.0
Development Cost	$92.0
	$1,379.8
Re-regulation Dam	$150.0
Total Project Cost	$1,529.8

Notes: USD = U.S. dollars.

Consistent with the IFC financial analysis, additional inputs affecting the total cost include a corporate tax rate of 35%, a discount rate of 10%, annual inflation rate of 2.5%, and financing of 75% debt to 25% equity. The debt interest rate is 9% with a term of 16 years, with repayment beginning after a six-year grace period. Development and construction costs occur over the first five years, with operation and maintenance (O&M) costs over the remaining 30 years of the 35-year project life. RETScreen allows the inclusion of other costs such as interest during construction, front-end and other financing fees, and a debt service reserve totaling about $528 million. It also captures the IFC assumption of $10 million USD per year for insurance and O&M costs of 7% of the total investment. The IFC financial analysis includes electricity pricing of $0.153/kwh, which is escalated over time at a rate equal to inflation.

The RETScreen analysis yields an after-tax internal rate of return (IRR) of 21.6% compared to the IFC financial analysis value of 20.3%. Figure 3-14 shows the annual cash flow curves generated by RETScreen and the IFC financial analysis. Figure 3-5 shows the resulting cash flow from RETScreen analysis; the cumulative cash flow becomes positive after 5.4 years of operation. Figure 3-16 shows the corresponding cash flow for the IFC financial analysis, which also yields a five-year break-even period.

Figure 3-14: Comparison of Base Case Annual Cash Flow Results



Notes: The Base Case is based on the ECHAM5, A2 emissions scenario, and Base Period time horizon. IFC = IFC Financial Analysis. RETS = RETScreen Financial Analysis.

The RETScreen estimated cash flow for the Base Case is shown in Figure 3-15; the cumulative cash flow becomes positive after 5.4 years of operation. Figure 3-16 shows the results for the IFC Financial Analysis. In this case, the IFC financial analysis value used for comparison is “cash available for dividend payment”; the RETScreen value is “after tax yearly cash flow.”

Figure 3-15: RETScreen Cumulative Cash Flow for Base Case

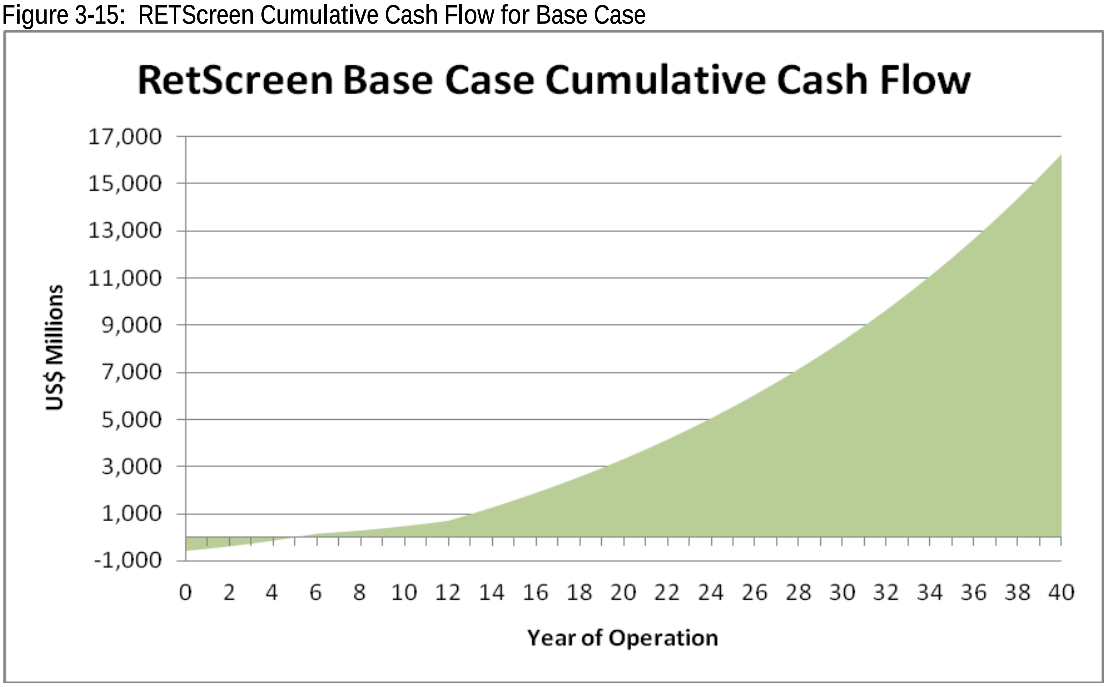
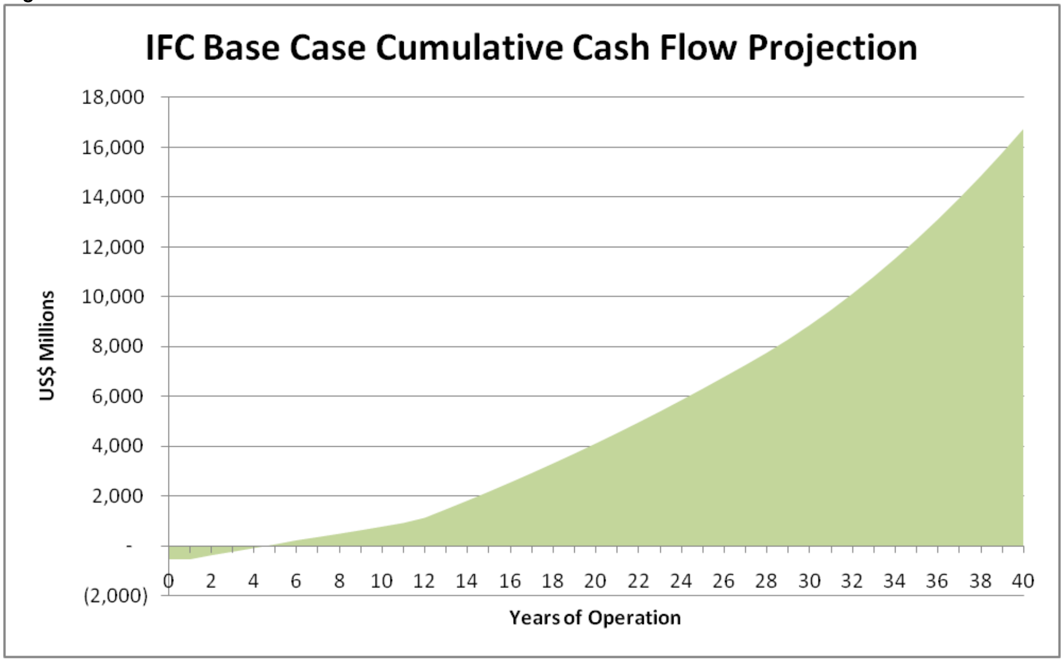


Figure 3-16: IFC Cumulative Cash Flow for Base Case



3.3.2 Financial Modeling Findings

Table 3-24 shows the financial performance results for the early-century period for the ECHAM5 A2 and B1 scenarios. The first column for each emissions scenario shows the projected level of energy generation and associated financial parameters for the P-1 (maximum power) scenario; the second column reflects the impacts of development scenario I-9.

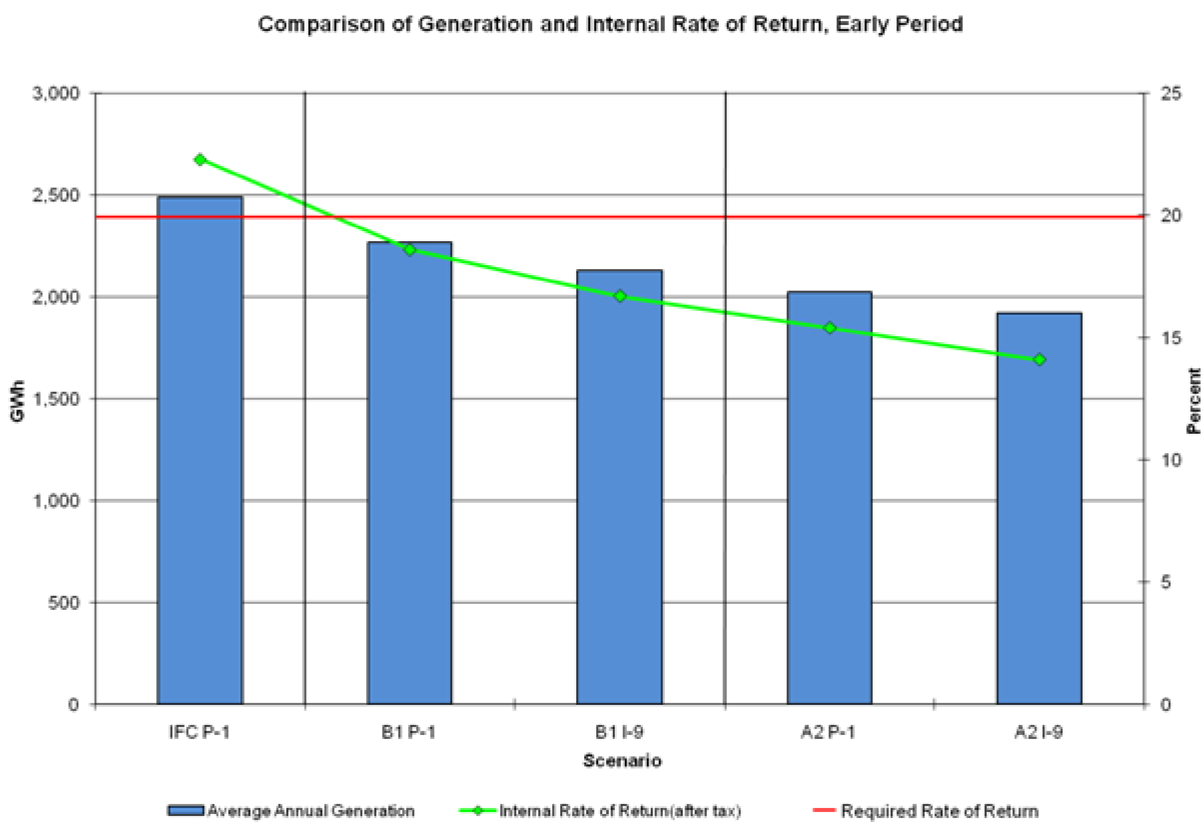
Table 3-24: Financial Performance for ECHAM5 A2 Scenario; Base Period and Early-century Time Period

	ECHAM5 A2, Early Scenarios		ECHAM5 B1, Early Scenarios	
Performance Category	P-1	I-9	P-1	I-9
Average Annual Generation (GWh/yr)	2,090	1,950	2,475	2,175
Internal Rate of Return (%) (after tax)	16.2	14.5	21.5	17.3
Net Present Value (USD Millions)	732	547	1,240	843
Payback Period (on Equity, in years)	8.6	10.7	5.5	7.6

Notes: GWh/yr = gigawatt hours per year; USD = U.S. dollars.

These results demonstrate that the differences between the two future emission scenarios have a significant impact on the operations, and therefore the financial viability, of KGL. Even with water withdrawals for development (I-9) in the B1 emission scenario, KGL performs better than in the A2 emission scenario for the maximum power operating scenario (P-1). Of these four alternatives, only the B1 maximum power scenario is projected to yield acceptable returns to investors, with an IRR in excess of 20%. Figure 3-17 shows the relationship between projected annual power generation and after-tax internal rate of return for each of these scenarios. The red line indicates the threshold return requirement of 20%, suggesting that average annual generation of about 2,450 GWh is the level needed to satisfy investor requirements.

Figure 3-17: Projected Early-century Annual Generation and After-Tax Internal Rate of Return for A2 and B1 Scenarios

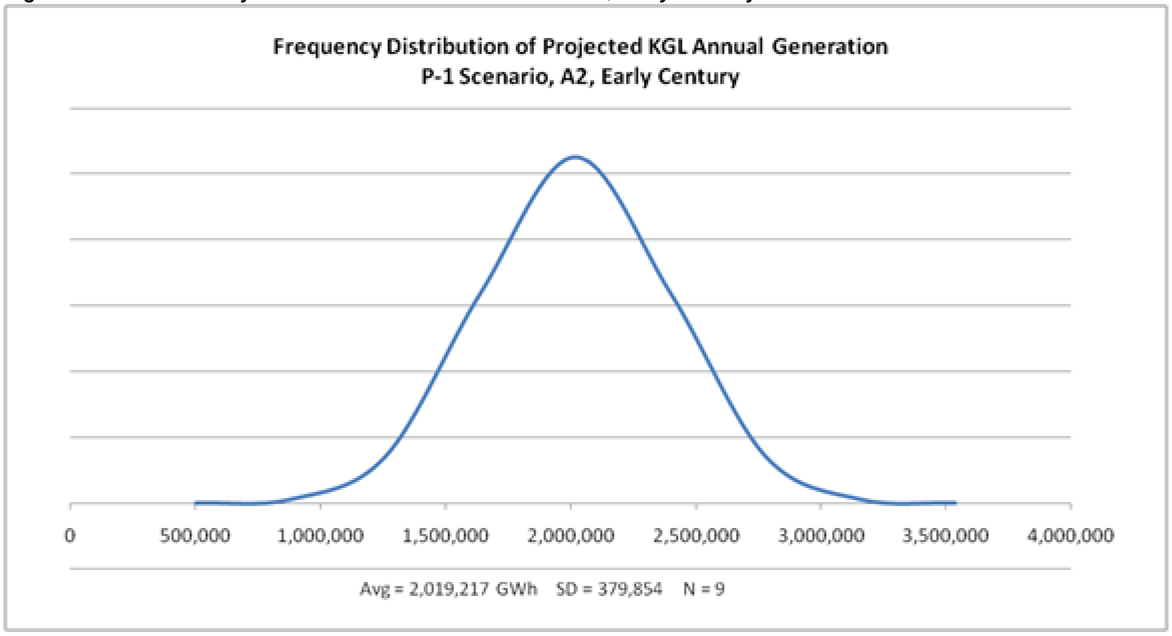


Notes: GWh = gigawatt-hour.

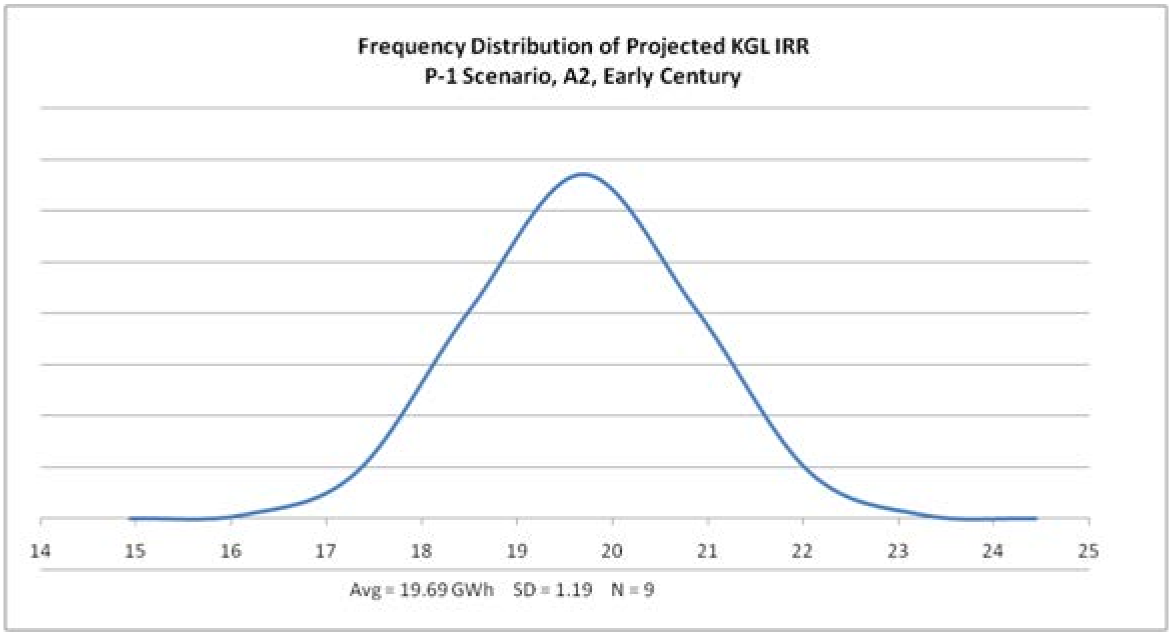
For each of these scenarios, these results effectively consider one possible outcome for the future time periods. A probability assessment provides a better characterization of the likelihood of a range of outcomes for the same period, varying the results of key inputs according to their distribution around their respective averages. For this study, a limited probability assessment was performed (i.e., nine times) for the "maximum power" option in the A2 emission scenario. The results for power generation and their corresponding IRRs are shown in Figures 3-2 (a) and (b).

In light of the variability in the annual generation across the 30 years of the early-century period, these figures show that the average annual generation of KGL may be 2,221 GWh rather than 2,090 GWhs, with an IRR of nearly 18% rather than 16%. A more robust probability analysis will deliver different results, which should better inform planning decisions. These results are generated by using the actual annual projected electricity projection for each of the 30 years to illustrate the possible impact for ROI. Further improvement would result with probability assessments of the available flow to the power plant.

Figure 3-18: Probability Assessment of KGL Performance, Early-century



3-18(a): Projected Frequency Curve, KGL Annual Generation



3-18(b): Projected Frequency Curve, KGL Internal Rate of Return
Notes: GWh = gigawatt hour; SD = standard deviation; N = number; IRR = internal rate of return.

As discussed in Section 7.0 and Appendix A4, there is uncertainty associated with a number of factors that tie to the financial analysis; in addition, the financial analysis uses the outputs of the modeling effort, which also include uncertainty in regards to climate change projections, flow projections, and energy generation. For example, the IPCC, which established the range of future emissions scenarios that includes A2 and B1, states that no one scenario is a more likely outcome than any other (Nakicenovic, N., et al., 2000). In addition to uncertainty associated with the modeling steps, there is also uncertainty about the future demands for conservation releases and other uses of water in the basin. Irrigation and DMI water demand levels will be driven by the growth of the economy in general and of the agriculture sector in particular and will be authorized by the Department of Water Affairs; in addition, climate change may drive the need for increased irrigation due to impacts on evapotranspiration (see Section 4.2). Other uses, such as DMI, are also anticipated to increase – but the precise amount is uncertain and generally considered less significant than changes to irrigation water demand for agriculture.

Given the significance of water flow on the financial viability of hydropower projects, adaptation planning should include considerations such as climate change, conservation, and development that introduce variability into available water flow to the project. Section 4 of this report considers climate change impacts on hazards and sectors that can impact ZESCO through structural impacts and changing water flows and demand (Section 4.0 and Appendices 5 through 9 of the full report provide further detail). This analysis supports the consideration of adaptation goals and options, also discussed in Section 5.0 of this report (Section 5.0 of the full report provides further detail).

4. Natural Hazard Risk and Sector Assessments

The significant projected average annual temperature rise – about 3°C for emissions scenario B1 and 5°C for A2 – is capable of greatly altering the geophysical, ecological, agricultural, economic, human livelihood, and health environment of Zambia and the Kafue River Basin. The highest seasonal temperature increases are projected for period of September through November, reaching up to 6°C for the A2 scenario by the end of this century. Section 3.0 modeling considered the impacts of changes in temperature and precipitation on the viability of the KGL power plant and ZESCO operations with some consideration of conservation releases and development scenarios that would affect ZESCO's operations. However, climate change will also affect natural hazards and economic/environmental sectors within the basin and throughout the country, which may also impact ZESCO operations. Therefore, this section considers some of the broader systemic impacts of climate change on a range of natural hazards and sectors that use water within the Kafue River Basin and the country.

Section 4.1 uses a two-step approach to evaluate the potential future impacts of natural hazard risks to Zambia and ZESCO hydropower operations. The first step involved a literature review to identify the most prevalent types of natural hazards and to document historical trends associated with the frequency, severity, magnitude, and vulnerabilities of each hazard type. The second step drew on the results from the climate projections and modeling described in Section 3.0 to consider how historical conditions documented in the literature might be influenced by future climate change. The following natural hazards are considered: flood, drought, disease, landslides, and wildfire. These hazards are considered in the context of the projected climate change impacts presented in Section 3.0, with a focus on the results from ECHAM5, MRI, and IPSL climate projections and their potential exacerbating impacts for these hazards.

Section 4.2 provides further consideration of the projected impacts of climate change on key economic sectors that rely on water. A literature review was conducted to consider each sector's current and projected water needs without climate change; the potential exacerbating impacts of climate change are then considered. Uncertainty associated with modeling, data, and findings is discussed in Section 7 and Appendices A5 through A9.

4.1 Natural Hazard Assessments

Climate change has already been established as having the potential to significantly affect Zambia (NAPA, MTENR; 2007). Many international entities have supported assessments of these impacts, their extent, and the prospects for effective response by a variety of stakeholders in Zambia.

This natural hazard risk assessment considers available information to help answer the following fundamental question, which is the cornerstone of the adaptation planning process: "*What could happen to ZESCO and its stakeholders as the result of climate change?*" This question is answered by implementing a natural hazard assessment and a vulnerability assessment of exposed populations and structures for ZESCO and other affected stakeholders.

The natural hazard assessment uses available natural hazard information to determine what types of disasters may affect ZESCO directly and indirectly, how often these events may occur in the present and future, and the potential severity of their consequences. The natural hazard assessment for this project also considers the potential exacerbating impacts of climate change on natural hazard frequency and severity. The vulnerability assessment evaluates the potential impact that natural hazard events may have on ZESCO operations and stakeholders – both currently and in the future. The vulnerability assessment references the adaptation potential of the people and infrastructure at risk. The risk assessment is used to help identify priority risks that could be reduced through adaptation efforts. This analysis helps inform the adaptation identification and recommendation process presented in Section 5.0. In addition to supporting adaptation planning, the risk assessment process identifies potential opportunities for collaboration, leveraging, and other planning opportunities for ZESCO; these are also addressed in Section 5.0.

In order to assess risk, a top down approach was selected. The top down approach analyzes how ZESCO customers will be impacted by climate change. A bottom up approach has been selected to analyze how ZESCO will be directly impacted by climate change at the site level. The top down approach provides a national view of the potential impacts of climate change, which provides a basis to assess the indirect impacts of climate change to ZESCO. This top down approach is able to rely on data and resources available at that national, rather than local level (where data are less available), and supports an assessment of impacts to customers across the country. The bottom up approach is appropriate to identify priority risks and make adaptation decisions at the local or facility level.

4.1.1 Flood

Millions of people in Africa suffer impacts from droughts and floods on a regular basis (IPCC, 2007). Floods are critical because they endanger lives and impact development and the economy in African countries. In some cases, recurrent floods in some countries are linked with ENSO events. ENSO is a quasi-periodic climate pattern that occurs across the tropical Pacific Ocean on average every five years, but over a period which varies from three to seven years. It is characterized by variations in the temperature of the surface of the tropical eastern Pacific Ocean and can cause extreme weather events. When major flood events occur, important economic and human losses result (Mirza, 2003; Obasi, 2005). For urban planners in Africa, the biggest threats to local populations and economies posed by climate variability and change are often expected to result from little-characterized and unpredictable, rapid-onset disasters such as storm surges, flash floods, and tropical cyclones (Freeman, 2003).

Since the 1990s, a number of studies have been implemented around the world to assess and quantify the impacts of climate change on water resources (Leavesley, 1994; Arnell, 1998). These studies generally project changes in climate in terms of rainfall and temperature parameters. Under projected climate conditions with higher temperatures, it is possible that convective, high intensity precipitation may occur more frequently (Middelkoop, et al., 2001). In addition to the impact of temperature changes and annual average precipitation changes, climate change will also cause changes in the amount, intensity, duration, type, and timing of precipitation, which will affect river flows (http://www.libraryindex.com/pages/3394/Rivers-Impacts-Climate-Change.html) (see also discussions in Section 3.1.6 of this report).

There are various reasons to expect increases in extreme precipitation, if and when, significant warming occurs. There will be more moisture in the atmosphere and probably greater thermodynamic instability (Kunkel, 2003). There is also evidence that rainfall events have become more intense during recent warm decades in some locations in the United States, Canada, Australia, Japan, South Africa, and Europe (Goudie, 2006).

During periods of high precipitation, the release of excess water from dams into the Kafue River would have adverse impacts downstream. Poor drainage systems have rendered some areas prone to floods, especially during times of year when water tables are high. This has been a common occurrence for the Lusaka, Central, and Copperbelt Provinces (DMMU, 2009).

Recently, Zambia has been negatively affected by floods, which occurred during the rainy seasons of 2006/2007, 2007/2008, and 2008/2009. In the 2006/2007 rainy season, the traditional flood-prone areas of Northwestern and Western Zambia were impacted, --with primary damage to infrastructure and food security (including, roads, schools, residences, agriculture, health, and water/sanitation services). Subsequently, the 2007/2008 floods came earlier than anticipated, affecting the southern half (low lying areas and major river basins) of the country. These floods primarily impacted infrastructure (such as, roads, bridges, and culverts). The 2008/2009 rainy season included flooding in the Northern, North Western, and Western Provinces, primarily impacting infrastructure and food security (DMMU, 2009). Specific flood impacts are discussed in Appendix A5.

Climate change may lead to an increase in intense rainfall events, which may cause more frequent or larger floods. These floods could result in direct economic losses associated with damage to ZESCO facilities and utility lines and the suspension of hydropower operations. Flood events also may cause substantial impacts to ZESCO customers, which could indirectly affect ZESCO. In addition, area stakeholders (the population in the Kafue River Basin) could be adversely impacted. If customers lose their homes or livelihoods, they cease being customers, which impacts ZESCO.

The following sub-sections provide the natural hazard assessment, vulnerability assessment, and risk findings for the flood hazard. Appendix A5 provides additional detail on the flood hazard risk assessment.

4.1.1.1 Flood Hazard Assessment

Historically, floods have been a great cause of concern for Zambia with flood events listed as two of the top five disasters recorded since 1982. Between 1982 and 2007, Zambia was impacted by an average of 0.42 floods per year, for a frequency of about one flood every 2.3 years (OFDA/CRED, 2007). During the rainy season of 2007/2008, Southern Zambia experienced 13 consecutive days of rainfall which compelled rural communities to adjust to new livelihoods and sometimes required relocation. Weather experts and researchers have cited global climate change as the cause of the floods and have indicated it is very likely that this kind of disaster will occur more often in the future (Kabange, 2008).

ZESCO has also been impacted by floods. On February 7, 2008, ZESCO opened the spillway gates at IT dam to prevent flood waters from potentially damaging the walls of the IT reservoir/dam (UN, 2008). People living downstream of the dam, were notified that the spillway gates would be opened so that they could evacuate; this helped to prevent casualties that could have occurred based on the release (Chilabi, 2008).

As detailed in Appendix A5, this study used historical precipitation and temperature data to establish a flood threshold. This threshold was defined as a 15% increase in rainy season precipitation (above normal precipitation for this period); this translates to precipitation of at least 873 mm in a year. The 15% threshold was derived for the rainy season (October to March) and is based on the actual deviation from normal seasonal rainfall documented for historic flood events. This indicator has limitations since the historical flood data shown in Table A5-1 is available at the national level only and because there are limited rainfall stations in the country and study area. The uncertainties present in recorded and modeled precipitation data are described in Section 7.0. To help predict future flood conditions, the probability of exceeding the flood threshold was identified for three GCMs and two emissions scenarios (A2 and B1), across the three future time horizons of this study.

The ECHAM5 A2 late-century and MRI B1 mid-century results were used because they exhibited the highest positive and negative changes from the normal seasonal rainfall. For the ECHAM5 A2 late-century results, the probability of reaching flood conditions is 39% (once in 2.5 years). These results align with flow modeling outputs (see Section 3.1.2) that indicate average annual flows increase by 11% in this period compared to the baseline flows. Using the ECHAM5 B1 mid-century results, the probability of floods is 16% (once in 6.2 years). With reduced flow compared to the baseline period for this scenario, it is expected that droughts could be more of a concern than floods for this time horizon and GCM/emissions scenario. For the MRI B1 mid-century results, the analysis shows there is a lower probability of flooding (14% or once in 7 years, which aligns with the 15% decrease in average annual flows). The analysis indicates that while flood frequency may increase or decrease (depending on the GCM/emissions scenario and time horizon considered), flooding will remain a problem for the region. Also, spatial and temporal variability analysis of precipitation (presented in Section 3.1.6 and Figure A5-2) shows that the floods may become more severe (greater in magnitude), even if they occur less often for some GCM/emissions scenario projections.

4.1.1.2 Flood Vulnerability Assessment

The population of Zambia is very susceptible to disasters due to a high degree of poverty (which results in fewer resources to prepare for, respond to, and recover from a natural hazard) and large numbers of children. Children are always one of the most sensitive population groups to natural hazards because they are not able to provide for themselves and often require special consideration for evacuation and post-hazard protection (from disease and other elements). Based on 2009 data, 51% of the population was considered extremely poor and 14% was classified as moderately poor (United Nations Environment Programme/Global Resource Information Database). The percentage of the population aged 0 to 14 years is 46.2%, while the percentage aged 60+ years is 9.6%. Senior citizens also are more vulnerable to natural hazards due to lower ability to evacuate and a greater susceptibility to natural conditions (cold, heat, disease, etc).

In Zambia, many residential structures that lie within floodplains are also particularly susceptible to flood damage. The people mostly affected are fishermen living by the river banks and herdsmen who graze their cattle in the flood plain (APFM, 2007). Residential building materials may include wood and mud among other materials. Homes, schools, and roads also may be damaged during the rainy season or by floods. In addition, commercial farms or industrial facilities may be impacted. While these structures are not ZESCO facilities, some of the structures may be owned by ZESCO customers who may need their electrical lines restored after a flood event.

Floods present a number of direct and indirect risks to ZESCO operations. In 2005, ZESCO hydropower activities were suspended because of flood-induced mudslides (see Appendix A7). In most cases, however, ZESCO can control the flow of water by opening the spillway gates and continue hydropower operations even under flood conditions. These releases may present a risk to downstream populations. Also, it may be difficult to mobilize power plant workers to the site during or after a major flood. Causes of concern related to the flood hazard for KGL could include: (1) line and transformer structural impacts which would need to be repaired by KGL staff and (2) damage to the transportation routes leading to KGL facilities.

4.1.1.3 Flood Risk Findings

Qualitative and quantitative flood risk assessment findings are provided in this sub-section.

Qualitative Assessment

The natural hazard assessment shows that floods are occurring frequently at approximately 0.42 times each year or once every 2.3 years (OFDA/CRED, 2007). According to several of the GCMs/emissions scenarios, events with higher than normal precipitation will continue in the region and in some months there is a chance to see events greater than what is recorded. Therefore, flood frequency is predicted to remain high in the future. Based on review of historical events and corresponding water depths and impacts, flood magnitude should also be rated as high now and in the future. This study shows that even if average annual precipitation decreases for some GCM/emission scenarios in some time future time horizons, changes to spatial and temporal variability in the basin may result in more extreme precipitation events and greater run-off.

The vulnerability assessment shows a moderate degree of exposure to floods in Zambia, since the floodplains only cover areas around water bodies. Vulnerability was ranked as moderate because many people live in the floodplains and their livelihoods are often tied to the water and land. ZESCO's exposure is considered moderate because it controls water flow upstream and through its facilities, but many of its customers, surrounding communities, and other infrastructure may be impacted by floods. It is anticipated that ZESCO control over flows will be sustained in the future. Therefore, its power generating facilities are not likely to be inundated except by the most extreme events, but its other infrastructure and customer base could be impacted. In addition, flood releases from the reservoirs have the potential to impact downstream residents negatively. The country has a high sensitivity to floods, which may be seen from the construction practices and social and economic losses from historical flood events. In particular, those with subsistence livelihoods or living in chronic poverty conditions are vulnerable because they are generally more significantly impacted by natural hazard events and other economic shocks (World Bank, 2005), and have less resources to support recovery (World Bank, 2005).

The country has a low adaptive capacity to the flood hazard because there are few financial and social networks in place to support displaced people and rebuild homes. ZESCO has a moderate adaptive capacity through its ability to manage flow and cope with flooding events.

The risk assessment shows that the country is at high risk to floods and climate change may exacerbate the magnitude of flood events. ZESCO has a moderate flood risk due to its low vulnerability. This risk may increase in the future due to climate change exacerbating the magnitude of the flooding and ZESCO customers continuing to build in high risk areas.

Quantitative Assessment

In order to better compare risk across the climate-exacerbated natural hazards which may impact ZESCO, historical losses were annualized; in cases where no historical losses had occurred, potential losses were modeled with an associated return period in order to calculate annualized loss.

KGU has been in operation since 1977 and suffered damage by flood waters in 2005; that event is recorded in Table A5-1 which shows that a flood occurred that year. Of the nine floods during the 31 years of ZESCO operations in the area that Table A5-1 identifies, damage to ZESCO facilities was recorded for only one. The annual loss is determined by plotting the probability of flooding on the x-axis and the corresponding losses on the y-axis and calculating the area under the curve. The average annual loss due to flooding for the MRI B1 late-century results is estimated as USD 449,586. More historical loss data would provide a more accurate value, but since the facility has only been in operation since 1977, the historical record is not long (in terms of meteorological timeframes). Table A5-3 in Appendix A5 was used to help calculate the modeled future annual losses for each GCM/emissions scenario across the future time horizons. The modeled future annual losses are shown in Table 4-1.

Table 4-1: Projected Financial Loss to ZESCO Due to Flood (Annualized USD)

GCM	Emissions Scenario A2			Emissions Scenario B1		
	Early-century (2010-2039)	Mid-century (2040-2069)	Late-century (2070-2099)	Early-century (2010-2039)	Mid-century (2040-2069)	Late-century (2070-2099)
ECHAM5	416,286	582,795	649,404	482,886	266,418	382,977
IPSL	349,677	599,445	266,418	716,004	432,936	482,886
MRI	366,327	466,236	299,727	316,377	233,118	449,586

4.1.2 Drought

One-third of the people in Africa live in drought-prone areas and are vulnerable to the impacts of droughts (World Water Forum, 2000). During the mid-1980s, the economic losses from droughts totaled several hundred million USD (Tarhule and Lamb, 2003). Climate variability, including extreme events such as storms, floods, and sustained droughts, already has demonstrated marked impacts on settlements and infrastructure (Freeman and Warner, 2001; Mirza, 2003; Niasse, et al., 2004; Reason and Keibel, 2004). Zambia has experienced an increase in drought frequency and intensity in the last 20 years (CEEPA, 2006). The droughts of 1991/1992, 1994/95, and 1997/98 worsened the quality of life for vulnerable groups such as subsistence farmers. Droughts have been a great cause of concern for the country of Zambia, with drought events constituting three of the top five disasters recorded since 1982.

The following sub-sections provide the natural hazard assessment, vulnerability assessment, and risk findings for the drought hazard. Appendix A6 provides additional detail on the drought hazard risk assessment.

4.1.2.1 Drought Hazard Assessment

A literature review indicates that direct impacts from drought combined with multiple water demands are not currently a major cause of concern to the KGU plant because of the overall hydropower system's reservoir capacity (particularly, capacity for storage at the IT reservoir). This capacity has provided sufficient water storage to allow ZESCO to continue operating during historic drought events although operating procedures have been modified to accommodate the lower reservoir volume, resulting in less power generation. The frequency of droughts in Zambia is about 0.19 times a year in the present; this means that historically a drought has occurred about once every five years (PreventionWeb, 2010).

Similar to the approach used to identify a flood threshold, historical analysis was used to identify a drought threshold. This threshold was established as a negative 12% change from the average annual precipitation for a period. Table A5-2 in Appendix A5 provides a comparison between the modeled and historical rainfall, number of drought events, drought probability, and drought frequency. The ECHAM5 A2 late-century and MRI B1 mid-century results were used because they have the highest positive and negative changes from the normal seasonal rainfall.

For the ECHAM5 A2 late-century, the precipitation results show that the probability of reaching drought threshold conditions would be lower at 10% (once in 10 years) than historical trends. These results align with average annual rainfall trends and precipitation variability analysis discussed in Section 3.1.6 for this GCM/emissions scenario in the late-century period (compared to its respective baseline). For the mid-century ECHAM5 B1 results, the probability of droughts is 19% (about once in 5 years). With reduced average annual precipitation projected during this time horizon for the same GCM/emissions scenario (compared to its respective baseline period) and the precipitation variability discussed in Section A5, it is expected that droughts will occur more frequently for several of the GCM/emission scenarios. Using the mid-century MRI B1 results, the analysis shows there is a higher probability of droughts of 26%, or once in 3.8 years compared to historic data, which aligns with the decrease in average annual precipitation and precipitation variability for this GCM/emissions scenario/time horizon.

Another analysis was conducted to evaluate the potential severity of droughts. This analysis plotted the monthly average rainfall projected by a GCM/emissions scenario for a specified time horizon with the low and high precipitation values projected for each month. Figure A5-2(c) in Appendix A5 shows the ECHAM5 A2 late-century results for this analysis. The bar graph shows that the average monthly rainfall values do not change significantly compared to the baseline period, but the variability in low and high precipitation values changes considerably for some months. The low precipitation values are 20% to 30% lower in some cases.

A final analysis for the drought hazard calculated the Keetch-Byram Drought Index (KBDI) for the area. The KBDI is an indicator of soil moisture deficit; it is based on a number of physical assumptions and is a function of temperature and precipitation (Chu et al., 2002). The complete analysis is conducted in Appendix A8, the wildfire risk assessment, since it is also used to calculate wildfire risk. The calculated KBDI value supports the conclusion that drought conditions will become more probable.

4.1.2.2 Drought Vulnerability Assessment

The majority of the Zambia's poor reside in the rural areas and approximately 60% are dependent on agriculture for their livelihood. Agriculture also remains by far the main opportunity for income and employment for women who comprise 65% of the rural population. There are approximately 800,000 small-scale farmers who depend on agriculture for their livelihood (Swedish Cooperative Centre, 2010). These farmers are particularly sensitive to droughts.

In some parts of the study area, small-holder farmers are now beginning to modify their livelihoods and are turning to different farming techniques such as planting drought resistant food crops and water harvesting. Adoption of these types of changes will increase the ability of farmers to adapt, reducing their vulnerability to climate change (Kabange, 2008).

A literature review and request for information from ZESCO did not identify any direct losses to KGU resulting from historic drought events. This may be due to the fact that the IT reservoir was designed with some excess capacity (to accommodate conservation releases and power generation) and likely the storage capacity helps plant operators manage water to avoid some adverse effects of low rainfall associated with periods of drought. However, after reviewing the power generation records during the drought periods, it was found that the operators appeared to alter operational procedures to accommodate the drought, which resulted in a decrease in power generation. This drop is detailed in the quantitative assessment discussion in 4.1.2.3.

4.1.2.3 Drought Risk Findings

Qualitative and quantitative drought risk assessment findings are provided in this sub-section.

<u>Qualitative Assessment</u>

The drought hazard assessment shows that the frequency of droughts in the recent past should be considered moderate since droughts occur an average of 0.19 times a year (or about once every 5 years) (PreventionWeb, 2010). The hazard analysis presented in Appendix A6 shows that conditions are projected to increase the frequency of future drought events. According to the analysis completed in the natural hazard section, the future frequency of droughts is predicted to increase to high in Zambia. After reviewing previous events and their durations, the drought magnitude is rated as high. For example, droughts constituted three of the top five disasters identified between 1982 and 2007. The GCMs and emissions scenarios considered for this study show that the temperature in Zambia, as well as within the Kafue River Basin, will increase significantly through 2100. This may exacerbate drought conditions (e.g., by increasing water needs for people, crops and livestock). A number of the GCM/emissions scenarios generally predict slight average annual precipitation decreases, but with increased temporal and spatial variability. This indicates there may be more intense periods of rainfall and drought.

The vulnerability assessment indicates high exposure to drought since the hazard has impacted most of the country at some point in time. ZESCO's exposure is high because there have been multiple drought events since 1982 and these have impacted the Kafue River Basin, as shown in Figure A6-1. Based on climate change projections of temperature and precipitation changes spatially and temporally across the 21st century, future drought locations are expected to follow a similar pattern. The country has a high sensitivity to droughts, as evidenced by the social and economic losses and impacts from historical events. ZESCO has a lower sensitivity to drought since its operations include the IT dam and reservoir, which historically has provided significant capacity to capture water when there is precipitation and store it through periods of drought to support hydropower generation at KGU. However, additional power units are being constructed which may increase water demand for power generation. Also, while power operations may not have been impacted historically, it appears that during periods of low rainfall, planned conservation releases to protect the Kafue Flats may not be implemented. ZESCO may be more susceptible to drought in the future due to more extreme drought events, ongoing development, conservation release needs, and climate change impacts that are likely to increase the demands of other water uses.

The country has a low adaptive capacity since there are few financial and social networks in place to support displaced people, restore impacted environmental areas, and address poor harvests. ZESCO has a moderate adaptive capacity to cope with drought events using operational procedures.

The risk assessment shows that the country is at high risk to drought and that climate change, combined with development pressures, population growth, and conservation needs may increase the risk posed by this natural hazard in the future. ZESCO has a low drought risk due to its low vulnerability. This risk may increase in the future due to climate change exacerbating the drought hazard and the additional pressure of non-climate stressors such as other demands for water.

Quantitative Assessment

In order to better compare the risk across the climate-exacerbated natural hazards which may impact ZESCO, historical losses have been annualized and, in the case that there are no historical losses, potential losses were modeled with an associated return period in order to calculate an annualized loss.

Daily power generation data was collected from ZESCO for the time period of October 2003 to August 2009. Table A6-1 shows that only one major drought, in 2005, occurred during that time period. The daily power generation data shows that during the period of the drought until several months after the drought, the daily power generation was 81% of its average level. So, although ZESCO continued to produce power during this period, the amount of power and corresponding revenue was reduced by 19%. If the average revenue/day is USD 769,500 then the reduced revenue would be approximately USD 623,300. Over the six-month drought period in 2005, this would amount to a USD 26,317,000 loss.

Looking at the events which impacted ZESCO's hydropower system, two major droughts caused a reduction in power over 25 years, one in 1995 and one in 2005. There is only detailed loss information for the 2005 drought event which is described in the paragraph above. This loss was used to approximate an average annual loss for drought of USD 2,105,360. Table A6-3 in Appendix A6 was used to help calculate the estimated future annual loss shown in Table 4-2. This loss does not include any modeled future loss for the additional power generating units at KGL and IT. Reduced power at these stations would increase the lost revenue during future drought events.

Table 4-2: Projected Financial Loss to ZESCO Due to Drought (Annualized USD)

GCM	Emissions Scenario A2			Emissions Scenario B1		
	Early-century (2010-2039)	Mid-century (2040-2069)	Late-century (2070-2099)	Early-century (2010-2039)	Mid-century (2040-2069)	Late-century (2070-2099)
ECHAM5	3,421,210	2,368,530	2,631,700	3,684,380	5,000,231	4,473,891
IPSL	3,947,550	3,684,380	5,789,741	1,315,850	2,368,530	2,631,700
MRI	5,000,231	3,421,210	5,789,741	5,526,571	6,842,421	3,421,210

4.1.3 Landslides

Landslides are a geological phenomenon which results from a range of ground movements, such as rock falls, deep failure of slopes, and shallow debris flows. Currently in Zambia, landslides can occur in areas with steep slopes (through natural terrain movement or disturbance by development), particular soil types, ground cover, and erosion conditions. They are often caused by precipitation or earth moving events such as earthquakes. Climate change may cause large storm events, flooding, and expansion of rocky terrain due to temperature increases, all of which would increase landslide frequency. This section considers the landslide hazard, including current and future conditions of the hazard (frequency, severity) and current and future vulnerability to the hazard. It also considers the potential exacerbating impacts of climate change.

Appendix A7 provides additional detail on the landslide hazard risk assessment.

4.1.3.1 Landslide Hazard Assessment

Historical losses are identified in data collected by the United Nations from 1982 to 2007. No large-scale landslides were identified in Zambia over this time period. Available local data was reviewed and indicates that landslides have impacted ZESCO facilities directly. KGU and the site selected for KGL are located in gorges with steep slopes. These are landslide-susceptible areas based on their soils and topography. On December 24, 2005, the KGU power station was shut down at approximately 9:00 p.m. due to massive landslides caused by heavy rains in the Namalundu area, where the power station is located (Hydropower Africa, 2006). Water, mud, trees, stones, and other debris from the landslide entered the power station through the emergency access tunnel. Of the four 150 MW generators in service at the time, two units were damaged (APFM, 2007). The total loss came to $1.67 million USD which includes the energy loss, response costs, and replacement materials and labor as detailed in Appendix A7.

A landslide hazard index may be defined in terms of elevation change, soil types, land cover, and triggering mechanisms among other elements. The major element which may change with climate change is the triggering mechanism. In the case of ZESCO, the primary triggering mechanism is floods and not earthquake (PreventionWeb, 2010). To help predict future landslide conditions triggered by floods, the probability of exceeding the flood threshold of 873 mm (15% deviation above average precipitation in the rainy season) was used (see Section 4.1.1 and Appendix A5 for more information on this threshold). Therefore, the flood hazard assessment presented in Section 4.1.1 (also see Appendix A5, Table A5-3) served as an input to consider landslide potential.

The results of the flood hazard assessment indicate that landslides are a current problem and will remain a risk for ZESCO in the future in the face of increasing development and climate change impacts. Figure A5-2 in Appendix A5 shows the precipitation variability for each month for the ECHAM5 A2 scenario. In several cases, the data shows monthly precipitation maximums that are higher than current maximums.

These conditions would continue to support flood events and as a cascading effect, could increase landslide frequencies or impacts.

4.1.3.2 Landslide Vulnerability Assessment

Historical losses were identified in data collected by the United Nations from 1982 to 2007 (OFDA/CRED, 2007). There have been no large scale landslides identified in Zambia over this time period. Large scale is defined as a landslide that fulfills at least one of four criteria: (1) 10 or more people reported killed, (2) 100 people reported affected, (3) a call for international assistance, and (4) a declaration of a state of emergency.

The 2005 landslide event documented at KGU resulted in the need for ZESCO to contract energy imports of up to 300 MW from Eskom of South Africa and ZESA of Zimbabwe and to institute load-shedding measures to address the power shortfall caused by the outage (ZESCO, 2005). Table A7-1 provides a summary of the losses incurred during this event, as reported in the *Strategy for Flood Management for Kafue River Basin, Zambia* (APFM, 2007).

4.1.3.3 Landslide Risk Findings

Qualitative and quantitative landslide risk assessment findings are provided in this sub-section.

Qualitative Assessment

The natural hazard assessment shows that the risk of landslide occurrence is low because landslides occur infrequently when compared to the other natural hazards in the region. Reviewing the future natural hazard analysis in Appendix A7, the conditions exist for a rise in the frequency and magnitude of landslide events. After reviewing previous events and the amount of land moved, the landslide magnitude should be rated as moderate. KGU and potentially KGL have steep slopes around the power generating units and are located in susceptible areas.

The vulnerability assessment shows that the country has a low exposure to landslides since landslides occur mostly in limited areas with large elevation changes, certain soil types, and land cover. ZESCO's exposure is high because its power generation facilities are located in gorges where there are large elevation changes and where landslides have occurred in the past. The future development locations are predicted to be similar, unless development is restricted. The country has a high sensitivity to landslides which may be seen from the typical construction type found in the region. The infrastructure and people in the impact area can suffer severe, localized losses associated with landslide events - although the total impacts are typically smaller than those resulting from drought, flood, or other natural hazard events. ZESCO also has a demonstrated high sensitivity to landslides since it operations were interrupted by a landslide event in 2005. ZESCO may be more susceptible in the future due to non climate stressors like deforestation and land use changes around the facilities. The country has a low adaptive capacity since there are few financial resources and social networks in place to support displaced people and destroyed structures in the event of a landslide event. ZESCO has a moderate adaptive capacity with the ability to cope with landslide events. This was seen during the last landslide when ZESCO was able to mobilize two hundred people to respond immediately and obtained alternate power supply from other sources.

The risk assessment shows that the country is at low risk to landslides due to a lack of exposure. The risk may increase in the future if development in landslide prone areas increases or conditions that result in landslides occur more frequently (e.g., floods). ZESCO has a moderate risk due to its higher vulnerability. This risk may increase in the future due to climate change exacerbating the landslide hazard and through the addition of several non-climate stressors such as deforestation and land use changes. It also will increase due to the addition of a new power plant, such as KGL, in a gorge.

<u>Quantitative Assessment</u>

In order to better compare risk across climate-exacerbated natural hazards which may impact ZESCO, historical losses were annualized and, in the case that there are no historical losses, potential losses were modeled with an associated return period in order to calculate annualized loss.

KGU has been in operation since 1977 and has been damaged by a landslide once, in 2005. The 2005 event is recorded in Table A5-1 which shows there was a flood that year. Of the nine floods in 31 years, only one resulted in a landslide causing damage to ZESCO operations. The average annual loss due to landslides for the MRI B1 late-century results is estimated as USD 49,954. More historical loss data would provide a more accurate loss assessment, but since KGU has only been in operation since 1977, only limited data is available. Table A5-3 was used to help calculate the modeled future annual loss (which is the same for flood and for landslide). The modeled future annual loss is shown in Table 4-3.

Table 4-3: Projected Financial Loss to ZESCO Due to Landslide (Annualized USD)

GCM	Emissions Scenario A2			Emissions Scenario B1		
	Early-century (2010-2039)	Mid-century (2040-2069)	Late-century (2070-2099)	Early-century (2010-2039)	Mid-century (2040-2069)	Late-century (2070-2099)
ECHAM5	46,254	64,755	72,156	53,654	29,602	42,553
IPSL	38,853	66,605	29,602	79,556	48,104	53,654
MRI	40,703	51,804	33,303	35,153	25,902	49,954

4.1.4 Wildfires

Wildfire is a natural hazard event that constitutes the ignition of fuel sources such as grasses, trees, and shrubs. Climate change in Zambia and the Kafue River Basin will increase temperatures, increasing evapotranspiration and providing greater conditions for ignition of fuel. These conditions increase the probability of wildfire in the future, in the face of climate change. Ongoing development also may increase the proximity of developed areas to wildfire-prone areas, resulting in a higher risk of wildfire fuel ignition and a more immediate impact to exposed populations and infrastructure.

The following sub-sections include a natural hazard assessment, vulnerability assessment, and risk findings for the wildfire hazard. Appendix A8 provides additional details on the analysis.

4.1.4.1 Wildfire Hazard Assessment

Fires have occurred in all of the Provinces of Zambia and have affected most of the key sectors of the economy. Fire disasters have affected not only markets sectors and private households, but also have impacted strategic infrastructure, such as bridges and hydroelectric stations. The fires have caused impacts to a number of major sectors of the economy such as mining, manufacturing, construction and commerce. Examples of major fires that have occurred in Zambia include: (1) the Society House in 1997 and the Cabinet Office in the same year; (2) Chisokone Market in Kitwe in 1998; (3) Indeni Oil Refinery in 2000; and (4) the KGU hydroelectric plant in 2008. These fires have resulted in the loss of lives and property damage worth billions of Kwacha (DMMU, 2008). Data on the occurrence of fires have shown that the frequency and magnitude of fires have increased over the last five years, rendering communities more at risk (DMMU, 2008). It should be noted that available data on historic fires does not always indicate whether a fire is human-induced or a wildfire.

Climate change may decrease precipitation and increase temperature, resulting in a higher probability of wildfire. Ongoing development may increase the urban/plant interface resulting in a higher risk of wildfires and associated impacts on power supply, infrastructure, populations, and the environment.

In order to assess future wildfire conditions, this study implemented a methodology outlined in *"Trends in Global Wildfire Potential in a Changing Climate"* (Liu, et al., 2010). The methodology measures fire potential using KBDI which is calculated using the observed temperature and precipitation. The KBDI is an indicator of soil moisture deficit and is based on a number of physical assumptions (Chu et al., 2002); it is used to help predict drought and wildfire. The formula for calculating KBDI is:

$$Q = Q_0 + dQ - dP, \qquad (1)$$

$$dQ = \frac{10^{-3}(800 - Q)(0.968\, e^{0.0486T} - 8.3)\, d\tau}{1 + 10.88\, e^{-0.0441R}}, \qquad (2)$$

Where Q and Q_0 are the moisture deficiency (KBDI) of the current and previous time increment, respectively, dQ is the KBDI incremental rate, T is the maximum temperature for the time increment, dP is precipitation for the time increment, R is mean annual rainfall, and dτ is a time increment. The precipitation and temperature variables projected using the GCM baseline period (1961-1990) were used and the present KBDI was calculated. The projected precipitation and temperature variables for the GCM time horizons were then used to calculate future KBDI values. The temperature variables selected for the analysis are derived from Tables A8-1, A8-2, A8-3, and A8-4 in Appendix A8.

The KBDI values for future time horizons (impacted by climate change) were compared to the baseline period for the ECHAM5 A2 and B1 emissions scenarios and expressed as a percentage change from the baseline. The results are shown in Table 4-4.

Table 4-4: Percent Changes in KBDI Compared to Baseline Period

GCM/Emissions Scenario	Early-century	Mid-century	Late-century
ECHAM5 A2	+25%	+50%	+80%
ECHAM5 B1	+25%	+37%	+50%

Note: KBDI = Keetch-Byram Drought Index.

The hazard assessment of current wildfire conditions indicates a low frequency of major events based on historical records. The climate change projections (additional detail provided in Appendix A8) for potential future increases or decreases in frequency show that the conditions exist for an increase in the future frequency and magnitude of the wildfire hazard. After reviewing previous events and the amount of land damaged, the hazard magnitude should be rated as low.

4.1.4.2 Wildfire Vulnerability Assessment

The wildfire vulnerability assessment shows that there is moderate exposure to wildfires since areas with appropriate fuel sources do not cover the entire country. ZESCO's exposure is moderate because its facilities are located in more remote areas (in areas with substantial wildfire fuel) and ZESCO facilities have been impacted by fires before. The only planned change in exposure would be the addition of the KGL hydropower plant. The country has a high sensitivity to wildfires, as evidenced by past social and economic losses. ZESCO also has a high sensitivity to wildfires since its operations have come to a halt in the past due to this natural hazard. Zambia and ZESCO may be more susceptible in the future due to non-climate stressors like land use changes and encroachment into forested areas. The country has a low adaptive capacity since there are few financial and social networks in place to support displaced people and destroyed structures. ZESCO has a moderate adaptive capacity with a demonstrated ability to cope with wildfire events based on its previous fire response (see Appendix A8).

4.1.4.3 Wildfire Risk Findings

Qualitative and quantitative wildfire risk assessment findings are provided in this sub-section.

Qualitative Assessment

The wildfire risk assessment shows that the country is at low risk to wildfires due to moderate exposure combined with the infrequency of the hazard. The risk may increase in the future due to the modeled increase in wildfire conditions and an increasing urban/plant (wildfire fuel) interface. ZESCO has a moderate risk due to its higher vulnerability and demonstrated past impacts of a fire event. This risk may increase in the future due to climate change exacerbating the wildfire hazard through increased temperatures and less precipitation leading to dryness.

Quantitative Assessment

In order to better compare risk across the climate-exacerbated natural hazards which may impact ZESCO, the historical losses were annualized and, in the case that there are no historical losses, potential losses were modeled with an associated return period in order to calculate annualized loss.

Since KGU became operational in 1977, there have been two incidents when operations have been suspended due to fires with damage to the power generating units. Because the losses were not documented publicly, the annual value of loss to ZESCO due to wildfire has been estimated at USD 93,750. The losses were based on minimal damage but several hours where there was no power production (Dow Jones Newswire, 2009). Additional data would support a more accurate loss value. Table A8-3 was used to help calculate the modeled future annual loss assuming that changes in KBDI over time are directly related to changes in wildfire probability. The estimated future annual loss is shown in Table 4-5.

Table 4-5: Projected Financial Loss to ZESCO Due to Wildfire (Annualized USD)

GCM	Early-century	Mid-century	Late-century
ECHAM5 A2	117,187	140,625	168,750
ECHAM5 B1	117,187	128,437	140,625

4.1.5 Disease

Malaria remains the leading cause of morbidity and mortality in Zambia. Given its prevalence and major impacts in Zambia, malaria was selected to evaluate the disease hazard. Diseases such as malaria that are transmitted by biting insects and other vectors are among the most important causes of ill-health in tropical regions. Climate affects the reproduction and survival rates of both the infectious agents and their vectors, and hence their ability to infect humans. This is reflected in the temporal correlations between vector-borne disease rates and weather fluctuations over weeks, months, or years and also the close geographical correlations between climatic factors and the distribution of diseases. Climate does not act on the transmission of vector-borne infections in isolation: socio-economic conditions, control programs, human immunity, and other environmental conditions also influence disease rates. In some cases, these socio-economic factors may have more influence than global climate trends on disease rates, particularly at small spatial scales. Africa is at greater risk from disease hazards like malaria that have socio-economic components. One out of ten of the world's annual one million malaria-caused deaths occur in sub-Saharan Africa (Lomborg, 2009). Appendix A9 provides additional detailed analysis of this natural hazard and the following sub-sections provide an overview of the natural hazard assessment, vulnerability assessment, and risk findings for this natural hazard.

4.1.5.1 Disease Hazard Assessment

The IPCC has concluded that climate change is likely to expand the geographical distribution of several vector-borne diseases, including malaria, dengue, and leishmaniasis to higher altitudes (high confidence) and higher latitudes with limited public health defenses (medium/low confidence), and to extend the transmission seasons in some locations (medium/high confidence) (IPCC, 2001). For some vector-borne diseases in some locations, climate change may decrease transmission through reductions in rainfall or temperatures changes that create conditions less conducive to vector transmission (medium/low confidence) (IPCC, 2001).

Disease should be considered as a high frequency hazard because a malaria epidemic has occurred in Zambia an average of 0.58 times a year (or about once every 2 years) since 1982 (OFDA/CRED, 2007). The Zambian Ministry of Health estimates that the number of malaria cases has tripled in the past three decades to more than 4 million clinical cases and 50,000 deaths per year in a population of less than 11 million people (Ministry of Health, 2000).

In order to assess the current malaria conditions in Zambia in greater detail, a malaria modeling program called Mapping Malaria Risk in Africa (MARA) was used. MARA is a biological model of the *Falciparum* malaria transmission that sets decision rules which govern how minimum and mean temperature constrains the development of the parasite and the vector and how precipitation affects survival and breeding. These decision rules were determined by reviewing laboratory and field studies throughout Sub-Saharan Africa and looking at current malaria distribution maps. The model uses three variables to determine climatic suitability for malaria: mean monthly temperature, minimum temperature, and total cumulative monthly precipitation. The MARA decision rules stipulate that both temperature and precipitation have to be favorable at the same time of the year to allow transmission, and suitable conditions have to continue long enough for the transmission cycle to be completed. The model application guidance recommends a five-month time frame as a sufficient length of time for conditions to be suitable for stable transmission.

To analyze how the malaria suitability and transmission season will change with climate change, the projected temperature and precipitation in the study area were compared to the conditions for which mosquitoes do not exist (i.e., minimum temperatures below 15°C and low moisture). Figure A9-3 in Appendix A9 shows the Kafue River Basin analyzed for this project with the GCM temperature and precipitation grid points across the area. The three areas that have traditionally had few or no malaria problems are identified with a red box. The GCM grid points in these three areas (north of Kafue Basin near Solwezi, near Kasempa, and south of Kafue Basin, near Choma) have been numbered to support the future hazard analysis.

The projected average annual precipitation values did not change substantially (+/- 3%) for this region and for the GCM/emission scenarios/time horizons, but the projected temperature values changed significantly for all scenarios. The A2 and B1 emissions scenarios were analyzed for each of the time horizons for the ECHAM5 model to provide a range of possible outcomes. Tables 4-6 and 4-7 show the percent number of days in each focus area with a minimum temperature greater than 15°C for the ECHAM5 A2 and B1 scenarios, respectively. These tables have been summarized by averaging the GCM grids in the three regions for the base period and three time horizons and are shown in Table A9-2 in Appendix A9.

Table 4-6: Projected Percentage of Days per Year (average of grid points) with Minimum Temperature Greater than 15°Celsius for ECHAM5 - A2 Scenario

Time Horizon	North of Kafue Basin near Solwezi	Near Kasempa	South of Kafue Basin near Choma
Base Period (1961-1990)	39%	43%	44%
Early-century (2010-2039)	51%	54%	56%
Mid-century (2040-2069)	58%	61%	61%
Late-century (2070-2099)	69%	72%	73%

Table 4-7: Projected Percentage of Days per Year (average of grid points) with Minimum Temperature Greater than 15°Celsius in ECHAM5 - B1 Scenario

Time Horizon	North of Kafue Basin near Solwezi	Near Kasempa	South of Kafue Basin near Choma
Base Period (1961-1990)	39%	43%	44%
Early-century (2010-2039)	49%	52%	53%
Mid-century (2040-2069)	58%	61%	61%
Late-century (2070-2099)	63%	65%	64%

The analysis shows that the projected climate change temperatures will provide a more suitable environment for malaria in all three areas and for all three time horizons. The three areas of higher elevation which have historically been mosquito free will not remain unsuitable and the malaria transmission season also will be extended. The tables show that the number of days suitable to mosquitos (based on temperatures) increases from four to six months in the baseline period to eight to ten months in the late time horizon. The ECHAM5 A2 emissions scenario provides the upper end of the modeled temperature results across all GCMs and emissions scenarios.

4.1.5.2 Disease Vulnerability Assessment

The Zambian Ministry of Health estimates that the number of malaria cases has tripled in the past three decades to more than 4 million clinical cases and 50,000 deaths per year in a population of less than 11 million people (Government of the Republic of Zambia (GRZ), Ministry of Health, 2000). Malaria remains the leading cause of morbidity and mortality in Zambia. Nine of the top ten deadliest events in Zambia from 1982 to 2007 were caused by epidemics (OFDA/CRED, 2007). Cholera, plague, acute diarrheal syndrome, yellow fever, and malaria have all impacted the population in the past. Yellow fever and malaria are spread by contaminated mosquitoes.

Current models provide a measure of changing exposure to malaria, rather than a complete measure of infection incidence or disease burden. That is, models like MARA identify areas where malaria-infested insects may be present but do not quantify the number of persons that will be infected or how the disease will impact them. To assess the disease burden, assumptions must be made about the relationship between changes in exposure and changes in infection rates/disease burden. The simplest method, applied in this analysis, is to assume that proportional changes in exposure (e.g., proportion of people living in areas climatically suitable for malaria), are directly related to proportional changes in disease burden. For example, if climate change in a particular region is estimated to cause a 20% increase in the number of people living in areas that are defined as climatically suitable for malaria transmission, the proportional method would assume this leads to a 20% increase in the malaria disease burden. This change is then used to estimate the increased number of infections. Estimates of the current disease burden of malaria at the national level are usually available from national statistics, or from the World Health Organization. For this study, proportional change assumptions are used.

4.1.5.3 Disease Risk Findings

The natural hazard assessment shows that disease frequency should be considered high since there is an epidemic 0.58 times a year (OFDA/CRED, 2007). The future natural hazard assessment detailed in Appendix A9 shows that the number of days with suitable temperatures for malaria increases from four to six months in the baseline period to a range of seven to eight months in the late time horizon for ECHAM5 B1 scenario and to eight to ten months using the ECHAM5 A2 scenario. After reviewing previous events and the number of individuals affected, magnitude should be rated as high when compared to the other natural hazards.

The vulnerability assessment shows that there is moderate exposure to diseases since outbreaks occur in most of the country but not all the time due to the seasonal nature of malaria. ZESCO's exposure is high because its facilities and personnel are located in areas which have been impacted by disease before. The climate models project that in the future, areas previously not suitable for malaria will have more suitable conditions and also that the disease season will be extended. The country has a high sensitivity to disease, which may be seen from the social losses from historical events and the average age of the population (with 48% of the population being 14 years or younger); younger persons are more susceptible to disease vectors, such as malaria. ZESCO has a lower sensitivity to disease than the general population because its personnel are adults and have access to health care. Zambia and ZESCO will probably have the same susceptibility in the future. The country has a low adaptive capacity because there are currently limited financial and few social networks in place to support those that contract the disease. ZESCO has a moderate adaptive capacity because its personnel are more likely to be able to prevent or obtain treatment for the disease, if infected.

The risk assessment shows that Zambia is at high risk to disease due to the prevalence of disease concerns and natural hazard vulnerability; this risk may increase based on projections of future conditions. ZESCO has a moderate risk due to its lower vulnerability. ZESCO's structures are not susceptible to the hazard, but its customers and workers are. This risk may increase in the future due to climate change exacerbating disease impacts; there are uncertainties about the impact on risk because the biotic impacts of warming are mediated through physiology and metabolic rate, which increase exponentially rather than linearly with temperature (Chaves, 2010). Other studies provide projections of the economic impact of disease on Zambia generally, and on some key sectors as well.

4.1.6 Natural Hazard Risk Conclusions

The risk assessments described in previous sub-sections have been summarized in tables to facilitate comparison and ranking. Table 4-8 shows the natural hazard evaluation results with the elements of frequency and magnitude for current and future conditions for each natural hazard. Each component has been ranked high, medium, or low. Table 4-9 shows the vulnerability assessment results with elements of exposure and sensitivity for current and future conditions and adaptive capacity. The adaptive capacity is a positive trait so a high adaptive capacity will decrease vulnerability, while high exposure and sensitivity will increase vulnerability. Table 4-10 shows the overall risk assessment evaluating the natural hazard and vulnerability.

The results of this analysis clarify that the financial risks to ZESCO associated with drought events are by far the most potentially expensive, ranging from 1.3 million USD to 6.8 million USD, depending upon the scenario and timeframe (all results are annualized). The potential cost of future loss due to floods yields results in the range of 233,118 to 449,586 USD. The potential cost of future damage to ZESCO due to wildfire yields results in the range of 115,000 to 170,000 USD. Landslides are projected to be far less damaging, registering between 25,000 and 80,000 USD. The increased risk of disease, in the form of malaria, produces zero financial risk to ZESCO based on the assumptions used in this assessment. Although assumptions made in the assessment of each of these risks include various levels of uncertainty (as discussed in Section 7.0), the magnitude of the differences among the results suggests that the ranking of the potential costs of these risks to ZESCO is likely to be correct. ZESCO's priority for climate change adaptation planning is drought.

The natural hazards considered high risk are addressed as part of Adaptation Options in Section 5.0. Other risk considerations described in Section 4.2 of this report also are evaluated as part of adaptation considerations.

To enhance risk modeling efforts in the future, several steps would be useful, including:

- Collect detailed precipitation and temperature data across the basin. Add additional rain and temperature gauge instrumentation across the basin to collect data to increase understanding of spatial variability. Staff using the instrumentation should have proper training and funds for maintenance and data collection.
- Capture detailed loss data associated with natural hazards that are impacted by precipitation and temperature variability. If these losses can be tied to a return period interval, they can be used to better estimate average annual loss for specific natural hazards.
- Develop better topographic data to support the hydrological modeling; this will help to reduce uncertainty associated with flow estimates and provide a more accurate floodplain delineation to assist in evaluating the flood hazard.
- Document changes in hydropower operation associated with periods of drought. This would provide better information concerning potential losses in power generation associated with drought conditions and help to determine if changing the operational procedures could be used in more dire circumstances.

Table 4-8: Hazard Assessment Findings

Hazard	*Current* Frequency	*Future* Frequency	*Current* Magnitude Range	*Future* Magnitude Range
Flood	H	H	M	H
Drought	M	H	H	H
Landslides	L	M	M	M
Wildfire	L	M	L	M
Disease	H	H	H	H

Notes: H = High; M = Medium; L = Low

Table 4-9: Vulnerability Assessment Findings, Zambia and ZESCO

Hazard	*Current* Exposure	*Future* Exposure	*Current* Sensitivity	*Future* Sensitivity	Adaptive Capacity
Flood	M (L)	M (L)	H (L)	H (L)	L (M)
Drought	H (M)	H (H)	H (L)	H (H)	L (M)
Landslides	L (H)	L (H)	H (H)	H (H)	L (M)
Wildfire	M (M)	M (M)	H (H)	H (H)	L (M)
Disease	M (M)	H (H)	H (L)	H (L)	L (M)

Notes: H = High; M = Medium; L = Low; results for ZESCO shown in parentheses; other results are for the country as a whole.

Table 4-10: Risk Findings, Zambia and ZESCO

Hazard	*Current* Potential Loss			*Future* Potential Loss		
	Social	Economic	Environmental	Social	Economic	Environmental
Flood	H (L)	H (L)	H (L)	H (M)	H (M)	H (M)
Drought	H (L)	H (L)	H (L)	H (M)	H (M)	H (M)
Landslides	L (M)	L (M)	L (M)	M (H)	M (H)	M (H)
Wildfire	L (L)	L (M)	L (L)	M (L)	M (M)	M (M)
Disease	H (L)	M (L)	M (L)	H (M)	H (M)	M (L)

Notes: H = High; M = Medium; L = Low. ; results for ZESCO shown in parentheses; other results are for the country as a whole.

4.2 Sector Assessments

In addition to considering the impacts of climate change on natural hazards, this study considers the potential impacts of climate change on various economic and environmental "sectors." Impacts on sectors may indirectly or directly impact ZESCO operations and can impact ZESCO customers and Kafue River Basin stake holders. For example, if climate change (combined with development) increases the need for water by other sectors, systemic impacts ultimately can impact ZESCO (even if climate change would not significantly hamper ZESCO operations in isolation). The remainder of Section 4.0 considers sector-based impacts on agriculture, conservation, and other uses, including a review of current sector conditions, potential climate change impacts on the sector, and overall development or other plans. It should be noted that this section does not consider increased demand for household energy as a result of average temperature rise because these increases are not considered significant relative to the other factors considered in the analysis. The findings of this section help to identify priority risk areas or concerns that tie to the adaptation options in Section 5 of this report.

4.2.1 Agriculture

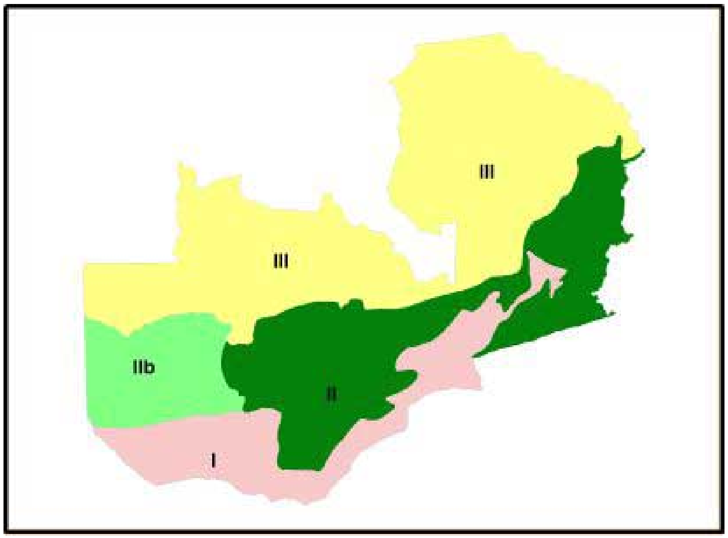
A number of studies of the impact of climate change on agriculture in Zambia estimate that the average annual temperature will increase by 2°C by the year 2070. The projections associated with this climate change risk study identify a possible annual average temperature increase of up to 5°C by the year 2100. These temperature increases, combined with projected increasing variability of rainfall, which may increase run-off, climate change impacts on agriculture and irrigation are likely to be significant (GRZ, 2007). This sector assessment of agriculture begins with a review of current agricultural conditions. The assessment then considers historical climate patterns that have impacted Zambia (natural hazard and vulnerability review). Finally, the assessment evaluates development scenarios and climate change projections that may impact this sector in the future (and indirectly impact ZESCO).

4.2.1.1 Current Agricultural Context

Zambia's population of about 12 million people includes a total labor force of about 5.4 million, of which approximately 60% to 85% are in the agricultural sector. The agricultural sector is an important component of Zambia's economy, responsible not only for about 22% of the country's gross domestic product (GDP) and nearly 16% of annual export revenues, but also for the population's food security. About 42% of the country's cultivated land is planted with maize, a key subsistence crop. Zambia has a rural poverty level of about 80%; this population is highly dependent upon maize for its daily diet (Thurlow, et al., 2009). The highest-value export crop in Zambia is sugar. Sugar exports are a key component of total GDP, with exports generating between 2.5% and 6% of Zambia's export revenue each year. About 420,000 hectare (ha) in Zambia is suitable for farming, yet only about 14% of this area is currently cultivated (Thurlow, et al., 2009).

Zambia is divided into the three agro-ecological zones (AEZ) shown in Figure 4-1. These AEZ reflect three categories of temperature and rainfall patterns across the country.

Figure 4-1: Zambia's Agro-Ecological Zones



Source: UN FAO at http://www.fao.org/ag/AGP/agpc/doc/Counprof/zambia/zambia.htm

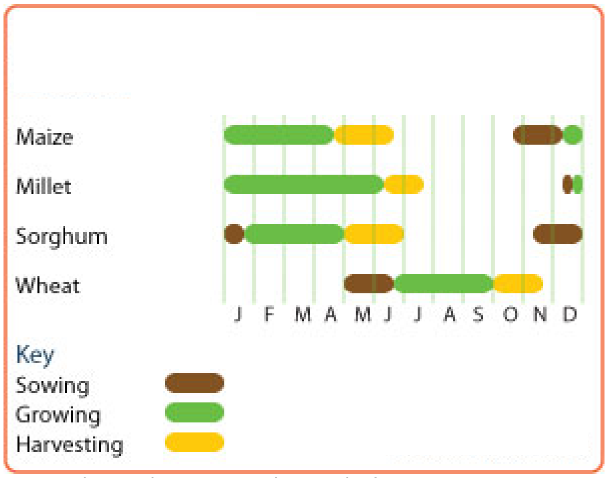
Zone I in the southern portion of the country is the hottest and driest with an average precipitation of 684 millimeters (mm) per year; Zone II (divided into IIa and IIb) across the mid-section of the country experiences more moderate temperatures and average precipitation of 830 mm per year. For the purpose of climate discussions, Zone IIa is sometimes further divided between its south-western portion (IIa1) and its eastern potion (IIa2). Zone III receives an average 1,151 mm per year of rain. The Kafue River Basin, which is the primary focus for this climate change risk assessment, falls predominately in Zone IIa1 and Zone III. In Zambia, crop viability is largely defined by these zones.

Zambia also has three primary seasons: (1) cool and dry (May to mid-August) with temperatures averaging up to 13°C to 26°C; (2) hot and dry (mid-August to November) with mean temperatures between 26°C and 38°C, and (3) rainy (November to April) with temperatures between 26°C and 34°C. Nearly all of the annual precipitation occurs during the six months of the rainy season (Thurlow, et al., 2009).

Zambia's agriculture sector is primarily composed of over a dozen crops, including: (1) food crops such as maize, wheat, sorghum, cassava, millet, rice, and soybeans, and (2) cash crops such as cotton, sugarcane, tobacco, flowers and coffee. About 42% of Zambia's cultivated land is devoted to maize. AEZs IIb and III are best suited to the temperature and precipitation requirements of maize, although maize is grown throughout the country.

Each primary growing season spans two calendar years, with crops planted during late October and November of one year and harvested in May and June of the next year. The major exception to this pattern is the cultivation of winter wheat, which is planted during May and June, and harvested in October and November. These growing seasons are shown in Figure 4-2.

Figure 4-2: Crop Calendar for Zambia



Notes: The X-axis represents the months from J, January to D, December.
Source: UN FAO at http://www.fao.org/giews/countrybrief/country.jsp?code=ZMB&lang=en

The Zambian agricultural sector is typically grouped into three farming categories: (1) small scale (farming households), (2) large scale (mechanized), and (3) commercial (mechanized with irrigation and hired labor force). The productivity of large scale and commercial farms is several times higher than that of small scale farms, which are dependent upon rainfall for crops. While Zambia is widely recognized as having substantial water resources, it has a very low rate of irrigation. Only about 3% of cultivated land is under irrigation, nearly all of which is controlled by large scale and commercial farms. Even at this low rate of irrigation, agricultural irrigation is responsible for about 75% of water use in the country (FAO, 2005).

Large-scale farms produce 22% of the country's total maize crop on about 8% of the total area planted with maize, with yields of about 6 tons per ha. Small-scale farmers are responsible for about 80% of the maize-cultivated area and realize an average yield of about 2 tons per ha. The winter wheat crop is produced entirely by commercial farms using irrigation methods (FAO, 2005).

4.2.1.2 Historical Climate Patterns

Statistical analysis of the past 30 years of temperature and precipitation trends in Zambia reveals a strong correlation between rainfall and maize yield in the Southern, Central, and Eastern Provinces. This statistical analysis also suggests that temperature increases that occur during the beginning of the growing season interfere with germination and have a negative impact on yield; however, temperature increases in the middle of the growing season have a positive impact on productivity (Thurlow, et al., 2009).

It is widely accepted in the literature that the experience of floods and droughts in Zambia has increased in the last two decades compared to prior patterns. Recent research has examined Zambia's historic rainfall patterns and correlated rainfall patterns with crop yields (Thurlow, et al., 2009; Lekprichakul, 2008). For maize, the drought period of 1991/92 resulted in the most significant reduction in maize yield for AEZs I and IIa2: 77% and 65% for each of the two affected years. However, in AEZ III, yield reduction was about 14%. The analysis concludes that droughts in AEZ III are very rare and AEZ IIa2 is also relatively less drought-prone; however, AEZs I, IIa1 and IIb are more drought prone. Drought experienced during the growing season of 2004/05 adversely affected over 1.2 million people, requiring the distribution of 120,000 tons of food aid (Lekprichakul, 2008).

4.2.1.3 Future Agricultural Context: Climate Change and Agricultural Expansion

This section considers the future agricultural context in light of climate change and projected expansion of the agricultural sector in the near- and long-term. Sugar is addressed first, followed by maize. The analysis focuses on climate change projections in terms of temperature and precipitation impacts on water availability for power generation at KGL and for irrigation needs. This section ends with overall findings regarding risks to this sector.

Irrigated Agriculture (Sugar Industry) and Climate Change

Temperature patterns in the Kafue River Basin are well-suited for the cultivation of sugar cane. Zambia's entire sugar crop is located in the Kafue River Basin, which is predominately in AEZ IIa, where the average temperatures during the warm months are between 26°C and 38°C. During the sowing season, optimal temperatures for sprouting are between 25°C and 34°C.

As a high-value crop, sugar is annually responsible for between 2.5% and 6% of Zambia's export revenue. Zambia is the sixth-largest source of sugar in the world. However, its production costs are not as competitive on the world market due to the relatively high costs associated with irrigation and transportation. As a landlocked country, Zambia faces added challenges in delivering products to world markets. Sugar is a water-intensive crop, but water access in the Kafue River Basin, combined with the seasonal temperature patterns in Zambia, result in high sugar crop yields. All of Zambia's commercial sugar plantations are located in the Kafue River Basin and these plantations use about 50% of the country's existing irrigation infrastructure. Sugar is also a relatively high-wage element of the Zambian agriculture sector, with average wages that are more than twice the national average for the agriculture sector as a whole (Palerm, et al., 2010).

The World Bank implemented a Multi-Sector Investment Opportunity Analysis (MSIOA) (World Bank, 2009). This study analyzed cultivation and irrigation patterns in the Kafue River Basin and reveals that roughly 35,000 to 40,000 ha of sugar have irrigation infrastructure, which represents the majority of the approximately 51,311 ha of irrigation infrastructure throughout the country (World Bank, 2009). In the Kafue River Basin, sugar is cultivated on roughly 24,000 of these irrigated hectares, with the balance used primarily for winter wheat and soybeans (Appendix D; World Bank, 2009).

In Zambia's National Irrigation Plan, the country's area under irrigation is projected to double from roughly 35,000 ha to about 70,000 ha, distributed as follows: (1) 10,000 ha for large-scale commercial farms, (2) 30,000 ha for large-scale farmers, and (3) 30,000 ha for small-scale farmers (Appendix C, page 39; World Bank, 2009)

Recent analysis by the World Bank (World Bank, 2009) developed several scenarios of increased future demand for irrigated land in the nine countries within the Zambezi watershed; Zambia and the Kafue River Basin fall within this watershed. One scenario is defined as "identified" projects for irrigation growth (Scenario 3; World Bank, 2009). In this case, the additional irrigation area needed is estimated for the Kafue River Basin as 38,500 ha, and for the entire country as 58,600 ha (page 212; World Bank, 2009). Another scenario (Scenario 4; World Bank, 2009) is defined as additional growth in irrigated land calculated as necessary to meet food security needs of the country. Total food security is usually defined as total food production to meet in country food demand (i.e., maize, required in the absence of food imports). For this food security scenario, the additional irrigation needed for the Kafue River Basin is estimated as 225,700 ha (Scenario 4; World Bank, 2009).

As shown in Table 4-11, baseline water abstraction for current irrigation needs in the Kafue River Basin equals 536,900,000 cubic meters (m^3) annually, which is equivalent to 17.02 cms. Water abstraction to meet irrigation needs for the identified future projects was calculated to be 566,556,000 m^3, which corresponds to an additional 17.92 cms (Appendix D, page 111; World Bank, 2009) for a total of approximately 35 cms.

Table 4-11: Irrigation and Abstraction Volumes for Selected MSIOA Scenarios

Kafue River Basin	Irrigated Area (ha)	Cumulative Irrigated Area (ha)	Incremental Volume (cms)	Cumulative (cms)	Annual Incremental Volume (m^3)	Cumulative Annual Volume (hm^3)
Current Irrigation	40,158	40,158	17.02	17.02	536,900,000	537
Additional Identified Projects	38,486	78,644	17.97	34.99	566,556,000	1,103
Additional for Food Security	225,709	304,353	86.21	121.20	2,718,690,000	3,822

Notes: Acronyms: ha = hectares; cms = cubic meters per second; m^3 = cubic meter; hm^3 = million cubic meters.
Source: Compiled from Tables 2-2, 2-3, 2-8, 2-9, 4-34 from MSIOA (World Bank, 2009).

Section 3.1documented the potential impact of climate change on water availability to KGL. In addition, the energy analysis in Section 3.2includes scenarios that evaluate the potential effect of increased demand for water from the Kafue River to meet growing irrigation needs. The four development scenarios considered in that section reflect additional water abstractions upstream of KGL, as summarized in Table 4-12.

Table 4-12: Irrigation Scenarios Evaluated for Climate Change in this Study

Scenario	Upstream of IT (Upper- and Mid- Kafue Basins)				Below IT (Kafue Flats)		Total Irrigation Abstractions	
	Upper Req (cms)	Mid Req (cms)	Total Req (cms)	New Ag (Ha)	Total Req (cms)	New Ag (Ha)	Total Req (cms)	Total New Ag (Ha)
I-3	6.5	5.4	11.9	20,000	11.1	0	23	20,000
I-6	6.5	0.1	6.6	0	22.5	20,000	29.1	20,000
I-9	6.5	5.4	11.9	20,000	16.8	10,000	28.7	30,000
I-10	6.5	16	22.5	60,000	33.9	40,000	56.4	100,000

Notes: Req = required; ha = hectares; cms = cubic meters per second. Source: See Section 3.2.1.

Comparison of Tables 4-11 and 4-12 shows that the I-10 irrigation scenario evaluated during earlier stages of this project captures the additional 38,486 ha of irrigation needed for the “identified projects.” A more incremental approach can be considered by disaggregating the “near-term” identified projects and the “long-term” identified projects. For the 38,483 ha of “Additional Identified Projects,” the World Bank study specifies that the majority of ha are not expected to be implemented before the “very long term” (Appendix D; World Bank, 2009). Also, one additional project sized at 960 ha is located downstream of KGL and would not impact KGL power production because the water would be withdrawn from below the KGL dam. Reducing the gross total for “Additional Identified Projects” by these two amounts yields a net near-term projection of 12,852 ha for new, shorter-term irrigation needs.

Table 4-13 shows the two subsets of “Additional Identified Projects,” divided between the near- and long-term. This distinction is relevant because the near-term demand will be significantly lower than the gross total for the category and also because possible barriers, such as insufficient capital, could arise that would interfere with the implementation of the long-term projects.

Table 4-13: Adjusted Irrigation and Abstraction Volumes for Selected Scenarios

Kafue River Basin	Incremental Irrigated Area (ha)	Cumulative Irrigated Area (ha)	Incremental Volume (cms)	Cumulative Cms	Annual Volume (hm^3)	Cumulative Annual Volume (hm^3)
Current Irrigation	40,158	40,158	17.02	17.02	536.9	537
Additional Near-term Identified Projects	12,852	53,010	6.00	23.02	189.2	726
Additional Long-term Identified Projects	25,634	78,644	11.97	34.99	377.4	1,103

Notes: ha = hectares; cms = cubic meters per second; m^3 = cubic meter; hm^3 = million cubic meter.
Source: Modified from Tables 2-2, 2-3, 2-8, 2-9, 4-34 (World Bank, 2009).

Projected changes in temperature due to climate change will have an added effect on agriculture through increased evapotranspiration (the exchange process in plants that allows water to evaporate into the surrounding air). As temperature increases, this exchange processes also increases, increasing the water requirement of the plant. In the presence of reduced precipitation, this additional demand for water becomes harder to meet and sustain. Calculations performed in the MSIOA study evaluated the effects of a 2°C and 4°C temperature increase on evapotranspiration. Results indicate that a 2°C increase in temperature will correspond to about a 6% increase in water needs for irrigated crops to compensate for the increase evapotranspiration associated with increased temperature. Similarly, a 4°C temperature increase will result in a 12% increase in irrigation needs for crops based on increased evapotranspiration effects (World Bank, 2009).

Projected results for temperature and precipitation changes due to climate change from the analysis presented in Section 2are summarized in Table 4-14.

Table 4-14: Projected Temperature Impacts (°C) of A2 and B1 Climate Scenarios for Lusaka

Lusaka Grid Point	Base Period (1961-1990)	Early 21st Century (2010-2039)	Mid 21st Century (2040-2069)	Late 21st Century (2070-2099)
A2 Projected Temperature	28	30	31	33
A2 Increase from Base Period	-	+2	+3	+5
B1 Projected Temperature	28	29	31	32
B1 Increase from Base Period		+1	+3	+4

As Table 4-14 shows, the near-term results for both scenarios are 1°C to 2°C. The increased irrigation to compensate for the associated evapotranspiration increases are about 6%. In the mid- to long-term, temperature increases are projected to range from 3°C to 5°C, resulting in a corresponding irrigation increase of 12%. In Table 4-15, the bottom row shows the corresponding additional water volume that will be needed by the end of the early-century period (2010-2039) as a result of the adjustment for evapotranspiration associated with temperature increases. Table 4-16 then shows the impacts for the long-term.

Table 4-15: Comparison of Near-Term Irrigation Needs, Early-century: Baseline Demand and Climate Change-Adjusted Demand

Kafue Basin	Irrigated Area (ha)	Cumulative Irrigated Area (ha)	Irrigation Volume (cms)	Cumulative (cms)	Annual Volume (m^3)	Cumulative Annual Volume (hm^3)
Current Irrigation Needs	40,158	40,158	17.02	17.02	536,900,000	536.90
Current Irrigation Needs, adjusted for ETo			18.11	18.11	571,392,000	571.39
Near-Term Identified Projects	12,852	53,010	6.00	23.02	189,195,492	726.20
Near-Term Identified Projects, adjusted for ETo			6.39	24.50	201,349,955	738.25

Notes: ha = hectares; cms = cubic meters per second; m^3 = cubic meter; hm^3 = million cubic meters; ETo = evapotranspiration.
Source: Modified from tables provided in the MSIOA Report (World Bank, 2009).

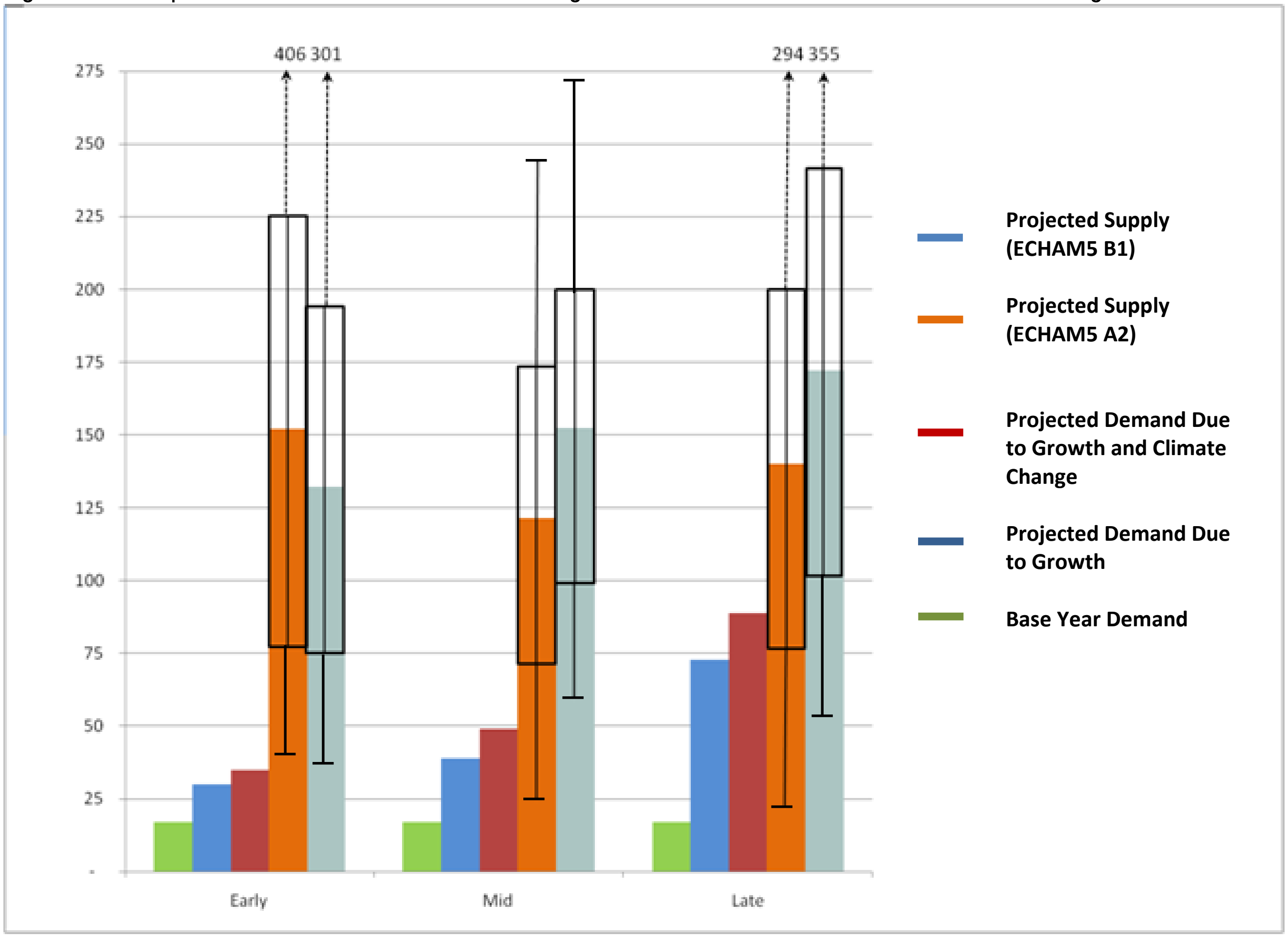
Table 4-16: Comparison of Long-Term Irrigation Needs, Mid and Late-century: Baseline Demand and Climate Change-Adjusted Demand

Kafue Basin	Irrigated Area (ha)	Cumulative Irrigated Area (ha)	Irrigation Volume (cms)	Cumulative (cms)	Annual Volume (m^3)	Cumulative Annual Volume (hm^3)
Current Irrigation Needs	40,158	40,158	17.02	17.02	536,900,000	536.90
Current Irrigation Needs, adjusted for ETo			19.10	19.10	601,328,000	601.33
Near-Term Identified Projects	12,852	53,010	6.00	23.02	189,195,492	726.20
Near-Term Identified Projects, adjusted for ETo			6.72	25.78	211,898,951	813.23
Long-Term Identified Projects	25,634	78,644	11.97	34.99	377,445,007	1,103
Long-Term Identified Projects, adjusted for ETo			13.41	39.19	422,738,407	1,236

Notes: ha = hectares; cms = cubic meters per second; m^3 = cubic meter; hm^3 = million cubic meter.
Source: Modified from tables included in the MSIOA Report (World Bank, 2009).

This additional irrigation demand due to climate change in addition to the baseline level of expansion of irrigated agriculture due to projected economic growth in the Kafue River Basin is shown in Figure 4-3.

Figure 4-3: Comparison of Future Water Demand for Irrigation with and without the Effects of Climate Change



For the KGL analysis of growth in irrigation needs for the Kafue River Basin, the parameters of the I-9 development scenario capture the near-term identified projects, with I-10 capturing the mid- and long-term. The total irrigation expansion in these scenarios of 30,000 ha and 100,000 ha, respectively, provide insight into the combined impact of future climate change and future growth in irrigation on the ability of KGL to generate power. Table 4-17 provides the corresponding changes in annual power generation for the ECHAM5 A2 and B1 climate change scenarios and I-9 and I-10 development scenarios. Note that because these ResSim values result from the output of the HEC-HMS modeling (as described in Section 2), they include the projected impact of climate-change-induced temperature increases on the water supply (flow) in the Kafue River and its corresponding impact on power.

Table 4-17: Projected Changes in Power Generation (ECHAM5 GCM) from Development Scenarios (Irrigation)

Emission Scenario	Baseline Power (GWh/Yr)	Changes in Energy Production for Development Scenarios: GWh/Yr (% Change from P-1 Base) for I-9 (Early) and I-10 (Mid and Late)		
		Early-century (I-9)	Mid-century (I-10)	Late-century (I-10)
A2	1,847	-126 (-7%)	-367 (-17%)	-362 (-15%)
B1	2,099	-125 (-6%)	-540 (-32%)	-362 (-18%)

Notes: GWh/Yr = Gigawatt-hours per year. Percentages are rounded to the nearest whole number.

The above changes in power generation associated with agriculture (compared to the P-1 base period) range from -6% to -7% for the early-century period to a much more significant range of -15% to -32% for the mid- and late-century periods. These annual generation results can be converted to corresponding values of lost revenue using the electricity price presented in Section 3.3 of $0.153/kwh. The projected revenue impacts for A2 and B1 are shown in Table 4-18 for the I-9 and I-10 development scenarios.

Table 4-18: Projected Changes in Revenue from Development Scenarios (Irrigation)

ECHAM5 GCM	Changes In Revenue (USD/Yr) for Development Scenarios I-9 (Early) and I-10 (Mid and Late)		
Emission Scenario	Early-century (I-9)	Mid-century (I-10)	Late-century (I-10)
A2	-21.4 Million	-62.4 Million	-61.5 Million
B1	-21.3 Million	-91.8 Million	-61.5 Million

Notes: USD/Yr = US dollars per year.

The World Bank MSIOA analysis also considered the power generation and cost impacts of increased irrigation withdrawals. Table 4-19 presents the annual power generation levels that the World Bank study estimated for KGL for scenarios 3 and 4, discussed previously.

Table 4-19: Summary of MSIOA Study Power and Revenue Impacts for Irrigation for KGL

World Bank Scenario	Energy Impact (GWh/Yr)	Resulting Generation (GWh/Yr)	Annual Revenue Loss (USD)
3	-289	2,102	-47.7 Million
4	-1,130	1,261	-186.5 Million

Notes: GWh = Gigawatt-hour per year; USD = US Dollar.
Source: Adapted from pages 273, 275 of the World Bank MSIOA Study (World Bank, 2009).

The potential revenue losses for KGL under these irrigation scenarios range from $21 million to over $48 million per year (USD) under the near-term growth scenario (I-9 of this study and Scenario 3 of the MSIOA study) to a range of about $62 million to over $186 million per year under the more aggressive longer-term projection of growth in irrigation demand (I-10 and MSIOA Scenario 4). While these impacts appear large, the near-term losses are about 10% to 16% of the after-tax annual revenue projected for KGL during years 20 through 25 of operation and the longer-term impacts would occur against annual revenue projections for KGL of between $750 million and $1 billion of annual after-tax revenue.

Rainfed Agriculture (Maize) and Climate Change

Maize is widely recognized as Zambia's most important crop; while some is grown commercially for export, most maize is produced through subsistence farming and for local sale (GRZ, NAPA, 2007; Thurlow, et al., 2009). As shown in Figure 4-2 previously, maize is grown during the rainy season and yield is highly dependent upon seasonal precipitation. Table 4-16 shows the distribution of maize among Zambia's AEZs. This distribution is significant in light of the corresponding projected impacts of climate change on intra-annual rainfall variability. As described in Section 4.2.1.1, Zone III (see previous Figure 4-1) receives the highest average annual rainfall; recent analysis suggests that Zone III has the lowest levels of variability (Thurlow, et al., 2009). Zones I and IIa1 have the highest variability, placing maize production in these Zones, which represent 63% of the country's total maize production in 2006, at risk. This threatens not only the contribution of maize to the country's GDP, but also domestic food security. However, given that only 14% of Zambia's total suitable land area is cultivated, this threat could be addressed by redistributing maize production to other AEZs and increasing the levels of production efficiency for agriculture at the subsistence level. Table 4-20 presents Zambia's maize production by AEZ for 2006.

Table 4-20: Maize Production per Agro-ecological Zone in 2006

Agro-Ecological Zone	Annual Production (thousands of tons)	Percent of Total Zambia Production per Zone (%)
I	169	12
IIa1	692	51
IIa2	179	13
IIb	24	2
III	304	22
Total	1,368	100

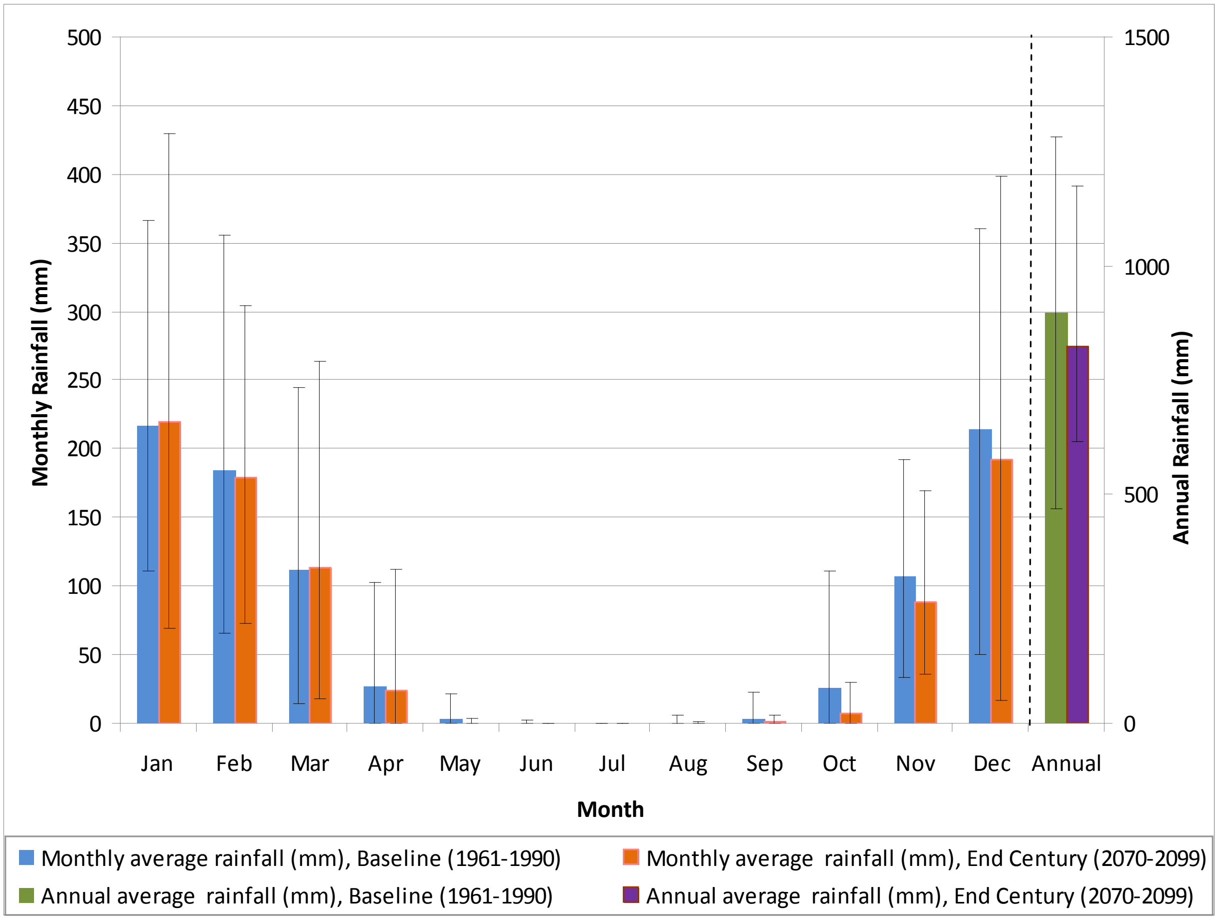
Source: Thurlow, et al., 2009.

Analysis of potential climate change impacts by AEZ is summarized in Zambia's National Adaptation Plan of Action (NAPA) (GRZ, 2007). Using the Hadley GCM to evaluate the years from 2010 through 2070 (see Table 2-1), it concludes that all three AEZ's will experience about a 2°C temperature increase by 2070. It also discusses changes in precipitation for each AEZ in terms of annual maximums, minimums, and means; it characterizes specific years for each AEZ that stand out as the wettest or driest.

Consistent with the results of other studies of the region, the climate change analysis completed for this study suggests that average annual precipitation may not change significantly as a result of climate change (as discussed in Section 2.1.2); however, the variability among precipitation events within a year is likely to be substantial (as discussed in Section 3.1). For example, as shown in Figure 4-4, by the end of this century (2070-2099), annual average precipitation in Zone IIa2 is projected to be reduced by about 8% (see secondary Y-axis), from a base period average of about 895 mm to about 820 mm using the ECHAM5 GCM model and the A2 emissions scenario.

When this annual average precipitation reduction is evaluated for individual months, it becomes apparent that most of the reduction occurs during the first half of the primary crop season (September through December); in the second half of the season, the average reduction is negligible. The reductions in precipitation across September and October suggest a decline in rainfall for those months, particularly in light of the larger variability-bars around the average precipitation for those months. It is also worth noting the size of the variability-bars associated with each value; while the annual variability is reduced in the future period as compared to the base period, the variability for December and January increases. September's rainfall is reduced from a very low amount to practically zero; October declines from about 25 mm and a maximum of over 100 mm, to about 10 mm with a maximum of about 30 mm. These changes indicate that maize seed planting should occur later, on average, or that the seeds will require supplemental irrigation for germination.

Figure 4-4: ECHAM5 A2 Comparison of Base Period and Late-century Average Monthly and Total Annual Rainfall



Notes: mm= millimeter
Comparison of monthly and annual average rainfall (mm) of ECHAM5-A2 Scenario at GCM Grid Point #46 (near IT Dam). The lines for each column show the high and low ranges of values.

Figure 4-4 shows results from a single GCM for a single emissions scenario and a single location in the Kafue River Basin. Further model and spatial analysis is recommended to inform adaptation responses across the basin. Nevertheless, this analysis and others support the conclusion of increased variability in future precipitation in significant portions of Zambia. This presents a challenge, especially for rainfed crops such as maize. Adaptation measures can help address this challenge, including options ranging from conservation agriculture, to improved road infrastructure for market access, to integrated water management policy. These and other adaptation options are discussed and evaluated in Section 5.0, Adaptation Options.

Table 4-21 shows the adjusted irrigation and abstraction volumes for projected food security needs for Zambia in the mid- and late-century periods as projected by the MSIOA (World Bank, 2009). These volumes include the consideration of increased evapotranspiration rates associated with increasing temperatures. Because this calculation is for the entire country, the very high water requirements shown for food security would not need to be met solely by the Kafue River. It also may not be necessary to meet these projected needs solely from sources within Zambia.

Table 4-21: Adjusted Irrigation and Abstraction Volumes for Projected Food Security Needs in the Long Term: Mid- and Late-Century Periods

Kafue River Basin	Incremental Irrigated Area (ha)	Cumulative Irrigated Area (ha)	Incremental Volume (cms)	Cumulative cms	Annual Volume (hm^3)	Cumulative Annual Volume (hm^3)
Current Irrigation Needs	40,158	40,158	17.02	17.02	536.90	536.90
Current Irrigation Needs, adjusted for ET_0			19.10	19.10	601.33	601.33
Additional for Food Security	225,709	304,353	86.21	121.20	2,718.7	3,256
Additional for Food Security Adjusted for ET_0			96.56	135.74	3,045	3,646.3

Notes: ha = hectares; cms = cubic meters per second; m^3 = cubic meter; hm^3 = million cubic meter; ET_0 = evapotranspiration.
Source: Modified from tables included in the MSIOA report (World Bank, 2009).

4.2.2 Conservation

The Kafue River Basin has been and continues to be one of the world's richest natural resource areas, and includes numerous fish species, zebra, buffalo, an endemic species of antelope, cheetah, wild dogs, hundreds of plant species, and over 450 species of birds. Data indicate that the Kafue River Basin is an area that provides water for at least one third of Zambia's population and its major industries (Chabwela, 1998). Therefore, conservation and preservation of the basin are extremely important to Zambia and to the numerous economic sectors, citizens, and wildlife that depend on it. Various stakeholders and ZESCO have been significantly involved in studying and working to address conservation issues in the Kafue River Basin since before construction of the IT and KGU dams. A major focus of these conservation efforts have been on the Kafue Flats, which is a unique natural habitat feature in Zambia and important to conservation of natural areas in Zambia.

The Kafue Flats is one of the major wetlands in the country. The Kafue Flats covers about 6,500 km^2 and is extremely flat, with a slope of less than 5 centimeter (cm) per kilometer (cm/km). As a wetland, the Kafue Flats naturally provides for high biological productivity (wildlife), agriculture, fisheries, groundwater recharge, flood control, sediment retention, and tourism (Chabwela, 1998).

As of 2004, approximately 800,000 persons lived in this region in four districts, including the Itezhi-Tezhi, Namwala, Monze, and Mazabuka districts (Nsongela, 2004). Residents of the basin and flats rely heavily on agriculture, fishing, and pastoral activities for their livelihoods. The area includes a number of identified rare and endemic species including: the Kafue Lechwe, Wattled Crane, and large numbers of crocodiles, birds, livestock, and other species. The Lochinvar and Blue Lagoon National Parks lie in the flats (Schelle and Pittock, 2005).

4.2.2.1 Current Conservation Context

Conservation efforts in the Kafue River Basin have focused on regulating the flow of water between the IT and KGU dams in a manner that substantially restores or mimics the natural flow patterns that prevailed before the dams were constructed. These efforts have resulted in the establishment of partnerships between ZESCO, the GRZ Ministry of Energy and Water Development (MEWD), the Zambian Wildlife Authority (ZAWA), local communities, and two private tourism companies. Numerous studies have been conducted by interested stakeholders and worldwide conservation organizations. The main rationale for conservation efforts is that the dams are believed to be the most likely cause of, or have at least contributed to, a number of growing negative impacts on natural resources in the basin over the past 30 years. However, it should be noted that the extent of damages that may have been caused by the dams does not appear to be clearly confirmed (Schelle and Pittock, 2005).

Numerous agencies, not-for-profit organizations, and development projects have studied the ecological and environmental situation in the Kafue Flats, both before the IT dam was constructed and after. These studies generally find that as for most dams, there are both positive and negative economic and social impacts associated with dam construction. A summary of the range of issues that have been identified and studied related to Kafue Flats conservation and management is provided below (Haller and Chabwela, 2009; SWP, 2003; Chabwela and Mumba, 1998; Schelle and Pittock, 2005):

- Changes in vegetation including colonization of parts of the floodplain by an invasive alien plant, *Mimosa pigra*;

- Changes in wildlife patterns caused by the dams and other development factors; poor and erratic rainfall over time has exacerbated breeding and habitat issues;

- Increases in tick populations that threaten cattle (the ticks are no longer washed away during floods on an annual basis and can spread infections among cattle);

- Uncertainty of flooding, which is a major disturbing factor to human settlements;

- Rapid population influxes, which have been connected to:

    - Development of national parks and commercial agriculture which inhibit use of the land and access to areas needed for pastoral activities
    - Immigrant groups (seasonal fisherman, commercial hunters, and absentee herd owners) that take economic value away from local residents
    - Water quality issues that impact water availability in the flats (e.g., cholera and schistosomiasis)
    - Pollution associated with mining, industrial, and agricultural uses of water impact water quality in the flats, causing high eutrophic levels, increased heavy metal concentrations, and decreasing fish catches and fish sizes and increasing plant growth;

- Institutional weaknesses and population growth are stressors;

- Decreases in populations of the Kafue Lechwe from about 90,000 to about 37,000 by 2005; reductions in the available surface area of grazing lands; and increases in cattle disease have been observed;

- Reductions in fisheries (largely due to loss of fish breeding grounds) but also likely exacerbated by unsustainable fishing methods. Annual catches of fish in the IT reservoir and Kafue Flats have been documented at approximately 2,000 tonnes and 7,000 tonnes, respectively. This includes numerous small-sized fish because of the greater use of small mesh nets. Fishing efforts have more than doubled in recent years (SWP, 2003); and

- Disruption of traditional communal approaches to common property governing access to fisheries, wildlife, and pasture and a resulting situation with some areas of open access and some areas of partial privation (both of which drive unsustainable use of the commons).

When the IT reservoir was designed, it was sized to allow extra capacity for conservation releases, an approach that was unusual in hydropower design at the time and which recognized the unique natural value of the Kafue Flats (Beilfuss, 2001; World Bank, 2009). This made the IT dam one of the first dams that considered managed flood releases at the design stage (Schelle and Pittock, 2005). However, in practice, these releases are not consistently implemented. In addition, in response to severe droughts in 1991 the operating regime of the IT reservoir was modified to account for recurring droughts. In terms of flood dynamics, the new rules were found to be an improvement because they flooded a larger area in the wet season; while on the other hand, a larger area went dry in the dry season. Overall, the regime was still far from mimicking natural flows and did not allow for a freshet release in the wet season (Schelle and Pittock, 2005).

More recent studies indicate that conservation release schemes should be modified to increase releases and extend their timing and duration (similar to conservation scenarios C-2 and C-3 included for this study). Data from pre-2000 indicate that the mean flow through the Kafue Flats was 248 cms after the dam was constructed in 1977, which is less than before the dam was constructed (286 cms) (Chabwela and Mumba, 1998). Studies in the late 1970s included water balance estimates for the Kafue Flats estimating that the flats received 795 mm in mean annual rainfall, had water inflow from streams such as Nanzhila and Nangoma, received water from groundwater to surface water discharges, and obtained water from the IT reservoir through a mean discharge of 314 cms; studies also attempted to quantify impacts such as infiltration, evaporation, evapotranspiration, watershed leakage, and water use. At the time, evapotranspiration from the flats was estimated at 1,000 mm per year (Chabwela and Mumba, 1998). In more recent times, the mining industry has become a source of releases of water to the Kafue River, which eventually discharges into the flats; however water quality impacts are a concern for such industrial discharges.

A summary of more recent conservation efforts in the Kafue River Basin include:

- Extensive modeling work and re-establishment of hydrological monitoring stations (in place as of 2005), with detailed studies continuing;

- Development of more positive working relationships as the WWF, MEWD and ZESCO have been cooperating to address integrated water management planning;

- An Integrated Water Resources Management effort for the Kafue Flats has been part of WWF efforts under the Partners for Wetlands Project – however, local partner participants, including that of ZESCO, has not been consistent. As of the early 2000s, efforts were underway to continue to strengthen local relationships (Schelle and Pittock, 2005);

- Implementation of the Partners for Wetlands Project in Zambia started in 2000 and has had mixed involvement from ZESCO (Schelle and Pittock, 2005);

- Recent studies have indicated that more water should be released from the IT during the months of January and February (Schelle and Pittock, 2005);

- Work has begun on developing an Integrated Water Management Strategy for the Kafue Flats; the strategy was completed in June 2002 and endorsed by the Zambia MEWD. The strategy identifies four areas of concern: (1) water management issues, (2) nature conservation issues, (3) community-based natural resource management (that recognizes and integrates livelihood and local land tenure;

and increases local participation and input; and (4) legal and institutional framework issues (Schelle and Pittock, 2005);

- ZESCO added an Environment and Social Affairs Unit in 1996;
- ZESCO conducted a Strategic Environmental Impact Assessment (SEIA) in 2002 to 2003, which identified water management in the Kafue Flats as a key priority;
- Planning for implementation of an improved hydro-meteorological network was completed or nearly completed by 2004;
- A Dialogue on Food, Water and the Environment was initiated in 2003, involving 10 international institutions;
- A new operating regime for freshet releases was developed; however, no freshet was released in 2004/2005, because the year was dry;
- More scientific studies are planned to demonstrate that conservation and power can both be accommodated; and
- Cooperation by MEWD, ZESCO, ZAWA, the Chiefdom of Tonga, two private tourism companies, and the sugar industry was initiated to implement various projects to support the environment in the Kafue Flats (for example, sugar farms implementing bio filters to lower nutrient levels).

4.2.2.2 Climate Change and Development Impacts on Future Conservation Efforts

The overall focus on conservation efforts is expected to continue and further studies by various stakeholders are expected to clarify the effects of various flow regimes on ecological conditions in the Kafue Flats area. Some of the negative conditions attributed to the presence of the IT dam include reduced fish spawning areas, reduced grazing areas, and increases in tick populations. Climate change may further exacerbate these impacts; currently however, there is insufficient information to reliably predict how climate changes, which generally are expected to result in increasing flow variability and increased temperatures, will influence (exacerbate/alleviate) all of these conditions.

Ecological concerns regarding fish, vegetation, and wildlife in the Kafue River Basin are expected to focus greater stakeholder attention on conservation efforts and may lead to increased pressure to implement high-volume, longer duration, and regular freshet releases, even during drought years. The legal basis for this potential pressure is found in the Republic of Zambia Water Act, as amended by Act 13 of 1994, which clearly defines three levels of water use as follows:

> "*primary use means the use of water for domestic purposes and the support of animal life (including the dipping of cattle);*
>
> *secondary use means the use of water for the irrigation of land and pisciculture;*
>
> *tertiary use means the use of water for mechanical and industrial purposes or for the generation of power;*"

Given the above, it is important to consider this project's modeling results in relation to freshet releases (C-1, C-2, and C-3), which are the conservation releases proposed for mitigating the negative conditions attributed to development and operation of the IT dam. These modeling results generally show manageable impacts on power at an average annual level across the three power plants, three time horizons for the GCM scenarios; however, they do not reflect the full impacts of proposed conservation releases on power outputs for the greater conservation releases (C-2 and C-3). Operational rules for the reservoir model in this study are based on historic ZESCO operating data and prevent IT reservoir draw down below certain levels (e.g., a certain minimum level of water is maintained in the IT reservoir). In effect, this prevents the full conservation water volumes from being released from the IT dam. The significant withdrawals at the IT dam observed with C-2 and C-3 indicate that these conservation releases conflict with current operating rules designed with a focus on power generation. To assess the complete impacts of C-2 and C-3 on power generation in greater detail, ZESCO could adjust the operating rules set in the model for the IT dam to allow the full volume of C-2 and C-3 to be released. Such model adjustments would allow a more detailed evaluation of how the larger releases of water prescribed by the C-2 and C-3 scenarios could be accommodated, given power generation needs anticipated by ZESCO in the future.

4.2.3 Other Sectors

In addition to the agriculture and conservation sectors, the domestic, commercial, public, and industrial sectors generate water demands that (1) are expected to increase with development and population growth and (2) have the potential to be affected by climate change. These water demand sectors have been previously studied as part of the 2003 SEIA and were considered and modeled as described in Section 3.2. The potential long-term impacts of these water demand sectors, including potential climate change impacts on demand, are analyzed in this section using methodologies independent from those of the SEIA. This provides a basis for evaluating the competing use assumptions modeled for this project, based on the SEIA, and incorporates updated and more recent studies now available.

Section 4.2.3.1 considers domestic, commercial, and public water demand and abstractions and Section 4.2.3.2 considers the mining (all types, including open pit and underground) and industrial sectors. For this study, domestic, commercial, and public water demands are estimated to grow in direct proportion to population growth, while mining and industry water demand are estimated to grow in direct proportion to industrial land area needs. In addition to the impacts of population growth and development, the potential impact of climate change on demand in each of these two other sectors ([1] domestic, commercial and public and [2] mining and industrial) is considered.

4.2.3.1 Domestic, Commercial, and Public Uses

The current combined rate of abstraction for domestic, commercial, and public uses is estimated for the greater Lusaka area in an *Interim Report on "The Study on Comprehensive Urban Development Plan for the City of Lusaka"* (Japan International Cooperation Agency [JICA], 2007) at 110,150 m^3/day (40,204,750 m^3/yr) for a total Lusaka area population of 1,454,243. This provides a per capita annual use rate of approximately 27.6 m^3 (or about 0.875 cms per million people). This use rate was reduced by 80% to estimate water consumption, because about 80% of the total water abstracted is returned to the river after post-consumer treatment (JICA, 2007). The per capita use rate of 0.175 cms per million people (20% of 0.875 cms per million people) was then multiplied by the 6.25 million people (approximately one half of Zambia's total population [UNPD, 2009]) that are estimated to be living within the Kafue River Basin (Mwelwa, 2004). This results in a total abstraction rate for domestic, commercial, and public uses in the Kafue River Basin for 2007 of 34.7 million m^3/yr (1.1 cms). This estimate is lower than the 7.4 cms usage rate estimated in the SEIA (2003) report; therefore, it appears that conservative assumptions were used in the P-1 scenario for domestic, commercial, and public water uses for the early-century period and was modeled as part of this climate change risk assessment. An escalated rate of 9.1 cms to account for 30% projected growth is included in the SEIA P-1 and I scenarios and modeled for this project across all three time horizons (early, mid, and late-century periods) for comparison to the baseline period.

Based on data from the Population Reference Bureau (www.pbr.org), the total population of Zambia is expected to increase to approximately 29 million in 2050 and approximately 34 million in 2099. Proportionately, this would result in approximately 14.5 and 17 million people living in the Kafue River Basin in the mid- and late-century periods, respectively. If these population levels are reached, the estimated current abstraction rate of 1.1 cms for domestic, public, and commercial water uses is expected to rise to 2.5 cms in the mid-century and 3 cms in the late-century based on population growth in the basin. Table 4-22 summarizes the results of this analysis.

In addition to the projected water use increases associated with population growth, climate change is expected to increase water use due to increases in the needs of the population to replenish the additional water losses through increased perspiration rates, increased water needs for cooling, or water losses that will be associated with higher ambient temperatures. A review of the literature, however, does not provide an estimated percent increase in water use associated with specific temperature increases, such as the 3°C or 6°C projected from this study's analysis (see Appendix A-1). Therefore, the percent rise in temperatures was used as a proxy for the percent rise in increased water consumption for domestic uses. This was accomplished by assuming a nominal average temperature of 28°C to calculate increases of 10.7% (3°C /28°C *100) in the mid-century and up to 21.4% (6°C /28°C *100) in the late-century period, corresponding to the percentage increases in temperatures for those two time periods.

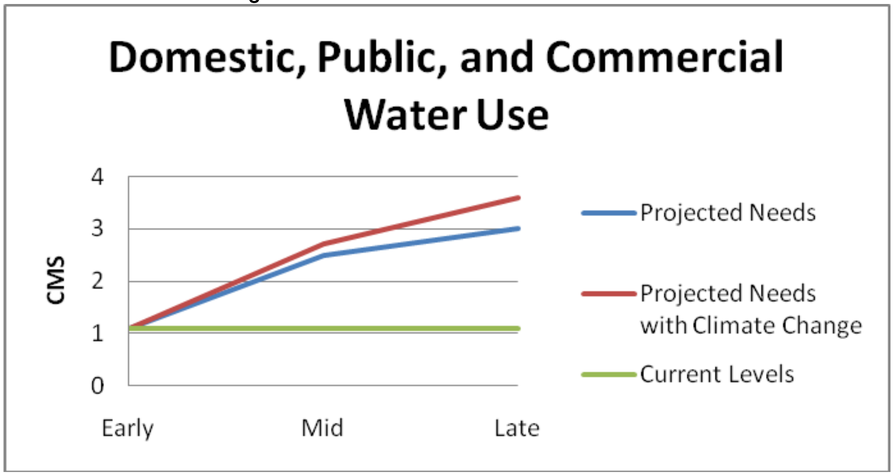
Table 4-22: Current and Projected Populations and Domestic, Public, and Commercial Water Abstraction Rates in the Kafue River Basin with and without the effects of Population Growth and Climate Change

Kafue River Basin	Early 21st Century (2010-2039)	Mid 21st Century (2040-2069)	Late 21st Century (2070-2099)
Population	6.25 million	14.5 million	17 million
Per capita usage (per million people)	0.175 cms		
Water abstraction rate adjusted for population growth	1.1 cms	2.5 cms	3.0 cms
Water abstraction rate adjusted for climate change	1.1 cms	2.7 cms	3.6 cms

Notes: cms = cubic meters per second.

The Table 4-22 estimates of withdrawals for domestic, public, and commercial water abstraction with and without population change reach an upper limit of 3.6 cms in the late 21st Century. This high-end estimate is lower than the domestic withdrawal estimate of 7.4 cms for current domestic water use found in the SEIA 2003 report and used for this study's hydrologic modeling (see conservation/development scenarios). Therefore, the modeling assumptions on domestic water use appear to be conservative in their assumptions. The results of these increases on cumulative water demand are shown in Figure 4-5.

Figure 4-5: Comparison of Future Water Demand for Domestic, Public, and Commercial Uses With and Without the Effects of Climate Change



Notes: cms = cubic meters per second.

As shown Figure 4-5, the impact of population growth (either with or without climate change) on domestic, commercial, and public water needs is not expected to be significant in the early-, mid-, or late-century periods; in fact, even with the increases, the abstraction rates fall below those used as inputs to the modeling results discussed and modeled in Section 3. Therefore, the modeling in Section 3 incorporates conservative estimates in considering future potential water use for domestic, commercial, and public water needs.

4.2.3.2 Mining and Industrial Uses

The abstraction rate for industrial uses for 2007 was estimated for the greater Lusaka area at108,000 m^3/day (which is 39,420,000 m^3/yr or 1.25 cms) for a total estimated population in that area of 1,454,243 (JICA, 2007). Approximately 20% of this flow (0.25 cms) is estimated to be consumed, and the rest is estimated to return to the river after treatment. This estimate is based on a total industrial land area of 1,350 ha, which amounts to a per capita industrial land area of about 930 ha per million people, and an estimated average daily industrial usage rate of approximately 21,900 m^3/ha (80 m^3/day/ha). The average industrial usage rate of 80 m^3/day/ha was based on existing industries, which tended to be heavy water users, and it was projected that future industrial growth would involve more moderate and light industrial water usage rates. Therefore, a lower usage rate of 60 m^3/day/ha was selected to represent the more moderate use of water expected by future industrial growth.

By applying these estimates to the current and projected population figures in the Kafue River Basin, the estimated current (early-century), mid-century, and late-century estimates of water demand for industry and mining were calculated and are shown in Table 4-23.

In addition to the projected water abstraction rates associated with population growth, climate change is expected to increase water usage due to increases in the evaporation rate for water withdrawn for industrial purposes and potential additional needs (for example, increased cooling needs) that can be associated with higher ambient temperatures. A literature review did not indicate specific percentage increases have been developed for industry water use in light of increasing temperatures. In lieu of reliable estimates for increases that could result from a 3°C rise in temperatures in the mid-century period and a 6°C rise in the late-century period, a rate of increase due to climate change was assumed to be half of the increase in the evapotranspiration rate that was estimated for irrigation in the MSIOA study. This assumption results in a 3% increase in demand in the mid-century period associated with climate change and another 3% in the late-century period associated with climate change.

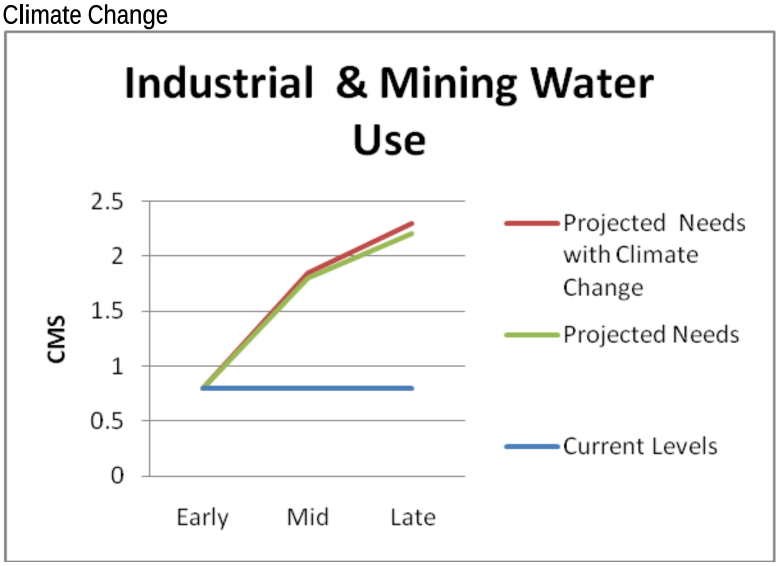
Table 4-23: Current and Projected Populations and Mining/Industrial Water Abstraction Rates in the Kafue River Basin with and without the Effects of Climate Change

Kafue River Basin	Early-Century (2010-2039)	Mid-Century (2040-2069)	Late-Century (2070-2099)
Population	6.25 million	14.5 million	17 million
Per capita industrial land usage (per million people)	930 ha		
Area of industrial land use	5,812 ha	13,485 ha	15,810 ha
Projected industrial water use rate per day, per hectare	60 cms		
Water abstraction rate adjusted for population growth	0.8 cms	1.8 cms	2.2 cms
Water abstraction rate adjusted for climate change	0.8 cms	1.85 cms	2.3 cms

Notes: cms = cubic meters per second.

The "water use rate adjusted for climate change" reached in the late century (2.3 cms) is lower than the estimate of 2.7 cms for current industrial and mining water use found in the SEIA 2003 report and used in this study's modeling assumptions (Section 3.0). Figure 4-6 summarizes the estimated impacts of the water abstractions for mining and industrial use with and without climate change impacts.

Figure 4-6: Comparison of Future Water Demand for Mining and Industrial Water Uses With and Without the Effects of Climate Change



Notes: cms = cubic meters per second.

4.2.4 Cumulative Results

The preceding subsections evaluate how growth and climate change impacts may increase water abstractions required for the agricultural, conservation, domestic, commercial, public, mining, and industrial sectors within the Kafue River Basin. Table 4-24 summarizes the cumulative impacts on the water demand across the time horizon for this study, based on the current baselines, projected increases in population or economic growth, and projected increases estimated for climate change impacts. Note that because "conservation" is not a consumptive use, its abstraction impacts are shown as zero.

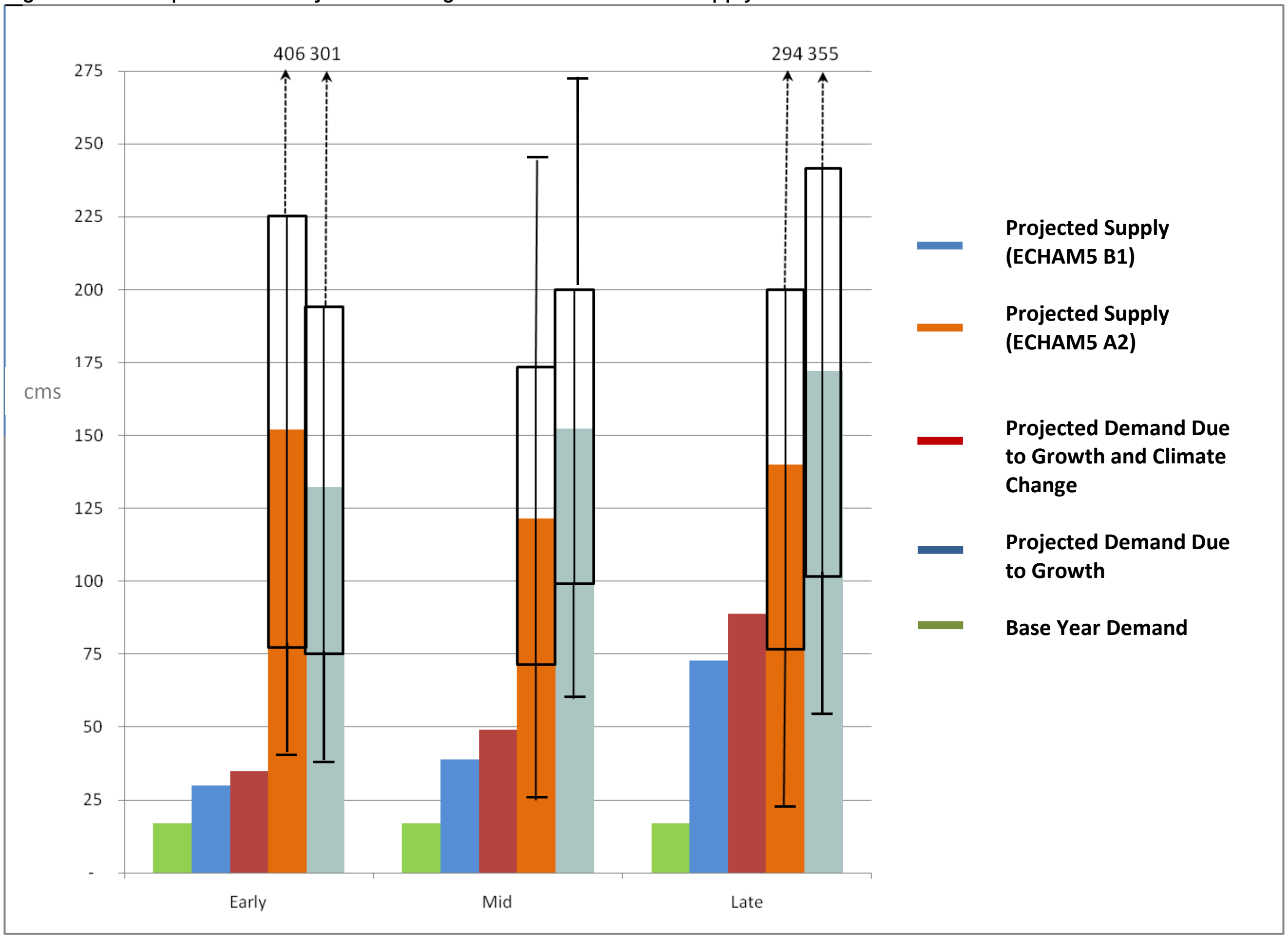
Table 4-24: Current and Projected Water Abstraction Rates (cms) in the Kafue River Basin for All Sectors with and without the Effects of Climate Change

Sector	Early 21st Century (2010-2039)	Mid 21st Century (2040-2069)	Late 21st Century (2070-2099)
Agriculture			
Baseline	17	17	17
Projected Needs without CC	17	23	35
Projected Needs with CC	17	26	40
Conservation			
Baseline	0	0	0
Projected Needs without CC	0	0	0
Projected Needs with CC	0	0	0
Domestic, Public, and Commercial			
Baseline	1.1	1.1	1.1
Projected Needs without CC	1.1	2.5	2.7
Projected Needs with CC	1.1	3.0	3.6
Mining and Industrial			
Baseline	0.8	0.8	0.8
Projected Needs without CC	0.8	1.8	2.2
Projected Needs with CC	0.8	1.85	2.3
Totals			
Baseline	**18.9**	**18.9**	**18.9**
Projected Needs without CC	**18.9**	**27.3**	**39.9**
Projected Needs with CC	**18.9**	**30.8**	**45.9**

Notes: cms = cubic meters per second. CC = climate change.

Figure 4-7 shows the impacts of three levels of projected water use in the lower set of lines and projected supply in the upper pair of lines. This allows for comparison of the projected "high" and "low" water supply results, from the ECHAM5/A2 and ECHAM5/B1 scenarios with the estimated water demands. The area in the graph between supply and demand represents the water supply available to KGL for electricity generation.

Figure 4-7: Comparison of Projected Average Annual Demand and Supply of Water in the Kafue River Basin



Note: cms = cubic meters per second.

The sector-based analysis in this section for agriculture, conservation and other uses, validates the assumed water volume requirements used in the modeling effort for other uses across the early- and mid-century periods. The combined volumes used for the P-1 and I-10 scenarios, ranging from 23.4 cms for P-1 to 67.5 cms for I-10 agriculture, domestic, mining, and industrial use, align with the range of volumes estimated in this section. Figure 4-7 illustrates that cumulative demands in future periods may exert significant pressure on the ability of ZESCO to maintain the same level of power generation that is expected in the earlier time periods, while addressing increasing water demand needs and more stringent requirements for conservation releases.

Given the evolving nature of approaches that consider climate change impacts on water needs , uncertainty is associated with the three sectors considered in this section (agriculture, conservation, other uses). Uncertainty associated with modeling and analysis is presented in Section 7 of this report. specific to these sector analyses?

5. Adaptation Options

As identified in numerous studies and through this project's assessment, climate change will present many challenges to the natural and economic systems in Zambia, affecting ZESCO directly through increased variability of flow in the Kafue River. In addition, increased temperatures combined with anticipated increases in precipitation variability may exacerbate natural hazards, such as flood, drought, landslide, wildfire and erosion. These natural hazards can impact ZESCO operations and ZESCO customers and stakeholders. Anticipated increases in temperature and changes in precipitation, combined with increasing or known development plans and population growth, likely will increase water demands for irrigation, conservation releases, and other sectors. The ZESCO hydropower system, therefore, is likely to be impacted by climate change, development, population growth, and food security needs.

Effective responses to these challenges must be identified, evaluated, prioritized, and implemented in a manner that achieves two primary goals: (1) address the most threatening and urgent concerns as promptly and effectively as possible and (2) implement those responses that have multiple benefits and/or are most cost-effective in order to minimize overall adaptation costs and maximize benefits. This section identifies adaptation goals that build on the modeling and other risk considerations of this study, other available information, and existing adaptation frameworks. This section provides a framework for consideration of adaptation strategies that can be refined with ZESCO and stakeholder input over time. Stakeholder input is important when planning adaptation options to ensure they fit well within the local context and accurately represent and address current and evolving local conditions.

Section 5.1 identifies and presents adaptation goals that are based on the modeling and risk assessment efforts implemented as part of this study. The goals are focused on the steps ZESCO may take to adapt to climate change using its own assets, while also supporting country-wide adaptation initiatives which have been outlined in the NAPA and those options that will benefit ZESCO, its customers, and area stakeholders. Section 5.2 presents adaptation strategies to meet the adaptation goals and provides and implements a framework to evaluate and prioritize the adaptation strategies.

5.1 Adaptation Goals

This subsection presents adaptation goals identified based on a review of information collected and generated (through modeling) for this study. These adaptation goals address priority risks identified by the study based on climate change impacts on energy production, combined with the direct and indirect impacts of climate change and development on natural hazards and various societal and economic sectors. The following three adaptation goals have been identified for further investigation in Section 5.2:

1. Reduce losses to ZESCO from drought and precipitation variability
2. Reduce losses to ZESCO from flood-induced landslides/mudslides
3. Mitigate reduced flow to ZESCO through improved agricultural methods

Although drought is not currently impacting power generation, the modeling for this study indicates that drought and precipitation variability (or decreases in precipitation shown for some models), combined with other water uses and conservation needs, may negatively impact water available for power generation in the future. This could decrease power generation in the future, compared to the present plans, during a future when power demand will be greater, through population growth, increasing sector needs, and other causes. Therefore, the potential for drought and precipitation variability warrant planning efforts to prevent losses to ZESCO.

A review of the risk assessment results shows that damage from flood-induced mudslides/landslides has already impacted ZESCO facilities; likely this natural hazard will be exacerbated by climate change and further development of additional hydropower systems along highly sloped gorges (e.g., KGL). Addressing landslide/mudslides was selected as an adaptation goal because adaptation will reduce losses that are likely from such events either with or without additional exacerbation from climate change impacts.

Given food security needs, the economic importance of agriculture in the Kafue River Basin, potential increases in local agriculture (family and commercial), agriculture's large percent of water use (75% of water demand), and the potential impacts of climate change (increased temperatures, precipitation variability, and changes in precipitation peaks), water demands for agriculture in the area likely will draw water away from ZESCO operations in the future. While the primary water demand is from agriculture, needs for conservation, public, and industry uses also would increase water abstractions and impact the timing of releases. Working with area stakeholders on water issues, with a strong focus on agriculture should help to reduce unplanned or negative impacts on ZESCO operations. Section 5.2 provides a range of adaptation strategies for each of these goals and a preliminary evaluation of priorities.

5.2 Adaptation Strategies

This subsection presents and evaluates adaptation strategies that support the three adaptation goals identified in Section 5.1. Several strategies are initially proposed for each goal, because (1) the adaptation strategy screening process usually removes some strategies from further consideration, and (2) concurrent and coordinated implementation of several promising strategies often helps to achieve an adaptation goal.

Potential adaptation strategies have been identified and evaluated for each of the three adaptation goals. These strategies were first categorized using the "POSE" approach developed by USAID (USAID, 2007): physical, operational, social, and economic (POSE). The adaptation strategies were then screened using criteria developed by the U.S. Federal Emergency Management Agency (FEMA). The seven criteria are: social, technical, administrative, political, legal, economic, and environmental (STAPLEE). FEMA uses these criteria to evaluate potential hazard mitigation options; they are described in detail in FEMA publication 386-3 (FEMA, 2003). The criteria used for the screening effort are summarized below:

- **S**ocial: Adaptation strategies are acceptable to ZESCO and customers if they do not adversely affect a particular segment of the population; do not cause relocation of disadvantaged people; and if they are compatible with social and cultural values.
- **T**echnical: Adaptation strategies are most effective if they are technically feasible; provide long-term reduction of losses; and have minimal secondary adverse impacts.
- **A**dministrative: Adaptation strategies are administratively easier to implement if ZESCO has the necessary staffing and funding, and can address the necessary maintenance requirements.
- **P**olitical: Adaptation strategies can be politically successful if all stakeholders have been offered an opportunity to participate in the planning process and if there is sufficient political and public support for the strategy.
- **L**egal: For proper implementation and enforcement of an adaptation strategy, it is critical that implementing and enforcement agencies are in place, have the legal authority to act, and support the strategy.

- **E**conomic: Budget constraints can significantly deter the implementation of adaptation strategies, therefore it is important to evaluate whether the strategy is cost-effective, if there are available funding sources, and if the strategy contributes to other economic goals.

- **E**nvironmental: Sustainable adaptation strategies do not have an adverse effect on the environment, comply with national regulations, are consistent with the country's environmental goals, and have benefits while being environmentally sound.

An evaluation rating system was developed and is presented in Table 5-1.

The STAPLEE evaluations for the three adaptation goals represent preliminary assessments which serve as examples for the process. They should be modified further based on ZESCO and appropriate stakeholder input at the local level. In these preliminary evaluations, some strategies are scored with a downward arrow to indicate possible negative impact. For example, conventional (fossil) energy source implementation would have an adverse impact on the environment as compared to renewable energy sources; other strategies may be relatively costly or technically challenging. An upward arrow represents likely benefits or positive traits that the strategy may have for the criterion being evaluated. For example, implementing some of the strategies may be beneficial to the environment, be low cost or yield social benefits. A "U" indicates that the directional effect for the strategy on a criterion is unknown at this time; each of these preliminary rankings may change with additional information. In the final column, "Total", the net impact of the individual rankings is represented and can be positive, negative or unknown/incomplete. Strategies with a positive ranking in the "Total" column should be retained as a potential recommendation pending further consideration, as needed.

After evaluation against the criteria, ratings for each adaptation strategy were assigned as follows: (1) Beneficial (B) = +; (2) Insignificant (I) = 0; (3) Adverse (A) = . Ratings of Unknown (U) were not assigned a numerical weighting. As such, they do not have any effect on the overall score of each strategy; however they do show a deficiency in data that, when resolved, may affect the overall priority of the adaptation strategy. Therefore, the ranking results in this section should be viewed as preliminary data and should not be applied to long-term planning efforts until additional data (acquired, for example, through stakeholder input) have allowed the U ratings to be replaced a STAPLEE ratings with a B, I, or A value. Input from ZESCO and appropriate stakeholders is recommended in order to address the items with U rankings, evaluate other ratings, and identify/confirm the most appropriate strategies based on current information and priorities.

A quantitative evaluation approach also has been implemented based on a benefit-cost analysis of the specific strategies. Avoided losses were calculated for current conditions and for future conditions subject to climate change. There are some strategies which are cost-effective under current conditions and have been described as "no regrets". Strategies also will be evaluated based on future conditions described in three models GCMs, two emission scenarios, and three time horizons.

Table 5-1: Adaptation Strategy Ranking Framework

Evaluation Criterion and Ratings			
Adverse (A)	Insignificant (I)	Beneficial (B)	Unknown (U)
Social			
Strategy is not acceptable to the customers because it may adversely affect a particular segment of the population; or there is potential to cause relocation of disadvantaged people; or it is not compatible with social and cultural values.	Strategy is not expected to result in significant effects on social or cultural values.	Strategy is acceptable to the customers because it significantly benefits the customer community as a whole; and promotes the local social and cultural values.	The effects of the strategy on social and cultural values are unknown.
Technical			
Strategy is not technically feasible; or does not provide long-term benefits; or has adverse secondary impacts.	Strategy is not expected to result in significant effects on technical issues.	Strategy is easy to implement, provides long-term benefits, and has no adverse secondary impacts.	The technical feasibility and/or the potential for secondary adverse impacts of the strategy are unknown.
Administrative			
Staffing and/or funding will be insufficient; or maintenance *requirements* will be beyond ZESCO's capabilities; such that it jeopardizes the success of the strategy.	Strategy is not expected to result in significant effects on administrative issues.	There is sufficient staffing, funding, and maintenance capabilities to meet the requirements for the strategy to be successful.	The effects of the strategy on administrative issues are unknown.
Political			
Most customers are strongly opposed to the proposed strategy or there may be significant political opposition to the strategy.	Strategy is not expected to result in significant effects on political issues.	Most customers and political stakeholders strongly support the strategy.	The effects of the strategy on political issues are unknown.
Legal			
Proper implementation and enforcement of the proposed strategy is jeopardized due to a lack of jurisdiction or legal authority.	Strategy is not expected to result in significant effects on legal issues.	Sufficient jurisdiction and/or legal authorities exist such that proper implementation and enforcement of the proposed strategy is likely to be successful.	The effects of the strategy on legal issues are unknown.
Economic			
Budget constraints will significantly deter the implementation of the strategy. Strategy cost outweighs the benefits.	Strategy is not expected to result in significant effects on economic issues.	Strategy is significantly cost-effective; or will result in significant economic benefit for ZESCO.	The effects of the strategy on economic issues are unknown.
Environmental			
The strategy has an adverse effect on the environment; or does not promote environmental sustainability; or does not comply with environmental regulations; or is not consistent with the country's environmental goals.	Strategy is not expected to result in significant effects on environmental issues.	Strategy may have a beneficial effect on the environment, promotes environmental sustainability, complies with environmental regulations, and is consistent with the country's environmental goals.	The effects of the strategy on environmental issues are unknown.

The following subsections present, and provide evaluations of, adaptation strategies for each of the three adaptation goals identified in Section 5.1.

5.2.1 Adaptation Goal #1: Reduce Losses to ZESCO from Drought and Precipitation Variability

The risk assessment described in Section 4 identified drought and precipitation variability as major concerns for ZESCO. Drought and precipitation variability will directly affect ZESCO as well as the rest of the country; therefore, any efforts by ZESCO to adapt to drought and precipitation variability should compliment national efforts described in the NAPA.

Several strategies that could help reduce losses to ZESCO are presented below. Some of these strategies may be undertaken by ZESCO directly; others would require a more coordinated effort with other government agencies.

Strategy #1: Integrate Water Management Approaches and Develop Water Regulations

Developing an integrated water management plan, which addresses both groundwater and surface water combined with adopting enforceable water regulations would help ensure that water use is managed within the basin to provide for food security, hydropower operations, conservation, and other needs. The goal of an integrated water management plan is to reduce the depletion of ground and surface water and protect the interests and rights of lawful users of the same water source, as well as to balance and reconcile alternative uses of water resources in the basin. This becomes particularly important in light of growing demand for water through population growth, development, and climate change impacts.

These types of integrated water management approaches and plans can involve a multi-tiered approach to water withdrawal limits. The first tier serves as a warning that a sub-basin is "potentially stressed." In potentially stressed sub-basins, applicants for new or expanded water withdrawals should be required to implement one or more programs to lessen adverse impacts of additional withdrawals. These programs could include: conjunctive use of ground water and surface water, expanded water conservation programs, programs to control ground water infiltration, artificial recharge, and spray irrigation. In addition to prioritizing water withdrawals, reduced use of water would need to be achieved, beginning with relatively low-cost programs that reduce waste (such as leak detection and repair programs), and continuing by encouraging or requiring conservation and efficiency improvements across all types of users. Such approaches have been effectively implemented in many countries, through awareness campaigns, rebates, and the development of an appropriate pricing signal for water.

ZESCO would be in a position to support such water management planning and regulations, building on the results of this study and other studies. The political will would need to be present and other agencies would be needed to pass, enforce, and promote (through outreach and training) regulations that improve standards, processes, and technologies, for efficiency of industrial and urban water use and discharges. The costs to implement a comprehensive water management program at the national level involving several government agencies needs to be investigated further.

Strategy #2: Implement New Land Use Management Planning and Regulations

Land use planning encompasses various disciplines which collectively maximize the efficient, sustainable, and ethical use of various types of properties. Some of the outputs of land use planning are new land use regulations and enforcement strategies needed to support them.

Land use regulations could be designed to ensure there is enough water for the hydropower operation by optimizing uses by other sectors (e.g., agricultural, mining, industrial, and livestock practices). There are other significant benefits to the country as a whole. Over 60% of Zambians live in rural areas, with the majority depending on subsistence, rain-fed agriculture and a single maize harvest for their livelihoods. This makes them very vulnerable to climate-related natural calamities and disasters, such as floods and droughts, which directly affect agricultural productivity (NAPA, 2007). An integrated, sustainable livelihood project (such as that recommended in the NAPA) would enhance people’s capacity to cope with and adapt to these natural calamities in vulnerable areas. The major sustainable livelihood interventions for coping with these natural calamities include land use planning for the following: water management, crop and livestock production, growing of crop varieties and fruit trees, rearing of animal breeds that are drought tolerant, using agro-forestry practices, fish farming and processing, increasing market access, and addressing cross cutting issues such HIV/AIDS, gender and the environment.

Development conditions affect the prevalence of HIV and the impact of AIDS and other diseases on individuals, households, and communities. Poor housing and settlement conditions have been correlated with high HIV prevalence. Inadequate access to services, to secure tenure, and to safe and affordable housing makes HIV positive individuals and HIV negative individuals alike particularly vulnerable to opportunistic infections.

ZESCO is in a position to support land use planning and regulations using the results from this study and others. Political commitment would need to be present and other agencies would be needed to pass, enforce, and promote the regulations (through outreach and training). The costs to implement a comprehensive land use program at the national level involving several government agencies has been estimated to be 1.2 million USD (NAPA, 2007). In all land use planning, the priority for food security must be kept in mind.

Strategy #3: Expand Reservoir Capacity

The IT reservoir could be expanded by increasing the size of the dam and flooding the areas around the current reservoir. This strategy would provide a larger water supply to draw on during drought conditions and would allow additional water to be captured during flood or high precipitation events or periods. The climate change projections indicate mixed results for average annual precipitation (of six GCMs, four indicated decreases in average annual rainfall and two indicate increases). However, flow modeling and spatial and temporal analysis of precipitation changes indicate that variability and extreme events may be more likely in the future. Other studies also indicate changes in precipitation are anticipated due to climate change (Kabange, 2008).

It is difficult to estimate the benefits of this adaptation strategy at this time, because records do not provide much data about instances where ZESCO has incurred losses due to low water supply in the reservoir. However, as described in Section 4.1.2.3, extrapolation from a major drought in 2005 suggests that a 20% reduction in generation over a six-month period could equate to financial losses of over USD 26 million. At other times, drought conditions may have been managed by reduced conservation releases. While the size of the IT reservoir includes extra capacity to accommodate conservation releases, these releases do not appear to be consistently implemented over time (Beilfuss, 2001; World Bank, 2009). This may result from management decisions that prioritize power production over freshet releases during low precipitation or drought-like conditions. Additional storage might improve reservoir capacity so that future water needs for power and for freshet releases could both be met during drought or variable precipitation events in the future. The reservoir operation model used for this project (HEC ResSim) could be used to assess the impact on the average energy generation of IT, KGU and KGL that might result from reservoir expansion at the IT dam, as well as to model the energy impacts of full conservation releases (as discussed in Section 3.2).

The costs and negative impacts of increasing the IT reservoir are easier to identify and quantify than the potential benefits. There are construction costs associated with increasing the dam size, costs for relocating people residing next to the reservoir, and costs for moving infrastructure, including roads and utilities that would be inundated. There are also environmental impacts from flooding a whole new region. A detailed environmental impact assessment would be needed in order to identify the impacts to the people, economy, vegetation, and wildlife around the reservoir. Such an assessment is beyond the scope of this study; however, models and outputs elaborated here can be used as a base for further research.

Strategy #4: Conserve Energy

An approach to prepare for potential future water shortages based on climate change or competing uses, is a focus on energy conservation. If improvements in energy efficiency can be achieved, growth will require less energy per unit increase in GDP than if current energy efficiencies remain in place. Commercial agriculture, industry, and mining might be areas that could achieve energy conservation. Over time, as domestic energy use increases, domestic energy efficiency could be an appropriate focus area.

Strategy #5: Diversify Energy Sources

Wind or solar energy sources can be developed as another strategy, to supplement hydropower energy. Alternative energy sources can help supplement hydropower generation during drought events, or in the future if dry periods combined with other water demands create a reduced flow for hydropower generation. These alternate energy sources are expensive and may not be economically viable in the present. However, funding for such technologies may be available through international donor agencies or other sources. In addition, there may be opportunities for small-scale power generation for villages or at the individual home level. Additional investigation into the types of technologies available and their technical feasibility for local power generation would be required. In addition, traditional and generally cheaper, fossil-fuel driven energy sources may also be used as backups to hydropower generation, but in contrast to hydropower or alternative energy sources would create more greenhouse gas emissions.

Strategy #6: Implement Pumped Storage Electricity Generation

Pumped storage hydropower implements load balancing. This management method stores energy in the form of water, pumped from a lower elevation reservoir to a higher elevation reservoir. At times of low electrical demand, excess generation capacity is used to pump water into the higher reservoir. When there is higher demand, water is released back into the lower reservoir through a turbine, generating electricity. Reversible turbine/generator assemblies act as pump and turbine. Some facilities use abandoned mines as the lower reservoir, but many use the height difference between two natural bodies of water or artificial reservoirs. Pure pumped-storage plants just shift the water between reservoirs, but combined pump-storage plants also generate their own electricity like conventional hydroelectric plants through natural stream-flow.

Taking into account evaporation losses from the exposed water surface and conversion losses, approximately 70% to 85% of the electrical energy used to pump water into elevated reservoirs can be regained (ESA, 2009). The technique is currently the most cost-effective means of storing large amounts of electrical energy on an operating basis, but capital costs and the presence of appropriate geography are critical decision factors. A new concept, hydroeolic generation, uses wind turbines (or solar) power to drive water pumps, in effect creating an "energy storing wind (or solar) dam." This could provide a process for transferring water between bodies that does not rely on electricity generated by the hydropower system (Bueno, 2004).

In order for ZESCO to implement this strategy, the area around the current plants would need to have ideal conditions – sufficient area for another reservoir or abandoned mines and proper elevation changes. An initial review of the area shows that an abandoned mine does not appear to be in the vicinity; however, there would probably be sufficient area to construct another reservoir. Even if technically feasible conditions exist, implementation would be costly. The construction costs would run between $1.5 million and $2.25 million USD. In addition, the social, economic, and environmental impacts of developing another reservoir would need to be studied. The current average annual loss for drought was calculated to be $2.1 million USD. If pumped storage can reduce this value by $1.5 million, the benefit (losses avoided) would be equal to the costs under present conditions. However, looking at the future with increased precipitation variability, the average annual loss goes up to $3.9 million USD in one early-century scenario (IPSL Scenario A2) which has been calculated in Appendix A6. Additional modeling may show a substantial benefit with this investment.

Strategy #7: Develop a Drought Management Plan

A drought management plan evaluates the drought hazard and develops thresholds for response actions. The includes an analysis of the drought hazard, identification of drought thresholds and time periods, delineation of clearly defined drought stages, development of response actions, dissemination of drought information, and assessment of penalties for noncompliance with any drought mandates. The drought threshold determination incorporates considerations such as water levels, recent precipitation, reservoir height, and flow rates. These thresholds should be forecasted and monitored on a periodic basis and evaluated more frequently as a drought event unfolds. Stages should be defined with corresponding strategies to be taken by government, industry, and the general public if certain thresholds are met. Strategies could be voluntary or mandatory depending on the stage and severity of the drought. A plan for dissemination of this information should be developed or adopted from the country's emergency management plan. Finally any restrictions on water use (response actions) should be made enforceable in the case of severe droughts.

ZESCO could benefit from a drought management plan and should be part of the development process. It would be a low-cost strategy for ZESCO with long term benefits. ZESCO could also get involved in the dissemination or public outreach component of the plan.

Strategy #8: Implement Public Outreach and Training

Public outreach and training may integrated with the other seven strategies or may be used as a separate strategy. It is important for the public and industry to understand water as a shared resource, opportunities to improve water efficiency use, the potential impacts of climate change and development, and when and how to conserve water. ZESCO could develop training and outreach material as part of a national strategy. Any material ZESCO develops internally should integrate into the national strategy to avoid mixed messages and mal-adaptation. Materials could be developed to focus on different sectors of the economy, different regions in the country, and different individuals. Hands on workshops and technology transfer events also could support adaptation in the country.

Strategy #9: Financial Strategies

Finance poses one of the greatest limitations to climate change adaptation and the ability to mainstream it into national developmental planning. National entities are well aware of their limited financial capacity to address climate change adaptation issues. There is a tendency at the national level to focus on traditional "hard" investments related to community infrastructure, leaving innovative "soft" investments such as changing cropping patterns or irrigation water management programs to international donors. There is a sound rationale—good intra-institutional relations are maintained between national and local farm groups, while directing the consequences of difficult adaptation decisions on the international donors. Nevertheless, there is recognition that the role of international donors will be critically important and have a growing impact on economic and social development on nations most directly affected by climate change. Some of the key financial sources, financial linkages, and funds specifically allocated to address climate change are listed below.

Financial Resources from International Financial Institutions (IFIs): All of the major international donor agencies and banks have begun the process of shifting their lending strategies to address the climate change issues. This includes institutions relevant to ZESCO and agricultural stakeholders, such as The World Bank, the International Fund for Agricultural Development, and the African Development Bank , among others. For projects in the pipeline, the shifting strategy is for the IFIs to mainstream adaptation measures at project design stage. This will be done in close dialogue with the countries, weighing clearly the long term benefits of ensuring climate resilience. This process is referred to as the “climate proofing” of future investments. Several of the IFIs are overviewed below.

Climate Investment Funds: The World Bank, in partnership with the Regional Development Banks, hosts the Climate Investment Funds worth about 6.1 billion USD. The climate investment funds have two main components, the Clean Technology Fund and a number of small funds referred to as Strategic Climate Funds (SCF).

Global Environment Facility: In addition to the CIF, the African Development Bank will leverage additional funds to address the challenges of climate change through the Global Environment Facility (GEF) which has allocated about $250 million per year in projects in energy efficiency, renewable energies, and sustainable transportation. The GEF is also designing a fund dedicated to adaptation which may be worth about 700 million USD. Zambia can also access GEF resources in partnership respectively with UNEP, UNDP and the World Bank. All of these projects have strong linkages with sustainable land and water management.

Multilateral Trust Funds: Zambia can benefit from existing multilateral trust funds, many of which have climate change as its core area of support, such as the Finnish Trust Fund, the U.K. Department for International Development resources, the Danish Funds, and Germany’s Deutsche Gesellschaft für Internationale Zusammenarbeit.

The Clean Development Mechanism: The Clean Development Mechanism of the Kyoto Protocol was created to allow the conversion of GHG emission reductions in developing countries into carbon credits that industrialized countries can use for complying with the emission targets set under the Kyoto. Under the Clean Development Mechanism, projects that reduce greenhouse gas emissions and contribute to sustainable development can earn saleable certified emission reduction credits. Countries with a commitment under the Kyoto Protocol can purchase certified emission reduction credits to meet a portion of their obligations under the Kyoto Protocol. This has consequently generated a huge carbon market that is currently estimated at about US $70 billion USD. There is a very large, and currently untapped, potential for mitigation in the agriculture and forestry sectors in Africa, including Zambia (as discussed in Section 4.2.1), through activities that are not currently allowed under the Clean Development Mechanism, such as avoided deforestation, sustainable agricultural and forestry practices, and soil carbon sequestration.

Strategy Evaluation

<u>Qualitative Assessment</u>

The nine strategies above have been evaluated based on the STAPLEE criteria and have been ranked in Table 5-2. Note that a number of criteria are provided with “U” findings, and are not scored. ZESCO and appropriate stakeholder input at the local level are recommended as adaptation strategies are further evaluated moving forward.

Table 5-2: Adaptation Goal #1 Strategy Evaluation

Adaptation Strategy (Category)	S	T	A	P	L	E	E	Total
Integrate Water Management Approaches and Develop Water Use Regulations (P, O, S, E)	↑	↑	U	U	U	U	↑	+
Implement New Land Use Planning Approaches and Regulations (O, E)	↑	↑	U	U	U	↑	↑	+
Expand Reservoir Capacity (P, O, S, E)	U	↑	U	U	U	U	↓	U
Conserve Energy (P, O, S, E)	↑	U	U	U	→	U	↑	+
Diversify Energy Sources (P, E)	→	↑	↓	U	U	↓	↓	U
Implement Pumped Storage Electricity Generation (P)	U	↓	U	U	U	U	↓	U
Develop a Drought Management Plan (S, O)	→	↑	U	U	U	↑	U	+
Implement Training and Public Involvement (S)	↑	↑	U	U	→	↑	↑	+
Financial Strategies	U	U	U	U	U	U	↑	+

Notes: For adaptation strategy: P = physical; O = organizational; S = social; E = economic.
For evaluation criteria: S = social; T = technical; A = administrative; P = political; L = legal; E = economic; E = environmental;
For ranking: Adverse - ↓; Insignificant = →; Beneficial = ↑; U = unknown.
For outcomes: Unknown = U; Positive = +; Negative = -.

Quantitative Assessment

To determine which strategies are most cost-effective, a benefit cost analysis (BCA) should be undertaken. In Section 4, the present day average annual loss for drought is calculated to be equivalent to USD 2,105,360. To calculate the benefit component of the BCA, the adaptation strategy to be implemented should be studied to determine how much of that average annual loss value will be reduced. The next step would be to calculate the Present Worth Factor (PWF) using the discount factor and lifespan of the structure. The Present Value Coefficient would then be multiplied by the difference in the average annual loss to get the total present value benefit which would then be divided by the cost of the project to get the benefit cost ratio (BCR).

Because the exact costs for some of the strategies are difficult to estimate without conducting a detailed study, the total benefit was calculated to identify the magnitude of costs which should be considered. If the selected strategy reduces the average annual loss to 25% of its current value (USD 526,340), the losses avoided benefit would be USD 1,579,020. If the project has a 50-year lifespan at an 8% discount rate (assuming no annual maintenance cost), then the PWF would be 0.979 and the Present Value Coefficient would be 12.23. The Present Value benefits would be USD 19,311,415. For this example, any project costing less than USD 19 million would be a cost-effective, no regrets strategy

Conducting this analysis using projected climate change, with the maximum average annual loss (MRI, Mid-Century, B1 Scenario) of USD 6,842,421 and the same assumptions above, the present value benefits would be USD 62,762,107. Looking at all the scenarios provides a range from USD 19 million to nearly 63 million depending on which GCM and scenario is being used.

Other Strategies Identified

The following strategy was also identified for Adaptation Goal #1, but was not carried forward for further analysis because it is outside the control of ZESCO.

Implement Inter-Basin Water Transfers: Inter-basin transfers involve projects designed to move water from one catchment to another. The purpose of an inter-basin transfer can be to generate hydropower, to alleviate water shortages in the receiving basin, or both. Inter-basin transfers are often controversial due to their typically large sizes, their costs, and their environmental impacts. While developed countries often have already exploited the most economical sites for inter-basin transfers, many large-scale inter-basin transfers have been proposed in developing countries such as Brazil, African countries, India and China. The transfers have been justified because of increased water demand for irrigation, industry, and municipal water supply; energy needs; climate change; and the desire to hedge against possible droughts. Inter-basin transfers are often large and expensive, involving major infrastructure and in some cases massive uses of energy for pumping. They can also be complicated in legal terms, since water rights are affected, especially if the basin of origin is a trans-boundary river. Furthermore, transfers can have significant environmental impacts on aquatic ecosystems (Ghassemi and White, 2007).

Summary

The results indicate several beneficial, low-cost adaptation strategies may be implemented to adapt to a low or variable flow scenario. ZESCO should work with appropriate government agencies and stakeholders to ensure its interests are represented in any new land use or water use regulations and drought management planning. A priority across all of the options should be protection of the area's population (including food security) and natural assets in the Kafue Flats. Developing and implementing training and public involvement efforts would also be a cost-effective way of helping area citizens prepare for and adapt to changing conditions and to ensure that their input is integrated into adaptation plans moving forward.

The structural strategies have several unknowns which would require additional study in order to determine if they would be cost-effective. Feasibility studies, environmental assessments, and a detailed BCA would need to be conducted before moving forward with any of these strategies. In addition, to support BCAs, it would be useful to have better data on historic drought losses or ZESCO operational revenue losses associated with historic dry periods. It is difficult to determine the potential losses due to drought and other water uses when there is limited data due to few major droughts since the hydropower plant has been operating; additional data for different drought periods would help refine the annualized loss developed for this study.

5.2.2 Goal #2: Reduce Losses to ZESCO from Flood-induced Landslides/Mudslides

The risk assessment identified flood-induced mudslides/landslides as a major concern for ZESCO. A mudslide event caused $1.66 million (USD) in losses to the KGU plant, including: lost power revenue of $1.0 million USD and labor, civil works costs, and electrical and mechanical materials (see Appendix A7). Since the planned KGL plant also will be located in a gorge, landslides will present a risk to that plant as well.

Since landslides are currently impacting ZESCO facilities, this adaptation goal is a "no regrets" option (e.g., it has benefits and would be reasonable even if climate change were not projected to exacerbate the natural hazard). Therefore, it provides a present-day priority. This also is a goal which may not be integrated into national adaptation strategies since the nationwide landslide risk is so low. Since this is the case, ZESCO may need to move forward with implementation of adaption at the facility level. Several strategies have been identified to help reduce losses to ZESCO.

Strategy #1: Stabilize Slopes

Slope stabilization may be accomplished by planting certain types of vegetation, by building man-made structures, or by integrating vegetation and man-made structural elements (such as biotechnical slope stabilization). Vegetative stabilization prevents landslides by intercepting rainfall and allowing transpiration of groundwater; this provides drier soils and reduces potential peak groundwater pressures. Vegetation roots reinforce the soil which increases soil shear strength; tree roots anchor and provide support to the upslope soil mantle through buttressing and arching. The soil cohesion induced by roots helps to prevent shallow landslides but not deeper landslides. The hydrological effect, reducing groundwater pressure, is beneficial to preventing both shallow and deep landslides (Singh, 1997).

Engineered slope stabilization has a negative visual impact on the environment which may be an issue if there are scenic, natural, or geological conservation interests. Vegetative or biotechnical slope stabilization techniques generally are more compatible with the environment. Also, engineered slope stabilization is usually more costly than the vegetative or biotechnical measures. Retaining structures with open grid work or tiered facings benefit from vegetation that binds the soil within and behind the structure (Singh, 1997).

Strategy #2: Improve Elevation Mapping Data

Elevation mapping may be accomplished using various methods including ground-based and aerial surveying. One type of aerial surveying uses Light Detection And Ranging (LiDAR), which is an optical, remote-sensing technology that measures the properties of scattered light to find range and/or other information about a distant target.

Historically, LiDAR has been difficult to implement in Zambia due to competing flight patterns of other aircrafts carrying hunters and tourists. Traditionally, elevation data has been developed for hydropower plants in Zambia using ground teams. A ground-based team approach may be most cost-effective depending on the amount of area to survey. The ground team that will be required to map elevation data in and around the planned KGL site could be expanded to increase the size of the study area and refine elevation data for other existing power stations and other steeply sloped areas of concern.

Elevation mapping does not directly reduce losses, but it provides additional information for decision makers concerning which areas are more susceptible to future landslides and a baseline for considering future development of these areas and identifying changing conditions in areas of concern. For these reasons, data on vegetative cover and soil moisture or slope conditions would also be useful to collect periodically in areas that pose a landslide concern. Data to support the evaluation of landslide potential also includes vegetative cover, hydrology, and previous landslide areas and impacts. This data collection process could be incorporated into other maintenance activities in areas around the power plants. This information provides a basis to focus adaptation strategies on the most susceptible areas and identify any changing conditions that warrant immediate actions.

Strategy #3: Implement Real-Time Monitoring

Real-time monitoring places instruments to measure ground motion and warn personnel in the event of a landslide. The sensors may include rain gauges, tiltmeters, extensometers, inclinometers, and piezometers. Video monitoring also may be used to identify movement. Once predefined threshold values are met or exceeded, the instruments send an alert to pre-identified emergency and management personnel.

Real-time monitoring helps prevent injuries and causalities, but is less effective at preventing damage to facilities than structural adaptation measures. Some other structural adaptation measures, potentially tied to the real-time monitoring alerts, would still need to be implemented to help lessen the impact of a landslide.

Strategy #4: Develop an Excavation and Fill Ordinance

A typical excavation and fill ordinance provides definitions of regulated activities. For example, a “cut” might be defined as any act that cuts into, digs, or moves earth material and “fill” might be defined as any act that deposits or places earth material by artificial means. Similarly, “grading” might refer to any combination of excavation and/or fill. Excavation and fill ordinances are often used to control the initial phases of construction to help build a foundation for a structure or prepare the land around the structure. Moving earth in a landslide hazard zone may increase the potential for landslide risk. By establishing ordinances or rules to prevent excavation and filling in potentially landslide prone areas, a reasonable level of control and awareness is maintained regarding development in these areas. These ordinances can also provide an opportunity to review development proposals in these areas for safety and appropriate mitigation means, where necessary.

These ordinances are a cost-effective way of controlling landslide risk by preventing an increase in natural hazard probability and also mitigating vulnerability by preventing construction in the landslide zone. If ZESCO owns the landslide-susceptible land adjacent to its facilities, it would be easy to restrict excavation and fill on its property – even without a formal ordinance and enforcement effort by the appropriate municipal or national agency. However, this strategy does not prevent damage to structures that are already located in landslide hazard zones.

Strategy #5: Develop Land Use/Building Restrictions

Land use or building restrictions are government ordinances, codes, and permit requirements intended to make the private use of land and natural resources conform to policy standards. Common regulations include: building codes; curb-cut permit systems; historic preservation laws; housing codes; subdivision regulations; tree-cutting laws; and zoning. Building in a landslide hazard zone may increase the potential for landslide risk. By establishing ordinances or restricting activities in landslide-prone areas, the same level of risk is managed.

These ordinances are a cost-effective way of maintaining landslide risk by preventing an increase in natural hazard probability and also mitigating vulnerability by not allowing structures to be built in the landslide hazard zone. If ZESCO owns the landslide susceptible land adjacent to its facilities, it would be easy to restrict building on their property – even without a formal ordinance and enforcement effort by the appropriate municipal or national agency. However, this strategy does not prevent damage to structures already in a landslide zone.

Strategy #6: Develop Training and Response Plans

Training and response plans for the landslide hazard, coupled with response equipment and evacuation plans can assist if a landslide occurs. The training and response plans would focus on ZESCO assets and personnel in landslide hazard areas first and could include some public outreach and training for any residents that live in these areas. It is important for the public and ZESCO workers to understand this natural hazard and appropriate actions to reduce risk, identify natural hazard conditions, and respond should a landslide occur. Such response plans can be developed and implemented at low cost and have significant benefits in terms of protecting equipment and personnel when a natural hazard occurs. Proper response equipment and mitigation efforts also should help the power plants return to operational conditions in a timely manner; reducing potential revenue losses associated with this natural hazard.

Strategy Evaluation

Qualitative Assessment

The six strategies for Adaptation Goal #2 include POSE actions as indicated in Table 5-3. The strategies were evaluated using the STAPLEE criteria and the preliminary ranking results are shown in Table 5-3. Note that a number of criteria are provided with "U" findings, and are not scored. ZESCO and appropriate stakeholder input at the local level are recommended as adaptation strategies are further evaluated moving forward.

Table 5-3: Goal #2 Strategy Evaluation

Adaptation Strategy (Category)	S	T	A	P	L	E	E	Total
Stabilize Slopes (P)	→	↑	U	→	→	↑	→	+
Improve Elevation Mapping (P)	→	↑	U	→	→	U	→	+
Implement Real-Time Monitoring (P)	→	→	U	→	→	U	→	U
Develop an Excavation and Fill Ordinance (O)	→	→	U	U	U	↑	↑	+
Develop Land Use/Building Restrictions (O)	→	→	U	U	U	↑	↑	+
Develop Training and Response Plans (P, O, S, E)	→	→	U	U	U	↑	↑	+

Notes: For adaptation strategy: P = physical; O = organizational; S = social; E = economic.
For evaluation criteria: S = social; T = technical; A = administrative; P = political; L = legal; E = economic; E = environmental;
For ranking: ↓ = adverse; → = insignificant; ↑ = beneficial; U = unknown; + consider further

Quantitative Assessment

To determine which strategies are most cost-effective, a BCA should be undertaken. In Section 4.0, the present day average annual loss (cost) for landslide is estimated as USD 49,954. To calculate benefits, each adaptation strategy should be studied to determine how much of that average annual loss value will be reduced. The next step would be to calculate the PWF using the discount factor and lifespan of the structure. The Present Value Coefficient would then be multiplied by the difference in the average annual loss to get the total present value benefit which is divided by the cost of the project to determine the BCR.

Because the exact costs for some of the strategies above are difficult to estimate without conducting a detailed study, the total benefit was calculated to determine the magnitude of costs which should be considered. If the strategy selected were to reduce the average annual loss to 25% of its current value (USD 12,489), the losses avoided benefit would be USD 37,466. If the project has a 50-year lifespan at an 8% discount rate (assuming no annual maintenance cost), then the PWF would be 0.979 and the

Present Value Coefficient would be 12.23. The Present Value benefits would be USD 458,203. In this example, any project costing less than USD 450,000 would be a cost-effective, no regrets strategy.

Conducting this analysis using projected climate change, with the maximum average annual loss (ECHAM5, Late-Century, A2 Scenario) of USD 72,156 and using the above assumptions, the present value benefits would be USD 661,851. Considering all of the GCM and scenarios combinations analyzed in this project, a strategy implementation cost range of between USD 450K and 650K would be justified.

Summary

The results indicate several beneficial, low-cost adaptation strategies may be implemented to adapt to landslide events. ZESCO should restrict building in landslide susceptible areas and acquire or work with adjacent land owners to restrict their building in these areas as well. There have been losses to ZESCO from landslides which should help drive the investments of developing structural solutions to landslides. Slope stabilization in the prone areas near the facilities could result in a large benefit (described as losses avoided). If there were more mudslide events to the KGU or other parts of ZESCO, a more detailed BCA could be undertaken with more loss data and engineering cost estimates to better determine how much should be spent to make the adaptation cost-effective. This would include an average annual loss analysis to determine how much ZESCO spends on an annual basis on losses.

5.2.3 Adaptation Goal #3: Minimize Reduced Flow to ZESCO through Improved Agricultural Methods

Depending on the selected GCM and SRES, the results of modeling conducted in this study indicate that climate change is projected to cause future changes from the base period energy production rates (P-1 scenario) ranging between -17% and 1.2% for the early-century period, between -22% and 4% for the mid-century period, and between -5.1% and 11.7% in the late period. Furthermore, the results of WXGEN modeling, predict that the net effects of climate changes on energy production may range between 1.3% and 49.4% compared to the base period, suggesting that climate change could cause slight to dramatic increases in electricity production. Increasing variability in precipitation also was identified as a potential outcome of climate change in the area. However, these estimates do not account for the fact that a number of other water uses are expected to reduce the flow rates of water available to power generation during the next 90 years. Therefore, these competing water uses also were evaluated to estimate the potential power impacts of other uses compared to the P-1 base conditions.

The results of these analyses show that the energy generation estimates for the early-, mid-, and late-century periods are adjusted downward significantly in response to the competing water use scenarios. For example, Table 5-4 shows the ECHAM5 GCM yields significant power adjustments for the I-9 and I-10 use scenarios for their respective time periods as compared to the estimated P-1 energy production level.

Table 5-4: Effects of Competing Water Uses on Projected Energy Generation Estimates Based on the ECHAM5 GCM

Development Scenario	Emission Scenario	Time Period		
		Early	Mid	Late
I-9	A2	-22.7%	N/A	N/A
	B1	-8.6%	N/A	N/A
I-10	A2	N/A	-18.5%	-4.5%
	B1	N/A	-47.2%	-25.6%

Note: N/A indicates "not applicable" for the time period.

As Table 5-4 shows, water withdrawals for other uses also are expected to reduce, in some cases significantly, energy generation. Therefore, adaptation planning is warranted to minimize these future adverse impacts.

In addition to reductions in energy production associated with the expected increases in water withdrawals for other uses, there may be additional climate change impacts that were not accounted for in the present study. For example, the increasing variability of rainfall due to climate change may increase run-off, which could further increase demands for withdrawals for irrigation (Thurlow 2009). In addition, other factors, such as population growth, are expected to increase the demands for irrigation withdrawals.

As discussed in Section 4.2.1, analysis of the above-mentioned water uses shows that the agricultural sector accounts for approximately 75% of all water used in the Kafue Basin (FAO, 2005), far exceeding domestic, mining, and industrial uses. Because agricultural water use is the primary other use, several adaptation strategies involving agricultural methods have been identified to help minimize reduced water flows to ZESCO. These strategies are described below.

Strategy #1: Support the Government in Implementing the Agricultural Adaptations presented in the NAPA Report

The GRZ should implement the agricultural adaptation measures listed in the NAPA report. Some of the more prominent NAPA adaptations for the agriculture sector include:

- Focus on early warning systems for temperature and precipitation changes in AEZ IIa1 in order to anticipate low maize production;
- Change from “mono-maize” production (NAPA, page 1) to more drought-tolerate strains of maize and diversify to include drought-tolerant alternatives to maize (e.g., sorghum, millet);
- Improve productivity for maize cultivation (e.g., improve access to fertilizer and to amendments such as animal manure, lime, and urea);
- Implement rain harvesting or other low cost/low-tech options for supplemental irrigation of maize;
- Expand conservation farming: these strategies help reduce runoff during heavy rain periods (e.g., through the use of planting basins) (Namanyungu, 2008);
- Improve post-harvest storage and marketing of produce – road infrastructure; design and promote appropriate on-farm transportation, processing, and storage structures, especially for small scale farmers to minimize or prevent post-harvest losses;
- Improve access to capital/credit/indexed insurance products for small-scale farmers; an irrigation development fund would provide the irrigation sub-sector with loans and matching grants for smallholder irrigation schemes (which are also Poverty Reduction Programmes). Through these programs, small-scale farmers can individually access loans to acquire irrigation technologies that will help farmers to address effects;
- Expand agriculture to new additional arable land not currently under cultivation, especially in Zone III, which is projected to be least susceptible to drought and future climate variability; recent data indicates that a small portion of Zambia’s arable land (about 14%) is being farmed (GRZ, 2004). The

spatial distribution of droughts due to climate variability results in high adverse impacts on maize production in the drier AEZs, but little or no impact on the wetter AEZs (Zone III and IIb). Therefore, expansion of maize production in these northern zones would increase the ability of the country to address food security challenges internally. Given the importance of maize for the rural population, cultivation throughout the country is likely to continue for subsistence reasons. For these other areas of the county, improved access to fertilizer and other resources would improve productivity. The ability to access these resources requires improved infrastructure, particularly rural feeder roads (Kalinda, 2008). Such infrastructure would also assist in the distribution of stored food reserves during periods of drought.

Strategy #2: Support a Comprehensive Study and Assessment of Actual Water Usage in the Kafue River Basin

The lack of accurate figures on the actual use of water in the Kafue Flats has resulted in a moratorium on new Water Rights since 2008 (from "Strategic Environmental Assessment (SEA) of the Sugar Sector in Zambia, January, [Palerm, et. al, 2010]). The Zambia Department of Water Affairs (DWA) has established this moratorium to allow for a detailed assessment of mining, agriculture, hydropower, and domestic water users. As recommended in the SEA report (Palerm, et al., 2010), the GRZ:

> "…needs to conduct a comprehensive Water Balance study of the whole Kafue River Basin (not limited to the Flats) to establish a realistic estimate of water availability for any increase in irrigated agricultural activity. Such a study has been foreseen but apparently not being given the importance it deserves. The study should address: (i) determining a comprehensive inventory of water users and their current and future demand (including illegal and unregulated water abstractions); (ii) establishing the water rights already allocated; (iii) mapping water abstraction points and flows; (iv) registering flow metering devices in place; (v) determining water inputs (e.g., run-off, groundwater and surface water in-flows) and losses (e.g., evapo-transpiration, outflows); (vi) determining water flows required to ensure environmental health of the basin."

ZESCO should support this moratorium and the detailed water balance study. ZESCO should also actively participate in discussions regarding future water allocation policies based on the detailed assessments of water users. In particular, ZESCO should actively support the development of a national knowledge base regarding the need to balance the impacts of irrigation on power production with the growing need for irrigation of crops to directly reduce the potential for future food security deficits in Zambia. A report from the MEWD acknowledges that water used for hydropower production is more valuable to the economy than water used for sugar cane production. However, more consideration is needed to determine how best to allocate this important resource (Palerm, et al., 2010).

Strategy #3: Forge and Maintain Active Partnerships with Other Water Users and Stakeholders in the Kafue River Basin

ZESCO should work with other major water users to explore and implement water conservation methods that will allow the most efficient uses of water and build a commitment by all water users to contribute to the elimination of the food security deficit. For example, ZESCO representatives could collaborate with sugar industry representatives to explore ways in which sugar growers can work with nearby cereal growers to share any surpluses of their allocated water rights in a manner that can boost the yields of cereal crops without the need to increase the total water rights already allocated. This example is based on the fact that the estimates of year-round irrigation needs used to calculate the reduced flow rates to ZESCO might be overestimated resulting in a surplus of as much as 14%, as discussed in the following paragraphs.

Calculations of water availability, water rights, and potential new demand for the sugar sector often use volumes that are expressed as constants throughout the year. For example, an industry standard for water consumption per ha of sugar is 1 liter/second, or 1 cms per thousand ha. The current area under irrigation for sugar in Zambia is between 33,068 ha (World Bank, 2009MSIAO) and 34,029 ha (Palerm, et al., 2010). Use of the industry's standard assumption would yield water needs of 33 cms to 34 cms per year. The two largest producers in the sector, Zambia Sugar and Consolidated Farming have current water rights from the DWA for the sector equal to 27.1 cms per year. Because their combined ha are 31,654, their allocation represents 86% of the value derived using the industry standard (31.65 cms). Further, recent analysis of challenges to growth faced by this sector suggest that the existing allocation provides a "comfortable" margin with which to meet current needs (Palerm, et al., 20100); this suggests that adjusting the industry standard assumption to 0.86 cms per thousand ha (i.e., 86% of current assumption) may still be conservative for meeting the annual needs of the sector.

A reduction of 14% in the assumed volume needed per ha is supported in part by the fact during the rainy season and during harvest, maximum irrigation levels are not needed, nor are they needed for the period between harvest and the next planting cycle. However, during the germination period, availability of the full irrigation volume is critical to the viability of the crop. It may be useful to consider a more nuanced approach to the allocation of water rights – allowing the sugar sector's excess volume to be used by others during certain periods, while having access to larger amounts for other periods. Rather than assigning an annual amount to users, perhaps assigning water rights by month would allow for a more accurate temporal distribution of water supply across various users.

Strategy #4: Assist the GRZ in Public Education and Outreach on Implementation of Efficient Irrigation Methods

Irrigation strategies in the Kafue Basin include center-pivots, which deliver water to crops with about 80% efficiency, and furrow irrigation, which is about 70% efficient. The present irrigation profile for the sugar sector is about 58% furrow irrigation and 42% pivot irrigation. The total water allocation to the large commercial sugar farms is 27.1 cms for 31,654 ha of sugar cane. Evaluation of the distribution of this allocation by irrigation type and adjusting for the inefficiency of the irrigation systems shows that about 20.5 cms, or 76%, of the allocated 27.1 cms is being used effectively. This equates to 6.49 cms per 10,000 ha. If all of these hectares were converted to drip irrigation, which can be over 95% efficient, about 21.6 cms would be needed for the same area, saving approximately 6.56 cms (see Table 5-5). Alternatively, using the current allocation of 27.1 cms with the more efficient drip method, the irrigated area could be expanded to 39,672 ha, accommodating sector growth of about 25% with no increase in water demand.

Table 5-5: Irrigation Efficiency Impact

Irrigation Type	Portion of Irrigated Area	Resulting Hectares	Allocation cms	Irrigation Efficiency	Effective cms
Furrow	58%	13,295	11.38	70%	7.97
Pivot	42%	18,359	15.72	80%	12.57
Total Effective Portion of Allocation:					**20.54**

Notes: Acronyms - cms = cubic meters per second

Strategy Evaluation

The four adaptation strategies for Adaptation Goal #3 include POSE actions as indicated in Table 5-6. The strategies were evaluated using the STAPLEE criteria and the preliminary ranking results are shown in Table 5-6. Note that a number of criteria are provided with "U" findings, and are not scored. ZESCO and appropriate stakeholder input at the local level are recommended as adaptation strategies are further evaluated moving forward.

Table 5-6: Goal #3 Strategy Evaluation

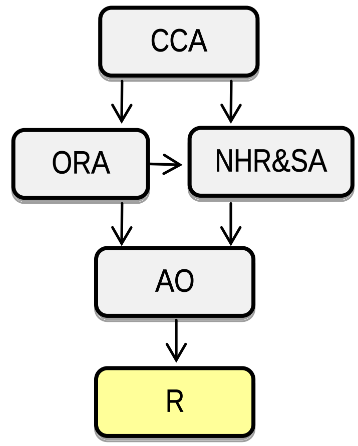
Adaptation Strategy (Category)	S	T	A	P	L	E	E	Total
Assist the GRZ in Implementing the Agricultural Adaptations in the NAPA Report (O, S, E)	↑	—	→	↑	→	U	↑	+
Support Comprehensive Study of Actual Water Usage in the Kafue River Basin (O, S, E)	↑	—	→	↑	→	U	↑	+
Forge/ Maintain Active Partnerships with Water Users/Stakeholders in the Kafue River Basin (O, S, E)	↑	—	→	↑	→	U	↑	+
Assist in Public Education and Outreach on Implementation of Efficient Irrigation Methods (S)	↑	—	→	↑	→	U	↑	+

Notes: For adaptation strategy: P = physical; O = organizational; S = social; E = economic.
For evaluation criteria: S = social; T = technical; A = administrative; P = political; L = legal; E = economic; E = environmental;
For ranking: ↓ = adverse; → = insignificant; ↑ = beneficial; U = unknown; + consider further

The results indicate that all four of the agricultural improvement adaptation strategies to minimize reductions in flow to ZESCO are expected to be beneficial within the social, political, and environmental evaluation components of the STAPLEE criteria based on the POSE/STAPLEE evaluation framework. In addition, the technical, administrative, and legal impacts of these strategies appear to be insignificant; however, the economic impacts, mostly represented by the costs to ZESCO for implementing the strategies, are largely unknown. Therefore, ZESCO should evaluate the potential costs of different levels of implementation for all four strategies, and determine the most cost-effective approaches that can be used to implement each strategy in the near and long terms. These strategies also will require significant coordination with other stakeholders in the agriculture sector and government.

6. Recommendations

This section presents the major recommendations of this study. Because different stakeholders may prioritize these recommendations differently, the numbering of the recommendations is for ease of reference, and is not intended to indicate a ranking of importance.



1. **Climate change challenges elevate the importance of managing water in an integrated manner** so that adequate supplies are available for power generation and for sector-based needs upon which the area economy and food security/livelihoods depend. While the hydropower system may be able to manage in isolation in the face of climate change, the system operates within the larger Kafue River Basin and water-related challenges will be exacerbated by climate change impacts on natural hazards and other sectors. The impacts of climate change, population growth, and development will impact ZESCO operations in the future. Therefore, combined water demand for power, conservation, domestic use, agriculture, industry, and other needs must be addressed through integrated planning efforts.

2. **It may be in ZESCO's interest to become proactively involved with national adaptation planning efforts.** Climate change will likely exacerbate any existing water demand and development tensions and challenges in the future. These concerns merit ZESCO's involvement in climate change planning and basin-specific approaches to water management and development planning.

3. **Improved data collection is needed to evaluate climate change impacts, especially for hydropower planning.** ZESCO's involvement in national- and basin-wide planning efforts would help identify opportunities to improve local meteorological, land use, hydrologic flow, and stream cross-section data to support refined modeling and analysis over time. To support daily modeling, increased consistency in the collection of daily data would be useful; in addition, a number of studies have cited that a greater density of meteorological stations would help to refine water modeling in developing countries.

4. **To improve the effectiveness of climate change adaptation efforts, ZESCO may want to pursue public involvement strategies**. These are generally lower cost strategies that can generate momentum, achieve significant positive results, and develop good will with customers and other stakeholders.

5. For physical adaptation strategies, feasibility studies and benefit/cost analyses, **capital project planning should be completed to determine which options would have the most positive financial and operational impacts for ZESCO.** Preliminary financial data has been included in the analysis, but additional stakeholder impact on priorities and costs would be required for detailed analysis and to support management decisions.

6. The significant withdrawals at the IT dam observed with C-2 and C-3 indicate that these **higher levels of conservation releases conflict with current operating rules for power generation**. The resulting inability to support conservation releases may be inconsistent with goals for preservation of the ecology of the Kafue Flats. Further study is required to identify and evaluate options for reconciling power generation and environmental goals.

7. In a larger environmental context, different phenological responses to the changing climate may cause disruption of coordination and interaction between species and their life cycles (e.g. plants and their pollinators, predators and their prey, insects and their host plants, etc.), and have cascading impacts on the food chain. **Analyses of climate change impacts on these life cycle interactions and the consequences for the Kafue River Basin are beyond the scope of this study, but merit attention in the future.**

8. **Climate changes that impact the flow of the Kafue River will have impacts on the financial performance of ZESCO's hydropower plants.** These impacts highlight the importance of considering changes in water supply due to climate change when implementing financial analyses for hydropower projects. Investors can be better informed about climate change risks to future hydropower projects by including projected changes in available water flow and power generation, rather than assuming constant flows and power generation rates.

9. To support future improvement in data and the incorporation of local knowledge regarding the hydrologic and reservoir systems studied, publicly available data and models were used. **Familiarity with these models can help ZESCO and other stakeholders refine the models over time to study climate change or inform other planning needs**. A training workshop to review study findings and share information on the models would facilitate the effective transfer of the skills and information needed for further application of the models as new information and conditions are identified. The models could also be used to study the impacts of potential adaptation strategies. For example, the reservoir operation model (HEC ResSim) could be used to assess the impact of IT reservoir expansion on average energy generation of the KGU and KGL power plants.

10. Numerous documents and studies were reviewed to **identify adaptation strategies; however, it is likely that local stakeholders will have additional input to, and ideas for, appropriate strategies** under each goal. Input on these strategies, is therefore warranted. **The input of local experts and stakeholders would improve the adaptation strategy rankings**. A working session could be implemented to review the adaptation findings and obtain input from appropriate parties on the most promising adaptation strategies. The session could also identify ways to obtain buy-in or address data gaps to move the strategies forward, working within existing programs and efforts with which stakeholders are familiar.

11. **The complexity of evaluating potential climate change impacts suggests that probabilistic assessments will provide substantial benefits over deterministic evaluations.** In this study, multiple simulations were completed at several stages of analysis. Increased use of probabilistic techniques for future assessments will better inform planning for climate change.

12. Climate change and climate risk assessments are evolving fields. Therefore, this report presents findings and recommendations, as well as strengths and limitations of the data and methodologies applied and uncertainties associated with the modeling and data inputs and outputs (see Section 7). The project approach recognizes that **while there are uncertainties associated with quantifying climate change impacts, there is a pressing need to plan for these impacts**. Approaches and findings should be reviewed to identify an over-arching framework that can be used to integrate climate change considerations into existing environmental or overall project considerations. It may be useful to convene a workshop or working session with a number of agencies, donors, countries, and technical specialists to review approaches and identify appropriate, cost-effective means to integrate climate change considerations into project evaluation methods.

7. Models, Data and Uncertainty

This section provides an overview of strengths, limitations, and uncertainties associated with this study's analysis. Uncertainty associated with the assessment accrues across each stage of the analysis and is overviewed below.

7.1 Climate Change Assessment

- The uncertainties associated with GCM projections of climate change have been categorized (e.g., IPCC, 2001) as (1) unknown future emissions of GHGs; (2) uncertain response of the global climate system to increases in GHG concentrations; (3) incomplete understanding of regional climatic changes and their impacts, that will result from global changes. Of these, the first two are the largest sources of uncertainty in GCM projections and are estimated to be of roughly equal magnitude on a global scale (Karl and Trenberth, 2003; Wigley and Raper, 2001). The degree of uncertainty resulting from the combination of these three major sources is unquantifiable. Confidence bounds cannot be placed on any GCM projections.

- Overall, the projected precipitation changes are relatively small, but are associated with large uncertainty, given that the simulation of precipitation remains one of the principal challenges in global climate modeling (additional information provided in Appendix A1). In particular, Africa has been noted as an area that presents significant challenges in terms of climate change projections for precipitation based on factors such as limited meteorological data and historical variability in weather patterns. In addition, the ENSO climate phenomena can impact weather patterns in Zambia. ENSO causes periodic extreme weather such as floods, droughts, and other weather disturbances, and these impacts are not necessarily captured by current GCMs. Studies are ongoing regarding how ENSO is impacted by climate changes and how ENSO and climate change might impact climate and weather patterns in particular countries over time. However, a study of various GCM models on their ability to capture ENSO phenomena indicated that ECHAM5 is one of the models that reflect ENSO reasonably well in sea surface temperature (SST) variability (van Oldenborgh, et al. 2005).

- There is considerable uncertainty with projecting temperature and precipitation changes associated with climate change, particularly for time frames beyond 2050. Current concentrations of GHGs in the atmosphere will affect climate through 2050; however the actual GHG emissions that will occur between now and 2050 are unknown; therefore, the corresponding impact on temperature and precipitation is more uncertain.

7.2 Hydrologic (Flow) Projections

- This study's hydrologic flow projections build on the temperature and precipitation outputs from the climate change assessment (GCMs, emissions scenarios, and time horizon projections). Therefore, the uncertainties associated with those outputs (discussed above) are carried forward through the hydrologic flow modeling effort.

- Development of the basic model for the hydrologic system incorporated available background information, including land use, hydrology, precipitation, hydrologic flow, rivers, basin designations and other data. Background documents and other publicly available data were used to develop the model. Data limitations introduce uncertainty associated with the model; for example, land use data are from the United Nations Food and Agriculture Organization (FAO) and may not be current for the entire basin. Where assumptions or input data differ from actual conditions, limitations and uncertainty are introduced into the modeling effort. Additional information on the data sources, approaches, and assumptions included in model establishment are provided in Appendix A2. Adaptation strategies and recommendations included in this report identify options for improving meteorological, land use, and river cross-section data in the future; modeling can then be refined as improved data is obtained.

- Seven meteorological stations with observed, daily historic precipitation and temperature data were available for model calibration and validation. These seven stations are generally located near the boundary of the study area, rather than within the interior of the basin. Based on UN World Meteorological Organization criteria, between 50 to 150 stations would be desirable in a basin of study area's size, with hilly areas benefitting from a higher density of stations. The findings and recommendations of this study also identify that similar to other studies in Africa, modeling and analysis of climate change would benefit from better local data. "The climate observing system in Africa is in a far worse state than that of any other continent, and is deteriorating" (Washington et al., 2004). There are eight times fewer weather stations on the continent than the minimum recommended level (Elasha et al., 2004) and "vast parts of central Africa remain unmonitored" (IISD, 2009)."

- The spatial distribution of the meteorological data set includes significant averaging of precipitation across the basin that is likely not completely representative of the actual precipitation variability in the basin area. Despite the limitations, this data set was used for model calibration and validation because it is a source of actual, observed data, and because the temporal resolution is daily, thus providing modeling benefits over monthly data for informing decisions related to hydropower projects.

- A stochastic weather generator (WXGEN) produces synthetic time series of weather data of infinite length for a location based on the statistical characteristics of observed weather at that location. This long term data captures climate extremes prolonged high and low rainfall periods which is very useful in risk assessment for hydrological or agricultural purposes. Some of the limitations in the application of WXGEN (as observed by Carney et al., 2008) are (1) the WXGEN does not accurately reproduce the temporal auto-correlation of the annual precipitation and (2) the WXGEN cannot generate multiple correlated precipitation inputs.

- The hydrologic model incorporates the impact of increased temperatures in calculating water losses due to evapotranspiration in the runoff generation process. However, because rainfall is the most crucial factor in the runoff generation process, it is used to evaluate the variability of flows among the GCMs (see Section 3.1.6, RCLIMDEX Findings). In the future, additional analysis of temperature (spatial and temporal distribution of minimum and maximum temperature) and other parameters (such as relative humidity and vapor pressure) could be evaluated. However, such analysis was beyond the scope of this project's hydrologic modeling effort.

- Additional uncertainty arises from the unknown hydrologic response of the Kafue River Basin to future climate changes. While the physics of hydrologic modeling are relatively well understood and reasonably represented in physically-based models, even a well validated model may not faithfully represent the natural system's response to future climatic conditions when those conditions differ considerably from historical conditions which were used for model calibration. In the case of the

Kafue River Basin, the GCM projections take the mean seasonal and mean annual temperatures well outside of the range seen in historical observations.

7.3 Reservoir (Energy) Projections

- As discussed above, the hydrologic flow projections build on the temperature and precipitation and hydrologic flow modeling that are associated with limitations and uncertainty (as discussed in the two sub-sections above). The reservoir (energy) modeling uses the HEC ResSim model, which builds on the flow projection outputs associated with the hydrologic modeling; therefore, the uncertainties associated with those outputs are carried forward through the HEC ResSim modeling effort.

- The use of the HEC ResSim model for evaluation of the Kafue River hydropower system is informed by available background documents, ZESCO operation data, and other publicly available information regarding power unit locations, sizes, efficiencies and operational rules (additional information is provided in Appendix A3). Numerous assumptions were made based on the available data to establish the model. Where assumptions differ from actual operational parameters, limitations and uncertainty are introduced into the modeling effort. Additional information on the data sources, approaches, and assumptions included in model establishment are provided in Appendix A3.

7.4 Financial Assessment

- The energy outputs used as inputs to the financial analysis build on the temperature and precipitation, hydrologic flow, and reservoir (energy) modeling outputs that are associated with limitations and uncertainty discussed above. Therefore the financial assessment carries forward any limitations and uncertainty associated with those combined efforts.

- The financial analysis uses the RETScreen tool which is designed to help analyze clean energy projects. Financial assumptions included in the IFC financial analysis (e.g., assumed inflation rate) are carried forward in the financial assessment for this study effort.

7.5 Natural Hazard Risk and Sector Assessments

- There are three main sources of uncertainty associated with the natural hazard risk section of the study: (1) the uncertainly associated with the literature on historical natural and sector-related natural hazards and losses/impacts, (2) the uncertainty associated with the model results presented in Section 3, and (3) the uncertainty associated with extrapolations that are based on the climate change assessment projections. The following bullets overview each of these uncertainties.

    1. The uncertainties associated with the literature are relatively low in respect to the present types of historical natural hazards and sector-related risks, because the Kafue River Basin has received significant national and international attention in the past 30 years. However, data are not always complete on losses and impacts; further refinement of economic and population data would assist in estimating potential losses associated with natural hazard risks. In addition, there may be other emerging natural hazards and/or risks that are not associated with historical trends or documentation. If such undocumented risks exist, they have the potential to cause damages that were not anticipated by the risks considered in Section 4.1 or adaptation options presented in Section 5 of this report.

2. The main uncertainties associated with the modeling effort are captured and presented in Sections 7.1 through 7.3 above. They include the fact that the projection of future climate change is a developing area and there are uncertainties inherent in the current models and tools, particularly for long-term projections and for some parts of the world where the factors affecting climate are particularly complicated. In particular, precipitation projections are challenging. Finally, the use of modeling to extrapolate historical trends in the severity, magnitude, and or vulnerabilities associated with any given natural hazard or sector-related risk includes uncertainty. Therefore, the evaluation in Section 4.1 provides an approach and starting point to inform further analysis; however, the magnitude of loss differences provide a foundation for prioritizing appropriate adaptations options and strategies.

- For the other sector assessments (agriculture, conservation, and other uses), uncertainty is associated with projections of population and industry growth, land use decisions, economic development and other factors. However, the assessment of these sectors indicates that the modeling used in Section 3.0 (conservation/development scenarios) is conservative in regards to other water uses and agriculture development. The projection of conservation impacts associated with climate change includes uncertainty regarding temperature and precipitation changes on the phenological life cycle of plants and animals; these are developing fields of study. Integrated approaches to water management will help stakeholders remain informed of developments across the sectors and better plan for water needs which will be impacted by the combined impacts of population growth, development, energy needs, and climate change.

7.6 Adaptation Options

- As discussed above, the hydrologic flow, reservoir (energy), and temperature and precipitation projections all include elements of uncertainty. The adaptation options presented in this study build on the findings of this study and therefore, there is some uncertainty in the materials used to identify adaptation goals. However, other sources of information, stakeholder input, magnitude of difference findings, and documented knowledge of past country and area-specific hazard impacts inform the adaptation goals and strategies and they provide reasonable and fact-based goals that drive adaptation options for ZESCO.

- The adaptation approach used here can inform planning, even in the light of uncertainties about climate change. The adaptation options presented in Section 5 include both climate change alternatives and “no regrets” alternatives. The term “no regrets” is used to describe actions that address challenges that have caused concerns in the past and that likely will be exacerbated by climate change in the future. But even without climate change, these “no regrets” actions are likely to be beneficial in addressing these concerns. If climate change does exacerbate these issues, then the investments in these actions will likely become even more cost-effective. Local stakeholder input into the Section 5 strategies and rankings will assist in identifying the best alternatives for immediate and longer-term action.

7.7 Implications

As outlined above, a number of uncertainties are associated with this climate change risk assessment study. Climate change evaluation is an evolving field and GCMs and data are anticipated to improve with time. This will help to reduce uncertainties associated with climate change projections and modeling such as that performed in this assessment.

Although uncertainty is associated with this assessment, it is clear that climate change impacts will increase temperatures and impact precipitation patterns over time. This will affect flows to ZESCO hydropower operations in the Kafue River Basin. Climate change impacts and anticipated power demand growth, combined with development and indirect climate change impacts (on natural hazards and other sectors), indicate that adaptation planning is warranted to manage use in the basin. The climate change, hydrologic, and reservoir modeling analysis completed in this study, combined with the other risk considerations discussed in this report, point to reasonable priorities for adaptation that will prepare ZESCO for potential climate change impacts.

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