CLIMATE RISK AND BUSINESS
HYDROPOWER

Kafue Gorge Lower
Zambia
Executive Summary

International Finance Corporation
World Bank Group

Acknowledgements

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About Climate Risk and Business
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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Foreword

Climate change is a reality, and the events and impacts associated with it are increasingly evident. Recent studies indicate that the levels of warming that are considered safety thresholds may be crossed as early as 2030 in several regions of the world, if not before is some cases.

Climate warming is expected to have significant effect on precipitation patterns and events, including variations in the quantities of average yearly precipitation and distribution of rainfall. Those factors may in turn considerably affect the availability of freshwater and the livelihood of many who depend on this resource. Continuing to plan the future based only on historical records without accounting for potential shifts in climate patterns may slow down economic and business performance. It also could have serious adverse effects on society and the environment, particularly in those areas that are heavily dependent on water use.

This study, part of IFC's Climate Risk Program, provides an analysis of the implications of climate change, in terms of climate risks and adaptation options, related to the hydropower production of the planned Kafue Gorge Lower hydropower project in Zambia.

As in previous Climate Risk studies, study authors recognize that projects and sectors should not be analyzed in isolation but rather in the context of a broader range of climate related economic, social and environmental factors to identify relevant and meaningful solutions. This is particularly true of water intensive sectors, where the importance of freshwater resource for development and in particular the nexus between water, food and energy; and projected global water deficits all mandate a more comprehensive perspective.

This latest study looks to take into account not only changes in the supply - precipitation and runoff - caused by climate change, but also the likely shifts in demand due to climate change by various users. It also considers the likely impacts that directly or indirectly may affect resources for hydropower production, and how all these factors may influence the overall water availability and use.

Through this work and as part of its larger Climate Risk Program, IFC shows its continued commitment to providing critical information and analytical tools that help identify options and support decision making in the face of climate challenges. I would personally like to thank Zambia Electricity Supply Corporation Limited, ZESCO and the Zambian institutions for their support and cooperation in this ground breaking work.

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Introduction

Kafue Gorge Lower climate risk study is part of IFC's Climate Risk and Adaptation Program, which explores the implications of climate change impacts on private sector financial, social and environmental sustainability.

A focus on long-lived infrastructure projects such as hydropower is particularly appropriate. The design and projected useful life of this type of large capital-intensive, physical assets typically spans many decades. And over this time considerable changes in climate are expected to occur, with the potential of considerable direct and indirect impacts on the life of these projects.

Another factor to consider is that sectors and businesses that are water intensive are particularly sensitive to the impacts of climate change because both the supply and the demand side are affected by shifts in climate. Increased content of greenhouse gases in the atmosphere and consequent increased warming lead to higher evaporation, which in turn is likely to lead to prolonged droughts. With each degree of warming the capacity of air to hold moisture significantly increases, resulting in larger quantities of water vapor in the atmosphere and precipitation events that often exceed historic values, which, as witnessed during the past year in several regions of the world, often results in increased flooding. The exact effects of these changes and their scale will depend on local and global factors, both climatic and non-climatic, and the possible magnitude of the impacts indicates the need to assess these risks in the project and location specific context.

As in previous climate risk studies, one of the focuses of this work is understanding of the implications of climate related changes not simply on the physical assets that are in direct control of a project but also on a wider range of factors, including the supply chain, overall supply and demand, environmental and social effects, and other characteristics relevant for a project's operation. This perspective is relevant for many sectors, but especially for water intensive businesses. Other things being equal, rising temperatures result in increased consumption of water for human use in both urban and rural areas, higher evapotranspiration leads to an increase of the use of water in agribusiness and the need for higher releases of flows for biodiversity maintenance, industries will require more water for their processes, etc. At the same time more water will be needed for increased demand for electricity: for example, for cooling in the industrial and urban context-, possibly at the same time there is diminished supply to meet the growing needs especially during increasingly frequent drought periods.

Indeed, one of the key findings of this study is that under some scenarios the frequency of annual flows projected to be lower than the average demand of different water will be on the rise. This possibility points to the need for the Integrated Water Resource Management approach that incorporates the effects of climate change in the planning process. In addition to other benefits, such an approach has the potential of identifying the most efficient adaptation solutions that would not necessarily be identified or undertaken if the components were analyzed in isolation of the others. This is especially relevant for the project assessed in this study: the findings about future climate variability, especially those related to drought, point to the possibility of financial underperformance; this is due to lower flows even in earlier periods and occurs under some scenarios and assumptions about required financial returns.

As always, it is necessary to interpret the results in the light of underlying assumptions and limitations; these are addressed in depth throughout the study. While the best available information has been used, several relevant assumptions, such as demographic, economic and policy decisions, including the global preference of levels of greenhouse emissions, are dependent on current and future policy choices. Another uncertainty is the response of the systems to climate change and the effects of these responses on the study area.

For example, how will the projected increase in evapotranspiration and droughts impact the miombo forest and other vegetation – this is important for controlling the water flows-, whether this will cause increased desiccation and number of wildfires, which in turn may affect soil structure, erosion levels, and frequency and intensity of floods. Although analyses of this type escaped the scope of the present study, they would need to be incorporated in further work around the Basin.

One of several issues highlighted in the study is to identify what data, tools and analysis is most appropriately collected and provided by public authorities or sectoral associations to enable the more detailed site and project specific analysis needed by individual stakeholders. The approach in this study is probably too expensive and complex for the capacity of all but the largest companies, pointing to the need for the development of freely accessible platforms that would provide the information that would enable appropriate decision making process in the face of climate change.

Two objectives of this project are related to this issue and the use of its outputs. One was to develop and propose an initial approach to the assessment of climate risk and adaptation analyses for hydropower and hydro-related projects that could be replicated and improved by other users. For this purpose, all modeling software chosen in the study is freely available on the internet, and the methodology, tools, and datasets are described in detail.

The other objective was to provide the possibility to use the study's outputs as a base for further work related to the Kafue basin, or to perform new runs of the same model but with different assumptions – which will certainly be needed as new information related to initial assumptions is produced. For this purpose, all results and numeric datasets used in the study are made available for download from IFC's website, with the exception of the daily meteorological station data.

Clearly this is not to be the final word on protecting the Kafue Basin from the ravages of climate change but through this analysis the authors do hope that the work presented here can be an important step forward.

This *Executive Summary* presents an abbreviated version of the full report of the approach and findings associated with the climate change risk assessment for the Kafue Gorge Lower (KGL) hydropower project. In addition to overall objectives of the Climate Risk and Adaptation Program[1], this study's purposes include development of an approach for identifying and evaluating climate change impacts and potential effects on power production, financial flows, operational risks, and adaptation measures related to the hydropower projects, more specifically for KGL, and development datasets, models and tools that are publicly available and suitable for supporting climate change risk assessment, planning, and adaptation strategies. The availability of this information in the public domain allows interested stakeholders to apply this process to support further assessments as new information becomes available or local conditions evolve. The complete *KGL Climate Change Risk Assessment Report* and its appendices are available at the IFC's website.

The major components of the study include:

- developing downscaled projections of temperature and precipitation for the study area across a base period and three future consecutive time periods extending through the year 2100,
- modeling hydrologic flow in the Kafue River based on these future projections of temperature and precipitation,
- modeling the corresponding reservoir/energy outputs for KGL,
- analyzing the potential financial implications of the energy outputs for KGL,
- considering climate risks for natural hazards and other uses of water in the study area (including agriculture, conservation, urban, and industrial), and
- identifying possible adaptation goals and strategies.

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 inset shows the location of the Basin within Zambia on the right and includes a representation of the major streams within the Basin in the left portion of the figure.

The Kafue River is one of the major tributaries of the Zambezi River. The area of Kafue River Basin measures about 156,000 square kilometers (km2) 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.

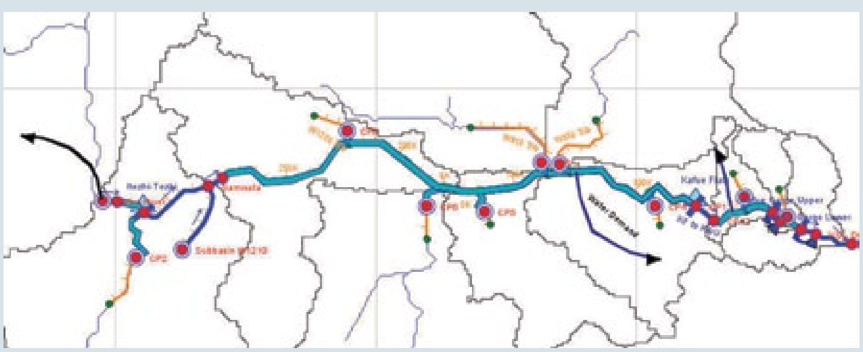
The Kafue River turns eastwards after the IT reservoir and flows for about 350 km across the Kafue Flats and into the Kafue Gorge Upper (KGU) reservoir (Figure 1-2). The Kafue Flats are a wide and flat area of the river, with natural water flow moving slowly across the flats at a shallow depth. The Kafue Flats are a valuable

Figure 1-1: Map of Kafue River Basin in Zambia

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 (completed in 1976) and hydropower power plant (planned in the short term); (2) the KGU dam and hydropower plant (completed in 1972); and (3) the KGL dam and hydropower plant (planned). The planned KGL project, planned to be operated by Zambia Electricity Supply Corporation Limited (ZESCO) , the country's primary domestic electricity provider, is the focus of this risk assessment pilot project.

Figure 1-2: Schematic of the Reservoir Network for the Kafue River Basin[2,3]



PHYSICAL PARAMETERS FOR DAMS, RESERVOIRS, AND POWER STATIONS

Dam	Top of dam elev.	Length	Storage (mcm)	Generating Capacity[2]	Combined Efficiency	Structural Features/Notes
IT	1035m	1800m	6,008 @ 1030.5m	120 MW	88%	3 spillway gates (4,425 cms @1030.5m), low level outlet for power releases
KGU	980m	300m	1178 @ 977m	990 MW	91%	4 spillway gates (3,660 cms @ 978m) 11 Km tailrace tunnel, 400 m head
KGL	586m	300m	80 @ 580m	750 MW	88%	3 spillway gates (3,959 cms @ 582 m), 7 km tailrace tunnel, 200m head

1. See www.ifc.org/ifcext/climatebusiness.nsf/Content/AssessingClimateRisks
2. Turbine and generator
3. 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 these parameters. (Acronyms: mcm = million cubic meters; MW = Megawatt; and cms = cubic meters per second.)

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 the report (Section 2.2). 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. Further information is provided in the full report and Appendix A3.

In addition to flows released from the IT dam, various local intervening inflows exist 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 Fund (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).

CLIMATE CHANGE ISSUES

Zambia's reliance on hydropower to meet current and future electricity demand faces three types of challenges:

- increased economic development leading to growing demand for water for other uses,
- 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
- increased 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, 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.

PROJECT APPROACH

The project approach is presented schematically in Figure 1-3, which is referenced throughout this section while Figure 1-4 provides a simplified version of the approach, highlighting the five major stages of analysis and their key components.

Climate Change Assessment

Time Horizons

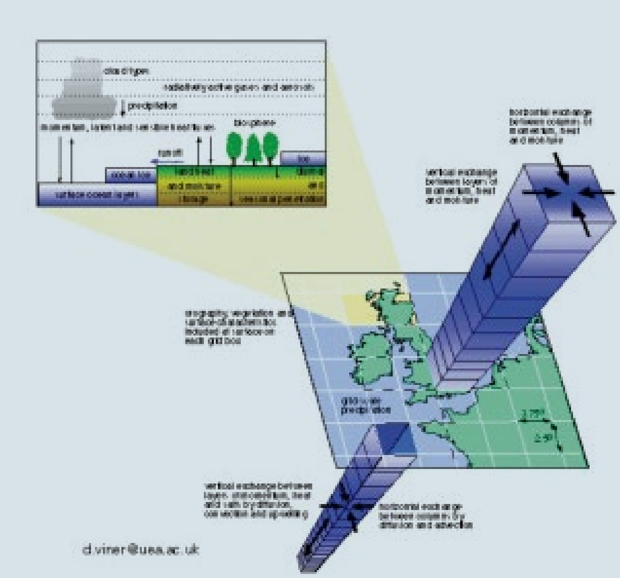
The project examines the potential effects of climate change during the remaining 90 years of the century, and also reflects estimated lifetimes of the KGL dam and hydropower time. For GCM modeling, projections for approximately the next 50 years are typically more accurate than longer-term projections, because the next 50 years will reflect the impact of current emissions. The 90 years are considered in 30-year segments (early-, mid- and late-century) to facilitate consideration of investment issues (early-century) and to allow for separate consideration of the late-century period results, which can be expected to be less certain than the earlier periods. The period of 1960 to 1999 is used as the base period.

- Time Horizons = 4 (base, early-, mid-, and late-century periods)

Global Climate Models

The climate change projections for this 90-year period were obtained from six Global Climate Models (GCMs). Nearly two dozen GCMs are used in the international climate science community. Their results are collected at the Coupled Model Intercomparison Project (CMIP) website for the benefit of researchers internationally. These GCMs are used to project the impacts of greenhouse gas (GHG) emissions on the major components of our climate system: land surface, ocean, atmosphere, and sea ice. These models are both data- and computationally-intensive and continue to be improved as more detailed data and more powerful computing resources become available. Figure 1-5 illustrates how GCMs represent the interconnected elements of climate in a three-dimensional system of grid cells. In Zambia, there are 270 of these grid cells.

Figure 1-3: Conceptual Structure of GCM Grid Cells



Source: www.cru.uea.ac.uk/cru/info/modelcc/

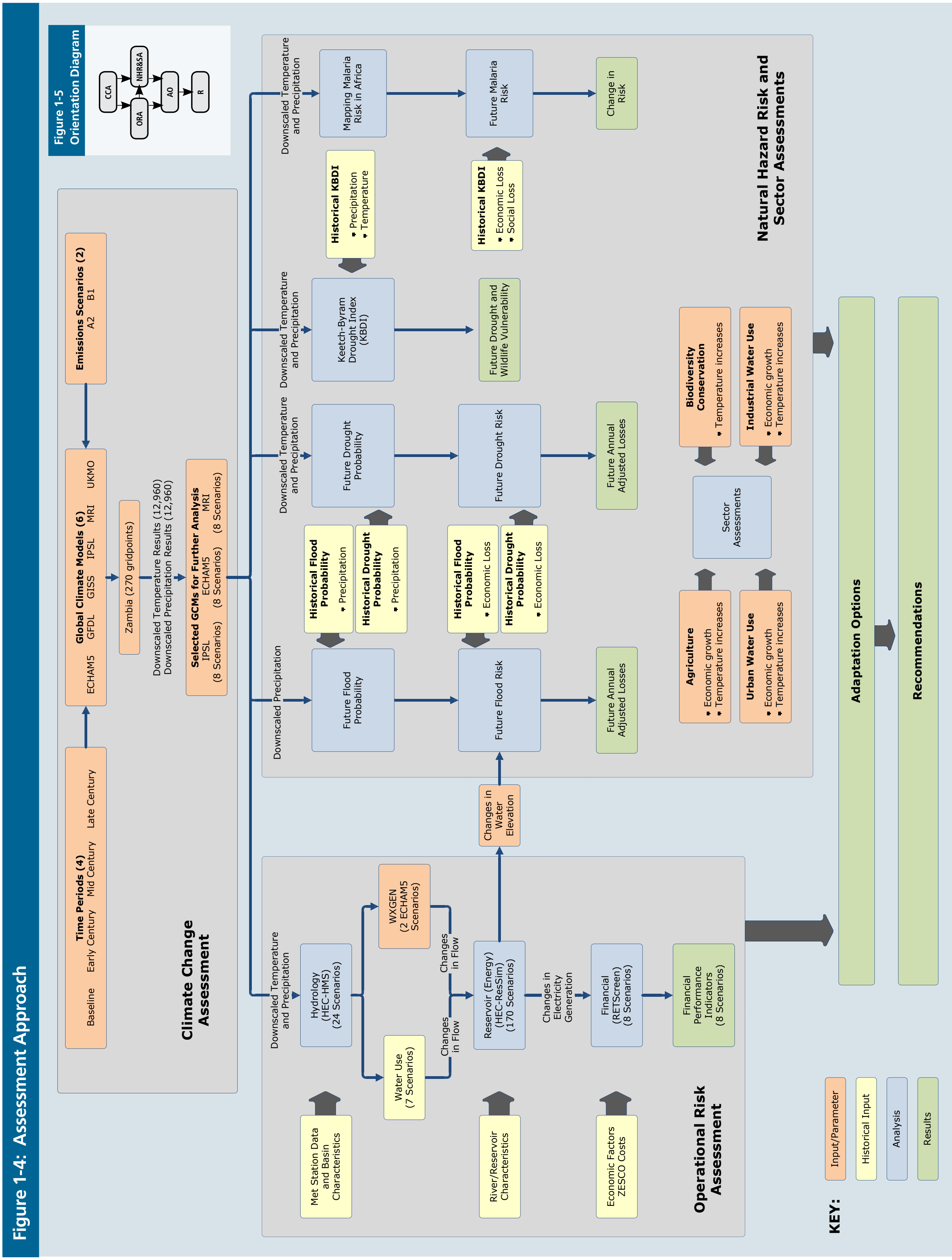


Figure 1-4: Assessment Approach

Model limitations are becoming better understood and GCMs are being continually revised to improve performance. For example, recent analysis of GCM projections compared with observed precipitation data indicates that the models tend to underestimate climate change impacts on extreme precipitation events (Min, 2011). As such findings emerge, researchers work to refine and improve GCMs over time.

Research has shown that use of all 22 GCMs is not necessary for most assessments of climate change (Pierce, et. al., 2009). As explained further in Appendix 1 of the full report, adding many GCMs makes relatively little additional benefit for the range of future climate projections, once the number of GCMs reaches about five. Therefore, this approach uses downscaled climate data obtained for Zambia from six GCMs (see additional discussion and references in the full report).

- GCMs = 6 (GFDL, GISS, ECHAM5, IPSL MRI, UKMO)*

IPCC Emission Scenarios**
Many emission scenarios have been developed by the Intergovernmental Panel on Climate Change (IPCC), in the Special Report on Emissions Scenarios (SRES) (Nakicenovic, et. al., 2000), with the goal of characterizing future possible "story lines" for development globally. The SRES scenarios include projections of future concentrations of carbon dioxide (a key GHG) in the atmosphere based on a range of factors. The IPCC developed the SRES scenarios to provide a standard approach to characterize future variables whose true future states cannot be known, such as level of economic growth, extent of technological innovation, the carbon intensity of energy sources, and political attitudes toward climate change. They are not designed to reflect actual future outcomes, but rather are intended to capture a range of possible outcomes. These outcomes are shown in Figure 1-6. Equivalent probabilities are assigned to these story lines.

For this project, two scenarios were selected, A2 and B1, for their ability to reflect a relatively carbon-intensive future (A2) and a potential future with relatively low carbon emissions (B1). These scenarios were developed in 2000. In the dozen years since their development, actual global emissions have exceeded the A1F1 projection, the SRES scenario with the highest projected concentration of carbon dioxide in the atmosphere (USGCRP, 2009).

- SRES Scenarios = 2 (A2 and B1)

The combination of six GCMs and two emission scenarios provides 12 different forecasts of temperatures and precipitation levels due to climate change for each of the time periods for Zambia (270 grid cells). This results in nearly 13,000 data points each for temperature and pressure. Further information about the modeling approach is provided in Section 6 of this summary report and Appendix A1 of the full report. These climate change results were then used as the basis for two sets of further analysis: the operational risk assessment, and the natural hazard risk assessment.

*Global Circulation Models elaborated and maintained by different research institutions
**Intergovernmental Panel on Climate Change

Operational Risk Assessment

Hydrologic Modeling
Hydrodynamic models are used to represent the functioning of complex water systems, including detailed water flow patterns and sediment transport. A model of the watershed is constructed by separating the water cycle into component parts and constructing boundaries around the watershed of interest, as illustrated in Figure 1-7.

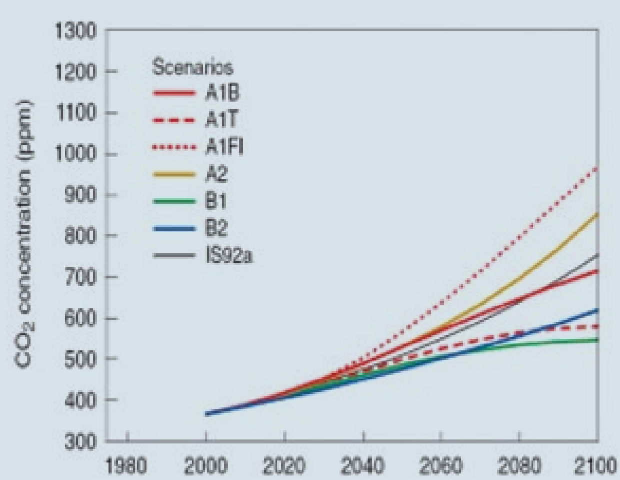
Of these 12 original GCM/SRES combinations, the results from three GCMs were selected for further analysis, as shown in Figure 1-3. Of the original six GCMs, these three GCMs yielded the upper, lower and median results for projected climate change. To manage the computational demands of the analysis, the results of these three GCMs became the focus of the subsequent analyses.

The climate outputs (principally temperature and precipitation) from the six GCM/SRES combinations were used as inputs for the hydrologic flow model. For this study, the model used is the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center (HEC), Hydrologic Modeling System (HEC-HMS), a generalized modeling system capable of representing many different watersheds. HEC-HMS is designed to simulate the precipitation-run-off processes of dendritic watershed systems. It is applicable across a wide range of geographic areas for addressing a wide range of project goals.

This analysis yields projected water flow volumes due to climate change at locations along the Kafue River for each of the six GCM/SRES combinations. Outputs were calculated for base period (in the 20th century) and the three future time periods for the 21st century.

Water Use Scenarios and the Weather Generator
These levels of flow were then further modified to reflect potential changes in available flow that could result from other usage requirements for the water supply in the Kafue River. The

Figure 1-6: SRES CO² Projections through 2100



Source: www.grida.no/publications/other/ipcc_sr/?src=/climate/ipcc/emission initial scenario represents a power maximization scenario (P-1); it includes assumptions of baseline water withdrawals along the river for irrigation and domestic, mining, and industrial uses (DMI). The alternative use scenarios are divided into two categories: development (the "I" scenarios), and conservation (the "C" scenarios). The "P", "I," and "C" scenarios are based on assumptions presented in the Strategic Environmental Impact Assessment (SEIA) of KGL (SWP, 2003). The eight scenarios are presented in Table 1-2 and are summarized below.

- P-1 is the maximum power scenario (P-1),
- C-1, C-2, and C-3 are the conservation scenarios, and
- I-3, I-6, I-9, and I-10 are the development scenarios.

The first seven of the eight water use scenarios correspond to the scenarios of the same names in the 2003 SEIA. In addition, this study added I-10 in order to characterize a larger potential level of development during the mid- and late-century periods. Each of these scenarios includes the projected effects of climate change on the available water supply in the Kafue River.

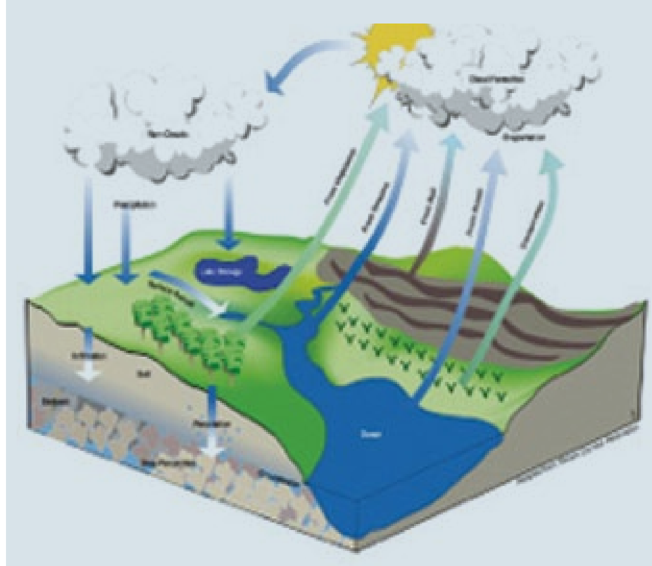
The details of each of the scenarios presented in Table 1-2 are presented in the full report. In general, the C-1, C-2, and C-3 scenarios also include all of the same assumptions about the annual volume of available water in the river as does the P-1 (maximum power) scenario, except they vary the timing and volumes of water discharged from the IT dam for conservation purposes. The I-3, I-6, I-9, and I-10 scenarios also include the same base assumptions as the P-1 scenario, but increase the estimated water abstractions for development, thereby, reducing the expected flow rates available for power generation.

A final set of flow analysis was applied to the P-1 scenario through the use of a weather generator model (WXGEN). The flow scenarios selected include ECHAM5, A2, late-century (highest increase in flow from the A2 base period) and the ECHAM5, B1, mid-century results (highest decrease in flow from the B1 base period). A weather generator uses a *Monte Carlo* approach to produce a synthetic time series of weather data of any desired duration for a location based on the statistical characteristics of observed weather at that location. While the GCMs each produce a projection of the future that typically extends about a century, a weather generator provides results over a much longer period, thus better capturing climate extremes, such as prolonged periods of high and low rainfall, which is useful in climate risk assessment.

Additional Statistical Analysis: RClimDex

ClimDex was developed as a Microsoft Excel program to assist researchers in the analysis of climate change and detection. It uses a a four-step analysis process that consists of quality control, homogeneity testing, calculation of desired indices, and regional analysis.

Figure 1-7: Illustration of the Hydrologic Cycle



Source: www.cfses.org/salmonid/html/water/cycle.htm

ClimDex has been adapted for use with R as the platform – an environment that does not depend on a particular operating system. R is a free and yet very robust and powerful software for statistical analysis and graphics; it runs under both Windows and Unix environments.

The RClimDex tool was developed and is maintained at the Climate Research Branch of Meteorological Service of Canada. Its initial development was funded by the Canadian International Development Agency through the Canada China Climate Change Cooperation (C5) Project.

Reservoir/Energy Modeling

The flow results were then used as inputs for the reservoir/energy model which was used to estimate the level of power generation that would be produced by the available flow, as shown in Figure1-3.

Reservoir/energy models support water resource studies by predicting the behavior of reservoirs under different scenarios. They are designed to model operations at one or more reservoirs whose operations are defined by a variety of operational goals and constraints. These tools help reservoir operators plan releases in real-time during day-to-day and emergency operations. This study used the USACE HEC Reservoir Simulation (ResSim) model. It is designed to reflect reservoir operations at one or more reservoirs whose operations are defined by a variety of operational goals and constraints. It uses an original rule-based description of the operational goals and constraints that reservoir operators must consider when making release decisions.

Financial Modeling

Annual electricity generation results for KGL for two representative scenarios were then used as inputs into the financial model to characterize the financial results of KGL. In order to determine the most desirable investment targets, investors evaluate a range of financial information. Investors will have target performance goals that include the size of the financial return, payback period for the investment, and the risk associated with the project. Projects are often evaluated using proprietary financial models. For this study, a publicly available financial model was used. Natural Resources Canada developed the Renewable Energy Technology Screening Tool (RETScreen) with project partners to provide a free, public resource for assessing clean energy projects. It captures key financial and operational inputs for a project and generates resulting financial performance outputs for project evaluation.

Natural Hazard Risk & Sector Assessments

The temperature and precipitation results from the 12 GCM/SRES climate change scenarios also informed an assessment of the impact of climate change on natural hazards that are a concern for the area, both for the operation of KGL and for the Kafue River Basin generally. These key hazards include flood, drought, wildfire, landslides, and disease. These analyses yield initial projections of possible future annual adjusted losses for each of the hazards. To provide further insight into the water demands that were modeled in the development scenarios, further evaluation was applied to select sectors that rely on water, including: agriculture, mining, and domestic residential use.

Adaptation Options

Finally, the study's findings were used to identify adaptation goals and strategies that ZESCO and stakeholders can consider in response to the climate change risks identified. The report concludes with recommendations for further action and analysis, as well as a discussion of uncertainty associated with the analysis.

Recommendations

Upon completion of the assessment steps described in Section 1.4, conclusions and recommendations were presented, and are discussed below, and at greater length in the full report. The major themes of the findings and recommendations are as follows.

The science of climate change risk assessment includes uncertainty but is continually improving; the projected impacts of climate change are better understood for temperature than for precipitation. (Precipitation projections are complicated by many factors, some of which are global in nature, such as large-scale weather patterns and feedback mechanisms, others of which are much more local, such as topography).

Despite the uncertainty surrounding projections of climate change and climate change variability, many areas are experiencing changes in temperature and precipitation that exceed historical patterns. Therefore, it is appropriate to plan for change, especially where such planning can yield other co-benefits, regardless of the extent of climate change.

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 livelihoods depend. The hydropower 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.

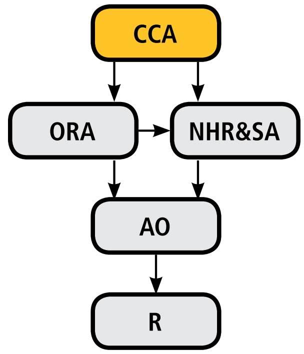
TABLE 1-2: WATER WITHDRAWALS FOR P-1 (MAXIMUM POWER), CONSERVATION AND DEVELOPMENT SCENARIOS

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.

Climate Change Assessment

The key findings of the climate change assessment are the projected changes in temperature, precipitation, and their variability. The full report provides additional information about each of these issues.

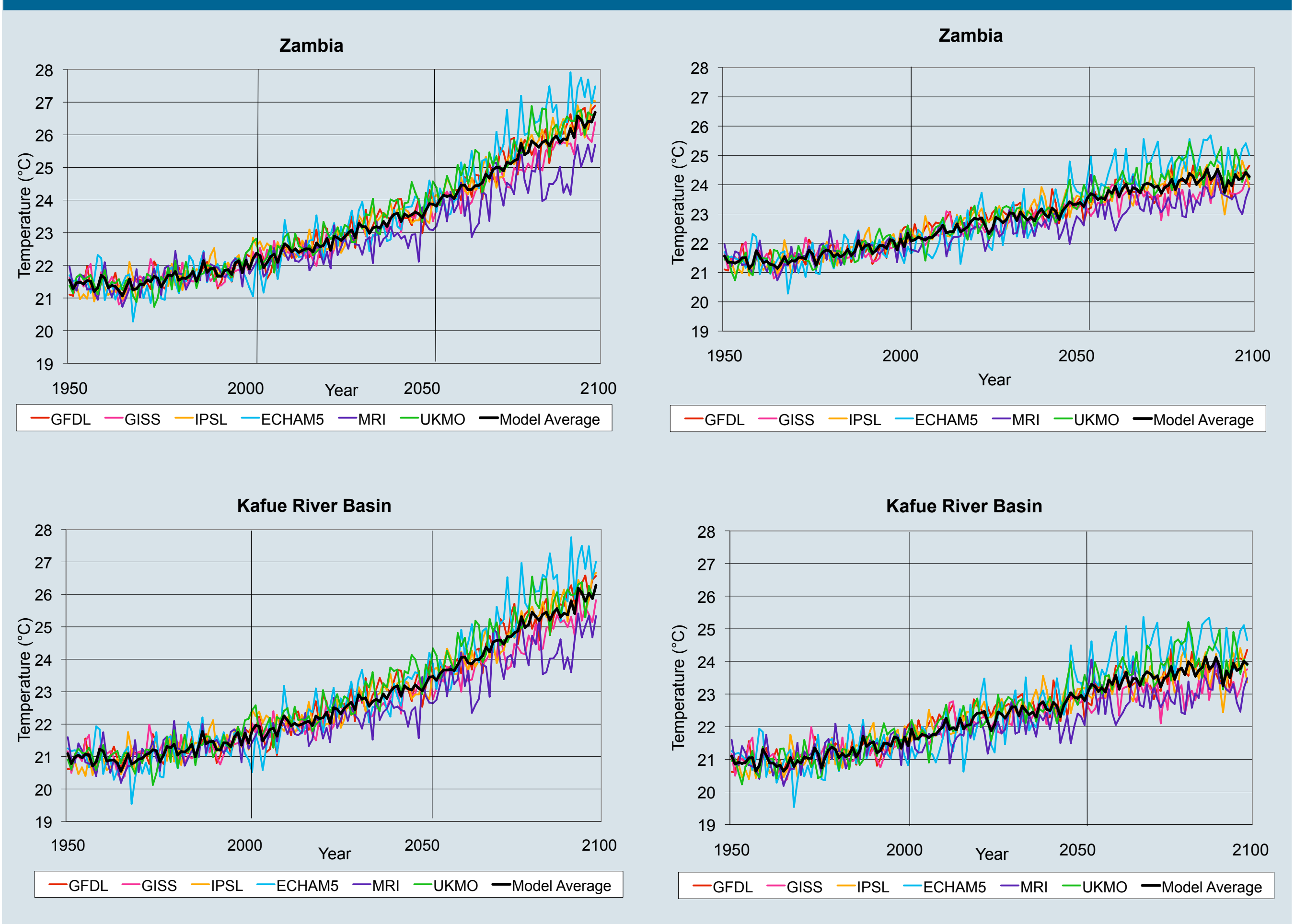


The range of evaluated climate change scenarios show a projected 3°C - 5°C increase in the average annual temperatures in Zambia by 2100, and 3°C - 6°C in the Kafue River Basin.

PROJECTED CHANGES IN TEMPERATURE

Figure 2-1 shows the projected mean annual temperature for the two emission scenarios for the six GCMs studied, and their average (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.

Figure 2-1: Simulated Annual Time Series of Temperature Spatially Averaged over Zambia (top panels) and the Kafue River Basin (bottom panels), for the A2 (left) and B1 (right) Emission Scenarios



PRECIPITATION

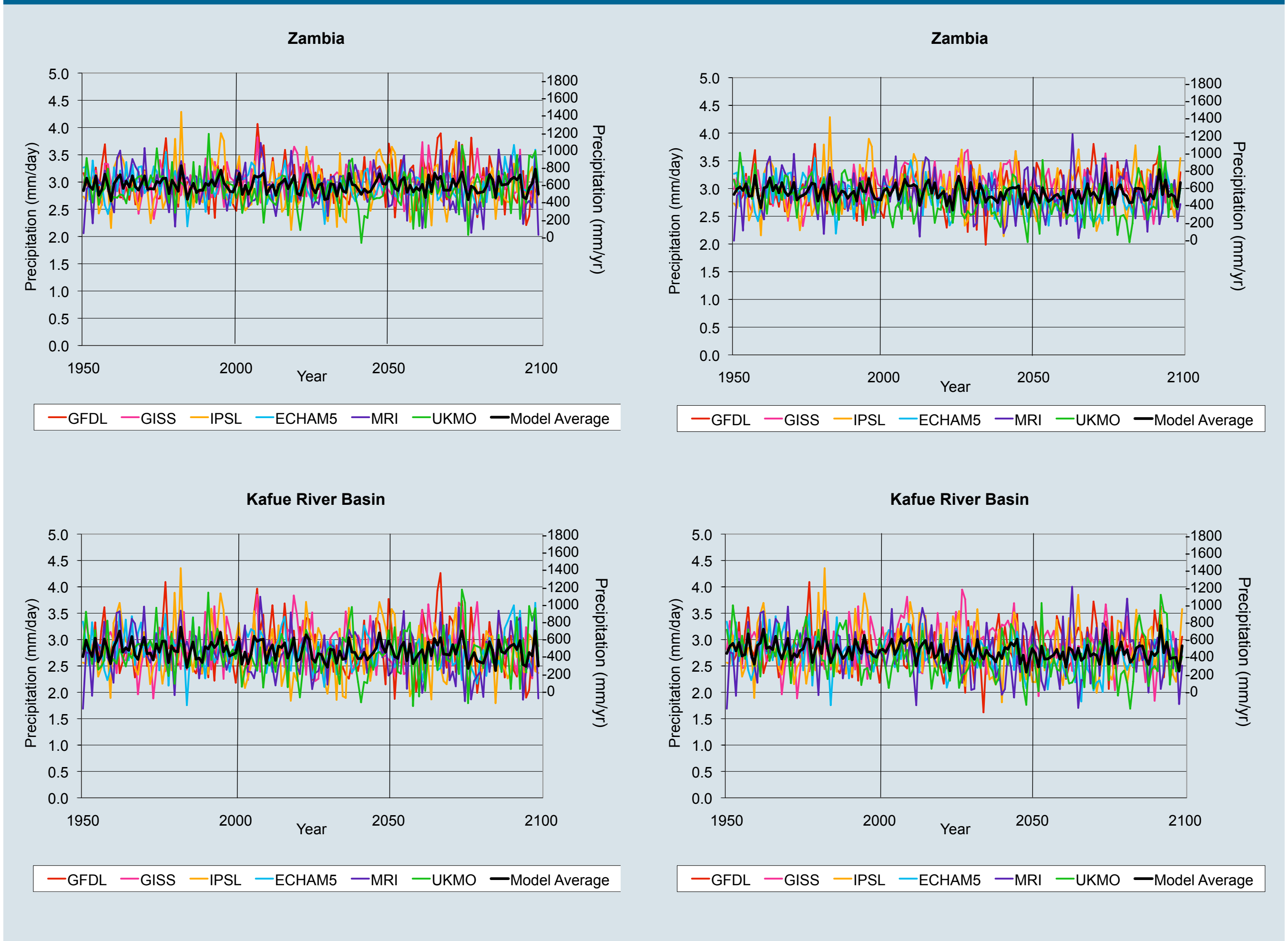
Figure 2-2 shows the mean annual precipitation per day projected through the 21st century by the six GCMs, and the average of the models (black line). None of the models projects significant changes in mean annual precipitation, for either emissions scenario B1 or A2. These results should be viewed in light of the uncertainty in GCM precipitation projections. These uncertainties are addressed further in the text and in the full report.

The impacts of climate change are not projected to significantly change average annual precipitation overall; model results range from -3% to +3% for the A2 and B1 scenarios through 2100.

Of the six GCMs studied, four indicate decreases in average annual precipitation and two indicate increases with a change of -0.09 to 0.06 millimeter per day (mm/d) or -3% to 2% across all three future time periods in the B1 emissions scenario and a change of -0.06 to 0.09 mm/d or -2% to 3% across all three time periods for the A2 emissions scenario. While average annual rainfall is not projected to change very much, climate change impacts on rainfall intensity are expected to be more significant.

The impacts of climate change are projected to increase the variability of precipitation. By the late-century period, maximum 1-day precipitation increases by over 275% for some scenarios; this type of variability makes dry days drier, and wet days wetter.

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



VARIABILITY

Consideration of projected average annual impacts of climate change on temperature and precipitation must be augmented with evaluation of the intra-annual changes in variability.

To quantify the impact of precipitation variability, several precipitation indices were analyzed using RClimDex: consecutive wet days, consecutive dry days, maximum 1-day precipitation (Rx1Day), maximum 5-day precipitation (Rx5Day), total annual precipitation (PRECPTOT), and the simple daily intensity index (SDII).

Figure 2-3 (a-c) shows the temporal variation in the average annual rainfall for the base period, 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 annual precipitation (red line) in the last decade of the late 21st century period and an overall decreasing trend in average annual precipitation (black line) in the B1 emissions scenario. The long term average annual rainfall changes are about -5% (early 21st century) and -2 % (mid and late 21st century) for the A2 emissions scenario and are -3% (early), -10% (mid), and -7% (late) respectively, for the B1 emissions scenario.

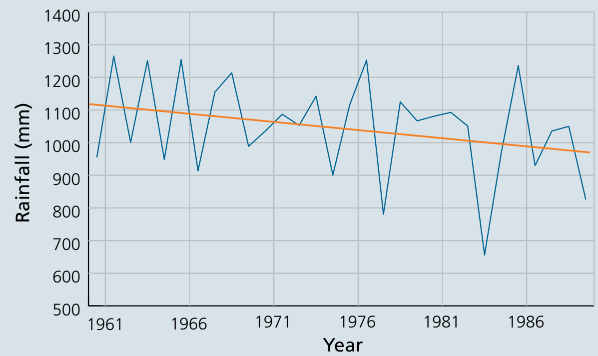
During the late century, the -2% change in rainfall temporally and the +1 to -13% change in rainfall spatially results in a positive change of +11% in Kafue River flows. In this period, the maximum 1-day rainfall (Figure 2-4(a)) and annual rainfall (Figure 2-4 (b)) (particularly for the last 8-10 years) are increasing compared to the base period.

Table 2-1 shows the summary statistics for precipitation comparing the base period and the late-century period for the A2 scenario in ECHAM5.

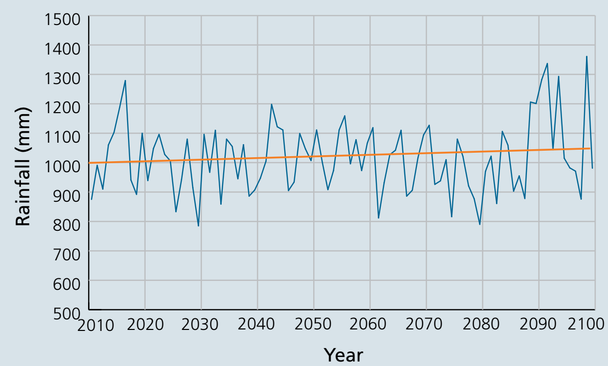
These results can also be considered in terms of "consecutive wet days" and "consecutive dry days" as shown in Table 2-2. A "dry day" is defined as a day with less than 1 millimeter (mm) of precipitation, while a "wet day" represents daily precipitation amounts that are greater than or equal to 1 mm. The values in Table 2-2 reflect the maximum number of consecutive dry or wet days in a year, summarizing the shortest duration, the average length, and longest duration of each of these conditions in the Base and the Late-Century periods.

Figure 2-3: Temporal Variation of Annual Rainfall Compared to Base Period - ECHAM5 A2

2-3(A): ECHAM5 – BASE PERIOD AVERAGE ANNUAL RAINFALL



2-3(B): ECHAM5 A2 – PROJECTED AVERAGE ANNUAL RAINFALL



2-3(C): ECHAM5 B1 – PROJECTED AVERAGE ANNUAL RAINFALL

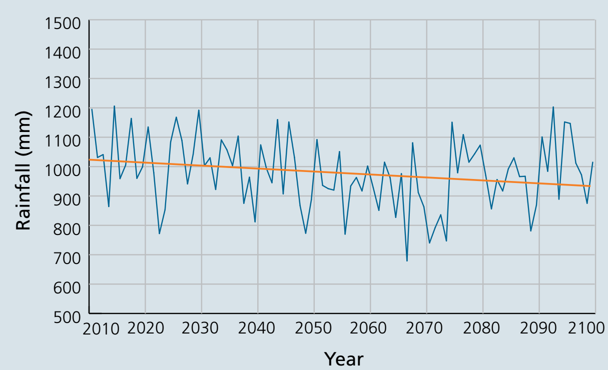


Table 2-1: Comparison of Precipitation for Base and Late-Century Periods for ECHAM5 A2

	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. St. Deviation = standard deviation.

Table 2-2: Comparison of Consecutive Wet Days and Dry Days for the Base Late-Century Periods for ECHAM5 A2

	Consecutive Dry Days		Consecutive Wet Days	
Parameter	Base Period	Late Century Period	Base Period	Late Century Period
Minimum	104	126	26	27
Average	148	170	75	77
Maximum	186	214	113	132
St. Deviation	19	17	25	29

Notes: St. Deviation = standard deviation.

The rainfall intensity (Figure 2-4(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. There are several factors including (but not limited to) the evapotranspiration, temperature, solar radiation, sunshine hours, relative humidity, and wind speed beside the spatial and temporal distribution of rainfall that 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; however, use of a SWAT model was beyond the scope of this project.

In the absence of a SWAT model, researchers focus on further analysis of precipitation, which is the most influential factor affecting flow (Mutreja, 1986). Therefore, precipitation was further evaluated to estimate spatial and temporal variability and its impacts on the flow regime of the Kafue River Basin.

The analysis shows that rainfall intensity and variability have considerable impact on the changes in the flow regime of the watershed over time for the projected climate change scenarios.

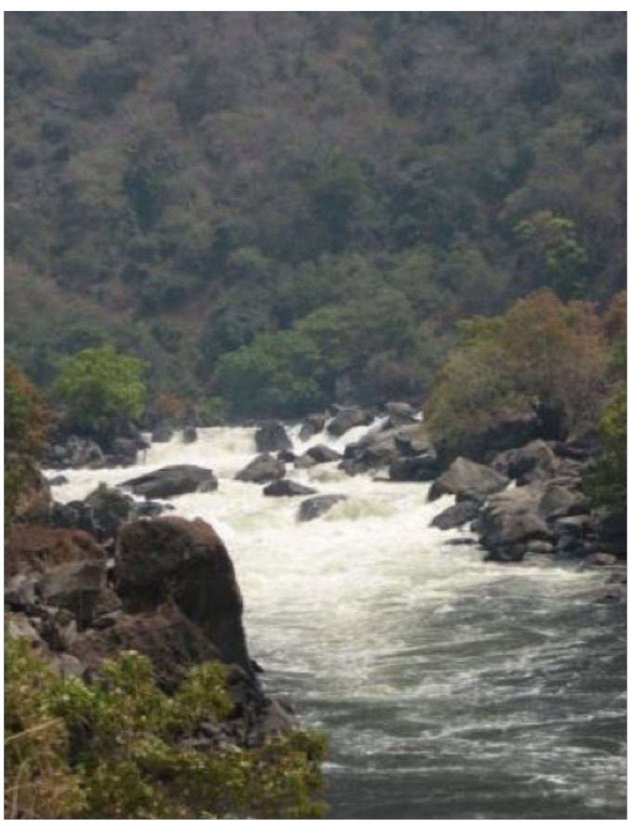
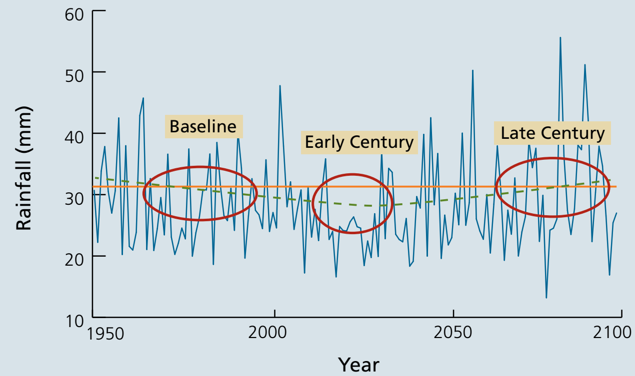
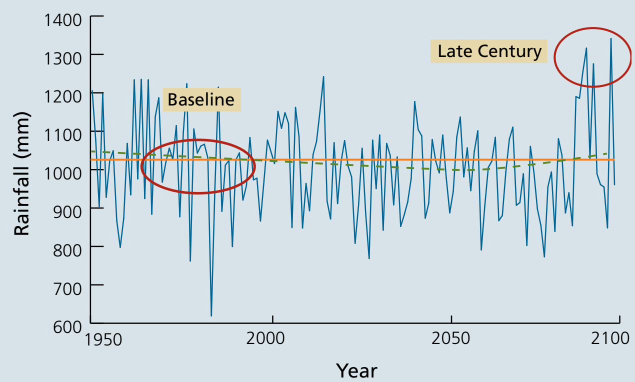


Figure 2-4: Variations in Extreme Rainfall Indices (ECHAM5 A2 Emissions Scenario)

2-4(A): 1-DAY MAXIMUM RAINFALL (ECHAM5 A2)



2-4(B): ANNUAL RAINFALL (ECHAM5 A2)



2-4(C): RAINFALL INTENSITY (ECHAM5 A2)

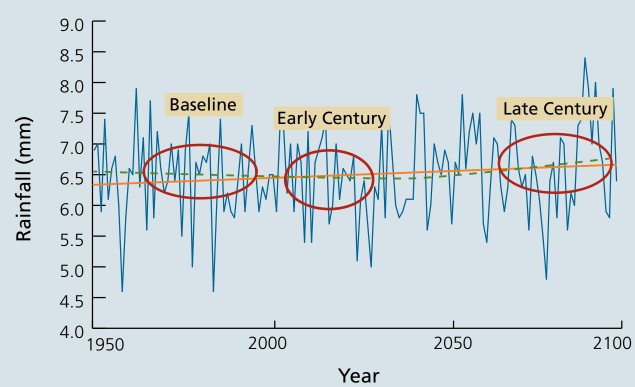
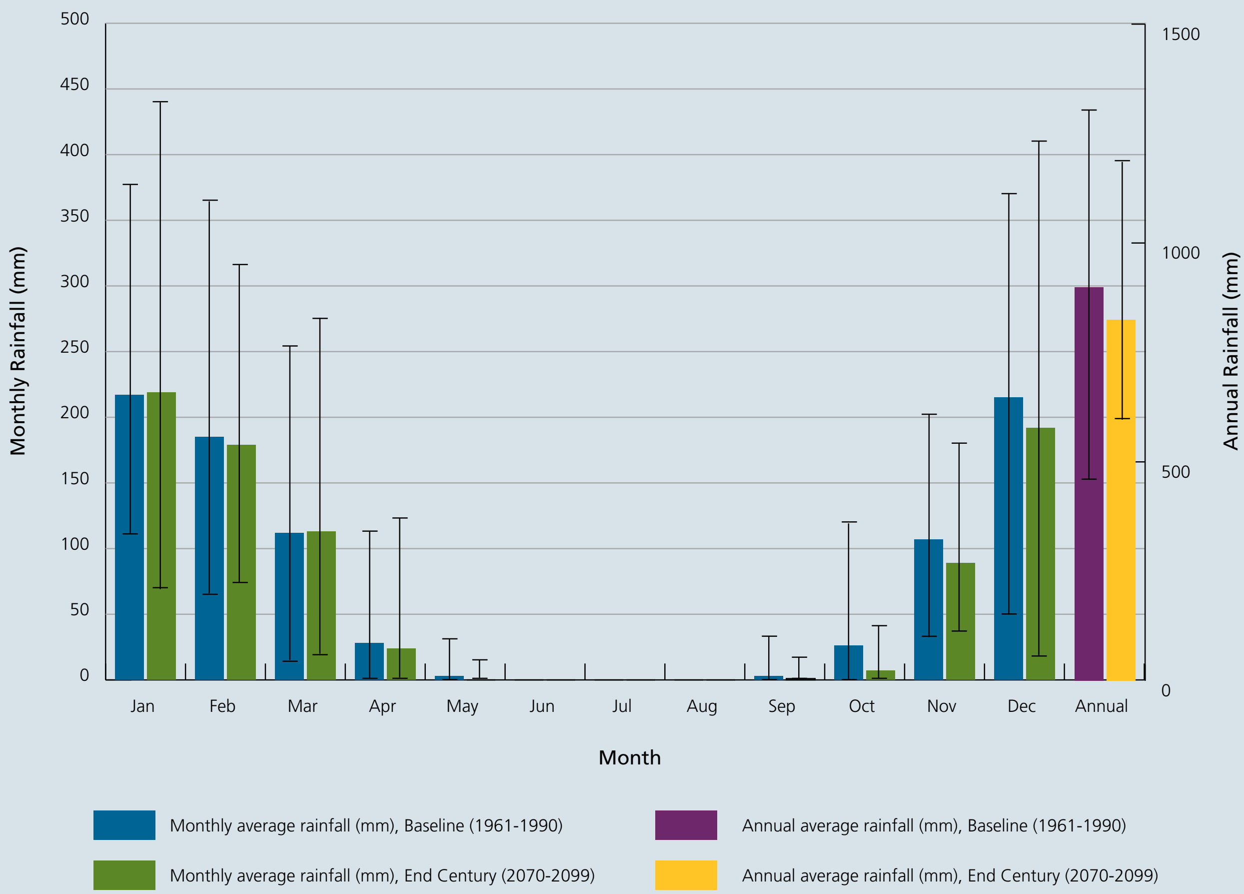


Figure 2-5: ECHAM5 A2 Comparison of Base Period and Late Century Average Monthly and Total Annual Rainfall



Comparison of monthly 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 monthly values.

These projected precipitation changes are an indication of the type of challenge that water-dependent sectors, such as agriculture, will encounter over the next century. As shown in Figure 2-5, the 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 also projected to experience reductions in average precipitation levels.

Comparison of monthly 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 monthly values.

These changes will occur in combination with the previously summarized temperature findings. Figure 2-6 illustrates the effect of these temperature shifts, compared to the base period. For the purpose of this example, the temperature range of the base period

By the late century period, maximum temperatures are projected to exceed historical ranges for 8 months per year; of the 7 months that have traditionally received rain, 3 are projected to become drier. These combined effects are likely to be disruptive to current life cycle patterns for a number of plant and animal species.

(16.9°C to 24.5°C) is divided equally into three relative temperature categories of "cool" (16.9°C to 19.4°C), "warm" (19.5°C to 21.9°C), and "hot" (22°C to 24.5°C). For the future period, values in excess of the base period range define a new, fourth temperature category, labeled "exceeds historical experience." The values and duration of this new category will likely require adaptation responses for humans, plants, and animals.

Temperature changes, combined with the changes in precipitation variability and intensity shown above, will likely have an impact

Figure 2-6: ECHAM5 A2 Comparison of Base Period and Late Century Average Monthly and Total Annual Rainfall

B1 Projected Temperatures		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
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
	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
	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
	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

B1 Legend: Number of Months per Temperature Category

	"Cool"	"Warm"	"Hot"	Exceeds Historical Experience
Base	3	2	7	0
Early	2	2	6	2
Mid	2	1	4	5
Late	0	2	2	8

A2 Projected Temperatures		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
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
	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
	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
	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

A2 Legend: Number of Months per Temperature Category

	"Cool"	"Warm"	"Hot"	Exceeds Historical Experience
Base	3	2	7	0
Early	2	2	6	2
Mid	0	3	2	7
Late	0	2	2	8

on traditional patterns of seasonality that will cause phenological (life cycle) changes for a number of species. This will be particularly relevant to agriculture, where planting and harvest dates will need to adjust to the shifting seasons, and 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; for example, plants and their pollinators, predators, and prey; insects and their host plants; etc. These types of interactions and dependencies may cause cascading impacts on the food chain. Analyses of these interactions and climate impacts, and consequences for the Kafue River Basin context are beyond the scope of this study, but merit attention in the future.

Operational Risk Assessment

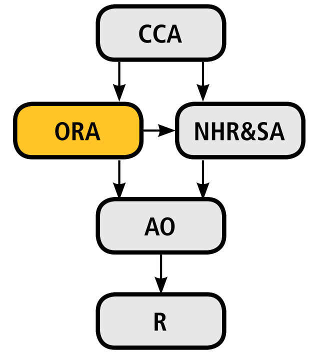
KAFUE RIVER FLOW

For the ECHAM5 A2 emissions scenario, the decrease in flows is much more significant than the decrease in average annual rainfall during the early-century period: an approximate -15% change in flows compared to an estimated -5% change in average annual rainfall for the temporal 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.

During the mid-century period, there is no significant change in average annual rainfall for ECHAM5 A2 (a projected change of -2%) and similar results are observed for flows (a projected change of -1%).

Due to increased variability in precipitation, changes in average annual rainfall of -2% to -5% correspond to changes in projected flows between -1% and -15%.

For the B1 emissions scenario, the temporal changes in long term average annual rainfall correspond to the change in the long term average annual flows. During the early-century period, there is no significant change in the average annual 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 average annual 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). During the late century, the change in average annual rainfall of -7 % temporally and -6.5 to -14 % 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.



KGL POWER

The changes in power generation relative to the base period (1961-1990) ranged from -17.1 to +1.2% in the early-century period, -22.1 to +4% in the mid-century period, and -8.8 to +11.7% in the late-century period across the GCM/SRES scenarios.

Table 3-1 provides a summary of energy production at the KGL power plant for the maximum power scenario, the two emissions scenarios, and the four time periods for ECHAM5. Results for the other GCMs are provided in Appendix 3 of the full report.

As shown in Table 3-1, energy production decreases in the early-period for both the A2 and B1 scenarios, but increases 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.

Under the P-1 scenario (maximum power), results indicate that reductions in water supply due to climate change could cause reductions in power generation of up to 17% to 22% at the KGL plant in the early- and mid-century periods; however, increases in water supply in the late-century period could increase power generation by nearly 12%.

TABLE 3-1: KGL ENERGY PRODUCTION FOR ECHAM5 SCENARIOS

KGL 750MW Capacity Unit – Annual Energy Production (GWh/Yr)									
GCM	**SRES**	**Develop-ment 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; GCM = global climate model; SRES = Special Report on Emission Scenarios

A WXGEN simulation was implemented to further evaluate select flow scenarios: the ECHAM5, A2, late-century (highest increase in flow from the A2 base period) and the ECHAM5, B1, mid-century results (highest decrease in flow from the B1 base period). Table 3-2 presents these results for the KGL power plant. Additional information on weather generators, their uses, and strengths and limitations is included in the full report.

The study also evaluated various development (withdrawal) scenarios ("I" and "C" scenarios) compared to the baseline P-1 power level scenario. Energy production at KGL for the development scenarios for the ECHAM5 A2 scenario is projected to be reduced between 2% and 16% in all four periods (base, early-, mid-, and late-century) as compared to P-1. Energy production at KGL for the development scenarios for the ECHAM5 B1 scenario has similar effects.

Appendix A3 of the full report provides additional information on the impacts at each power station across the various time periods and development scenarios, for KGL and system power generation.

Conservation releases from the IT reservoir help recreate the natural ecological systems in the Kafue Flats by approximating the river flooding conditions that existed during the rainy season before construction of the IT dam. Operational rules for the reservoir model are based on historical ZESCO operating data and prevent the reservoir level from falling below a minimum threshold. In some cases, this threshold prevents the model from evaluating full conservation release volumes for scenarios C-2 and C-3. Therefore, current operational rules may mask the full impacts of implementing these scenarios on power output.

For average annual power generation at KGL, the conservation scenarios do not appear to have a significant impact. However, the modeling power outputs do not reflect the full impact of conservation releases because operating rules based on ZESCO information include minimum drawdown levels for water depth in the IT reservoir. These operating rules in the HEC ResSim model sometimes 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 clearly 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 is consistent with the results of the SEIA Report (SWP, 2003) which indicates that power

In the B1 emission scenario, all four development scenarios (I-3, I-6, I-9, and I-10), result in decreases in average annual energy production compared to the P-1. This is true also for A2, except for the late-century period which shows an increase for I-3, I-6 and I-9.

reductions of up to 65% could occur at the IT generating station due to the implementation of C-3. These results would be further exacerbated with the effects of climate change on water flow and water demand. These conflicts between power generation goals and environmental/conservation goals may require ZESCO and other stakeholders to reconsider water management approaches, particularly in light of climate change impacts.

The review of the impacts of climate change, conservation releases, and development scenarios indicate that the hydropower system at KGL operates with positive power outputs for the P-1 scenario, which assumes increases of 30% in future water withdrawals from the river for agricultural, domestic, mining, and industrial demands due to economic growth and without the impacts of climate change. Additional increases in water demand due to climate change and development impacts are considered in the next section. The extra capacity added at the IT reservoir during development (World Bank, 2009 and Beilfuss, 2001), provides additional water storage capacity that supports productive management of the power system even given rainfall variability and potential precipitation decreases for some climate change projections. However, negative power generation impacts compared to the base period are observed for all future periods for the ECHAM B1 scenarios and for the early- and mid-century periods with ECHAM5 A2; for ECHAM5 A2, late-century, modeling results project power increases.

When development scenarios are considered, average annual increases in water withdrawals rise to 59% for I-3. For I-6 and I-9, the increase is 92% (with differences in the location of the withdrawals). For I-10, a scenario that is only applied to the late-century period, the increase in water withdrawals is 275%. All of these withdrawal levels yield negative impacts on power generation compared to the P-1 scenario for various time periods.

These negative impacts highlight the need to view hydropower operations in a systemic manner within the Kafue River Basin, where climate change impacts will occur over time, in combination

TABLE 3-2: 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; GCM = global climate model; SRES = Special Report on Emission Scenarios with continued development and population growth. In addition, it is important to note that reductions in flows are not only likely to result in the above-mentioned reductions in power, but they 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 (Stenek et al., 2010).

Further, while not estimated in this report, increases in water temperatures in the Kafue Flats will result from the rise in average air temperatures that are predicted to occur by the late-century period. The potential future impacts of climate change on water temperature, industrial discharges, and water-borne diseases were not modeled as part of the study.

FINANCIAL ASSESSMENT

Investors in the KGL power plant will expect to realize the expected return on their investments during the early-century period. Thereforehe impacts of climate change alone on the "maximum power" (P-1) scenario will not interfere with required returns. However, the combination of climate change and other expected demands on the water supply may reduce power generation and the corresponding revenue stream below levels that would be required by most investors.

The power results presented in the previous section represent the projected average annual generation for the respective 30-year future time periods. For the financial analysis of the early-century period, the projected annual generation for KGL was used for each of the 30 years. The financial analysis focuses on a comparison of the P-1 (maximum power) and I-9 (maximum development forecast for the early-century period) scenarios. The conservation scenarios (particularly C-2 and C-3) sometimes produce low reservoir levels that violate KGL operating rules established by ZESCO; therefore, the ResSim Model prevents these releases from occurring in some years. Because the full impact of the conservation scenarios on power and revenue generation is not captured, they are excluded from the financial analysis.

Table 3-3 shows the results of the financial analysis for the early-century period for the ECHAM5 A2 and B1 scenarios. The first row of each table shows projected energy generation for the P-1 (maximum power) scenario, followed by the results that reflect additional impacts of the assumed additional development needs (I-9) during this time period. Subsequent rows then provide corresponding results for key financial indicators. Electricity is valued at $153.3/MWh and indexed to inflation for future years. Additional financial assumptions are explained in the full report and its Appendix A4 (Financial Analysis).

These results demonstrate that the differences between the two future emission scenarios have a significant impact on power generation, and therefore, on the financial viability of KGL. Even with water withdrawals for development (I-9) in the B1 scenario, KGL performs better than in the A2 "maximum power" scenario (P-1). Of the four scenarios in Table 3-3, only the B1 maximum power scenario is projected to yield an internal rate of return (IRR) exceeding 20%, a common threshold for defining an acceptable return for investors. Figure 3-1 shows the relationship between projected average annual power generation and the after-tax IRR for each of these four scenarios, as well as the corresponding finding from the original (without climate impacts) financial analysis. The red line indicates the threshold IRR of 20%, suggesting that an average annual generation of about 2,450 gigawatt-hours (GWhs) is the level needed to satisfy typical investor requirements.

The combination of climate change and other expected demands on the water supply is projected to reduce power generation – and thus KGL's internal rate of return (IRR) – to levels below 20%, an IRR threshold that is not uncommonly required by investors.

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. In this case, 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 become 2,221 GWh rather than 2,090 GWhs, with an IRR of nearly 18% rather than 16%.

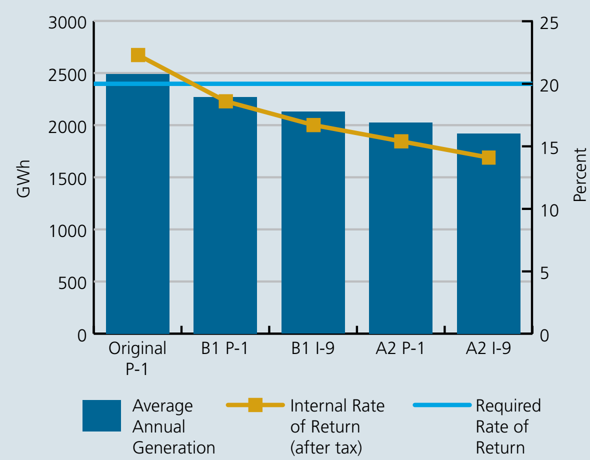
TABLE 3-3: FINANCIAL PERFORMANCE FOR ECHAM5 A2 SCENARIO; BASE PERIOD AND EARLY CENTURY TIME PERIOD

	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.

A more robust probability analysis will deliver different results, which should better inform planning decisions. Again, these results are generated by varying the distribution of the 30 years of annual electricity production to illustrate the possible impact for ROI. Further improvement would result with probability assessments of the available flow to the power plant.

Figure 3-1: Projected Early Century Annual Generation and After-Tax Internal Rate of Return for A2 and B1 Scenarios

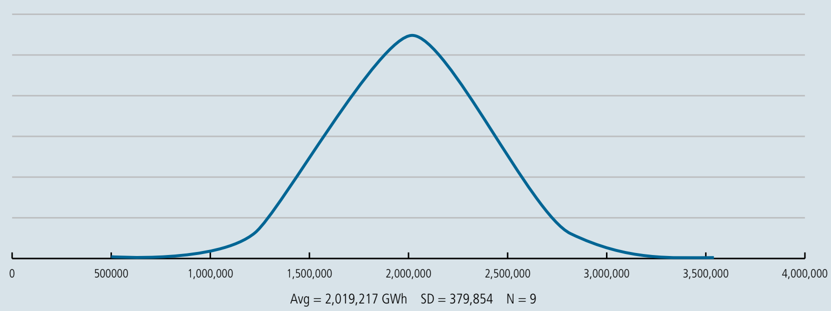


As discussed further in Section 3.5 of the full report, there is uncertainty associated with a number of factors that tie to the financial analysis; in addition, the financial analysis uses the outputs of the modeling effort, which also includes uncertainty in regards to climate change projections, flow 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. 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.

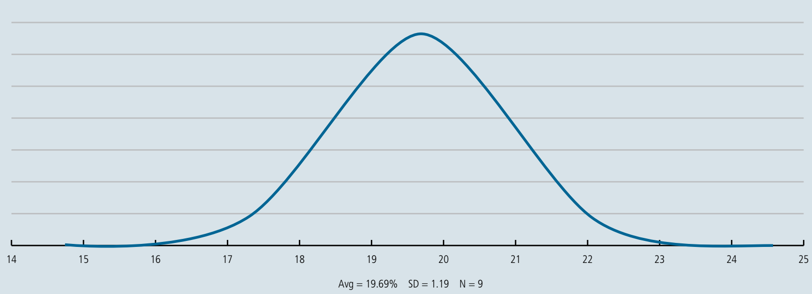
Figure 3-2: Probability Assessment of KGL Performance, Early Century

3-2(A): PROJECTED FREQUENCY CURVE, KGL ANNUAL GENERATION



Notes: Avg. = average; MWh = Megawatt-hour; SD = standard deviation; N = number of evaluations of annual MWh variability.

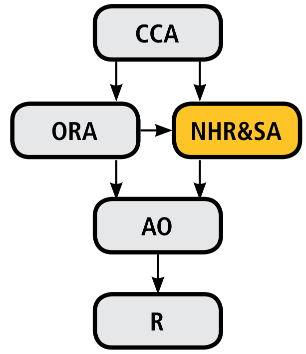
3-2(B): PROJECTED FREQUENCY CURVE, KGL INTERNAL RATE OF RETURN



Notes: Avg. = average; IRR = internal rate of return; SD = standard deviation; N = number of evaluations of annual MWh variability.

Natural Hazard Risk & Sector Assessment

NATURAL HAZARD RISK



Climate change variability causes greater uncertainty in water supply and demand in the future. This can result in fewer, more extreme precipitation events, and longer, more severe periods of drought between them. This would greatly impact water supply and management issues for ZESCO and other sectors.

FLOODS: The flood hazard risk assessment shows that floods have been occurring approximately 0.42 times each year or once every 2.3 years (OFDA/CRED, 2007). To help understand the conditions which caused each flood event, precipitation data were analyzed for each flood time period. This data was used to identify a rainfall deviation from normal seasonal rainfall (October to March) that constitutes a flood event; this "flood threshold" was identified as 15% in Lusaka. That is, a 15% deviation from the normal rainfall for the rainy season results in a flood. According to several of the GCMs/emissions scenarios, events that exceed the flood threshold will continue and in some cases, increase, in the region. Therefore, flood frequency is predicted to remain high in the future. Table 4-1 shows the probability of exceeding the flood threshold across the three GCMs, two emission scenarios, and three time horizons. These probabilities may be converted to return period events. For example, ECHAM5, A2, Early Century shows a flood event (exceeding the threshold) occurring every 4-years (100/25), then increasing in the mid century to ever 2.9 years (100/35). If the dam was built to withstand a maximum probable flood of 1000-years based on historical events, it should be understood that the future maximum probable flood may change based on the GCM and emission scenario.

Greater variability in precipitation could increase the likelihood of floods and droughts.

Based on a 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 for some future time horizons, changes to spatial and temporal variability in the basin may result in more extreme precipitation events and greater run-off; this could increase the frequency or severity of floods.

KGU has been in operation since 1977 and was damaged by flood waters in 2005. Of the nine floods identified in 31 years in the ZESCO operations area, damage to ZESCO facilities was recorded for only one event. The annual loss for a hazard is determined by plotting the probability of occurrence on the x-axis and the corresponding losses on the y-axis and then calculating the area under the curve. The average annual loss for flood is calculated to be USD 449,586. To put this in perspective, the total annual revenue for the Kafue Gorge power system (IT, KGU, and KGL) is USD 850 million. 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 representative annualized loss 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 of the full report 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 4-2. This loss does not include any potential future losses for the additional power generating units planned for KGL and IT.

TABLE 4-1: PROBABILITIES OF EXCEEDING SEASONAL PRECIPITATION FLOOD THRESHOLD

	Emissions Scenario A2			Emissions Scenario B1		
GCM	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	25%	35%	39%	29%	16%	23%
IPSL	21%	36%	16%	43%	26%	29%
MRI	22%	28%	18%	19%	14%	27%

TABLE 4-2: PROJECTED FINANCIAL LOSSES 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

TABLE 4-3: PROJECTED FINANCIAL LOSSES 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	13%	9%	10%	14%	19%	17%
IPSL	15%	14%	22%	5%	9%	10%
MRI	19%	13%	22%	21%	26%	13%

DROUGHTS: The drought hazard assessment shows that droughts are occurring frequently at approximately 0.19 times each year or once every 5 years (OFDA/CRED, 2007). 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 each documented drought event. 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 3.2 of the full report 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 Appendix A5 of the full report, it is expected that droughts could occur more frequently for several of the GCM/emission scenarios, as shown in Table 4-3. 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.

Looking at the events which impacted this system for ZESCO, two major droughts caused a reduction in power over 25 years, one in 1995 and one in 2005. Detailed loss information is available 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. To put this in perspective, the total annual revenue for the Kafue Gorge system (IT, KGU, and KGL) is USD 850 million. Table A6-3 in Appendix A6 of the full report was used to help calculate the estimated future annual loss shown in Table 4-4. This loss does not include any modeled future loss for the additional power generating unit.

The financial risks to ZESCO associated with drought events are by far the most potentially expensive compared to the other evaluated hazards, with costs in the millions of dollars (USD), depending upon the scenario and timeframe. Therefore, ZESCO's priority for climate change adaptation planning would likely need to focus on the drought hazard.

The financial risks to hydropower productiion associated with drought events are by far the most potentially expensive compared to the other evaluated natural hazards.

The risk assessments presented in the full report have been summarized in tables to facilitate comparison and ranking. Table 4-3 in the full report shows the hazard evaluation results with the elements of frequency and magnitude for current and future conditions for each natural hazard. Each component has been

TABLE 4-4: PROJECTED FINANCIAL LOSSES 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

ranked high, medium, or low. Table 4-4 in the full report 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 4-5 in the full report shows the overall risk assessment results, incorporating the hazard and vulnerability findings.

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 annualized cost of future loss due to floods yields results in the range of 233,118 to 449,586 USD. The potential annualized 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 annualized losses between 25,000 USD and 80,000 USD. The increased risk of disease, in the form of malaria, produces a low level of direct 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, 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. Therefore, ZESCO's priority for climate change adaptation planning needs to be the drought hazard.

The hazards identified as high risk are considered further as part of Adaptation Options in this report (and Section 5.0 of the full report).

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

1) Collect detailed precipitation and temperature across the basin. Add additional rain and temperature gauge instrumentation across the basin to better understand spatial variability. Staff using the instrumentation would need to have proper training and funds for maintenance and data collection in order to support a consistent and accurate approach.
2) Capture detailed loss associated with 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 hazards.
3) Develop better topographic data to support the hydrological modeling and help to reduce uncertainty associated with flow estimates and provide a more accurate floodplain delineation to assist in evaluating the flood hazard.
4) 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.

SECTOR ASSESSMENT

Figure 4-1 summarizes the combined effects of future development, with and without the additional impacts of climate change, on water demand. For each future period, the first three columns show current and projected demand for water from the agricultural, domestic, mining, and industrial sectors. These are the major categories of demand; however, because no other type of water demand is captured by these bottom three lines, they represent an understatement of total potential demand. These estimated demands were developed from resources independent of the estimated water demands that were incorporated into the modeling analysis (based on the 2003 SEIA Report), and further corroborate the values used as withdrawals to support flow and power modeling.

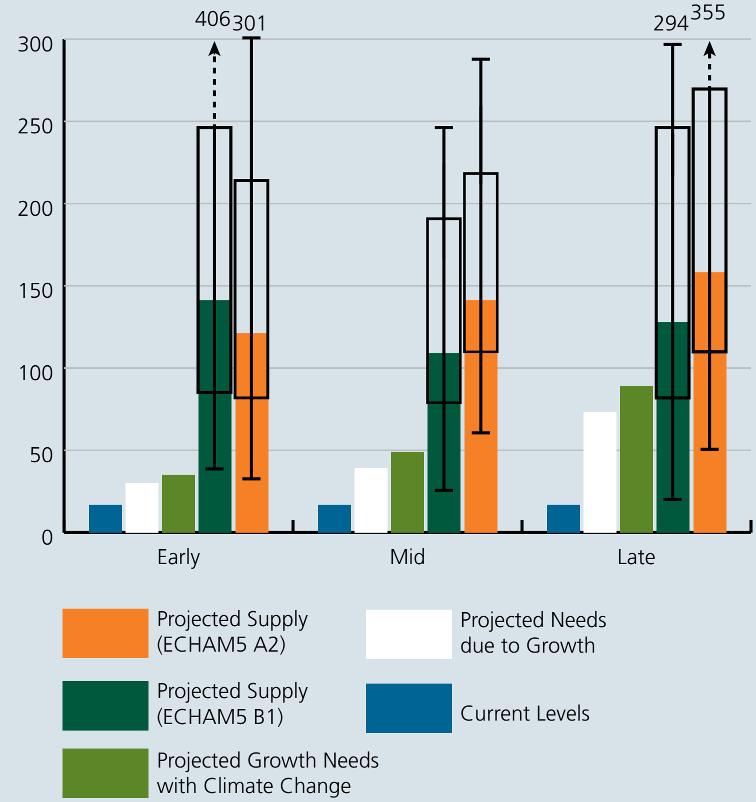
The final two bars for each future period in Figure 4-1 show projected water supply in the Kafue River based on the outputs of the A2 and B1 emissions scenarios for the ECHAM5 GCM.

Temperature increases are projected to contribute to increases in future water demands, due to increased evapotranspiration, with annual average increases of 6% in the early- and mid-century periods and 13% in the late century period. These averages mask the much larger effects of intra-annual variability in evapotranspiration that will drive demand higher among humans, animals and plants.

These are the same flow rates used as inputs for electricity generation projections in the HEC ResSim (energy) modeling. The height of the column shows the 30-year average supply for the two scenarios; the boxed area surrounding the top of these columns illustrates the extent of one standard deviation of the 30 years' of projected supply levels around the 30-year average. Finally, the lines bisecting the supply columns indicate the further extent of the maximum and minimum values for the 30-year period. The distance between the heights of the supply and demand columns represents instantaneous flow available in the Kafue River for hydropower generation. It is important to note, however, that flow to the hydropower plants is managed with reservoirs, where the available water accumulates over time. As with economic demands for water, the water requirements of hydropower plants can be represented in units of cubic meters per second, but the power plants draw upon the stored volume in the reservoirs, not the instantaneous available flow in the river.

The graph shows that for the ECHAM5 B1 scenario, the instantaneous supply for hydropower generation in the early-century period is, on average, about twice as large (90 cms) as it is projected to be in the late period (45 cms); however the alternative projection from ECHAM5 shows supply increasing at a rate that is nearly equal to the projected increase in demand (about 80 cms in the early period vs. about 75 cms in the late period).

Figure 4-1: Comparison of Projected Average Annual Demand and Supply of Water in the Kafue River Basin



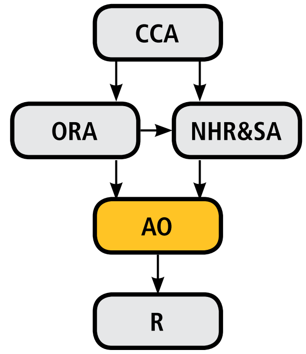
Note: cms = cubic meters per second
Projected supply columns show average results for the period, as well as the range of +/- 1 standard deviation (about 66% of the results), and the extent of the maximum and minimum projected values for the 30-year period. Additional detail for supply results are included in the full report.
"Projected Demand" = projected combined annual water demand from the agricultural, domestic, mining, and industrial sectors. Projected values for early-, mid-, and late-century reflect average values for each 30 year period. Agricultural projections reflect scenarios I-3, I-9, and I-10. Other sectors incorporate input from other sources, as explained in the text. Because conservation releases for biodiversity are not consumptive uses, they are not reflected.
"Base Year Demand" = 2008 Water Demand (World Bank, 2009).

Adaptation Options

Based on climate change projections for flow and energy impacts, other water uses, and the hazards risk assessment and sector analyses, three adaptation goals were identified for ZESCO. These were based on high risk concerns to ZESCO operations as summarized below.

Although drought is not currently impacting power generation, 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 higher than the present (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 discussed in the full report has already impacted ZESCO facilities. It is likely this 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 adaptation goal, since adaptation will reduce losses that could occur from such events either with or without additional exacerbation from climate change impacts.



Given food security needs and the economic importance of agriculture in the Kafue River Basin, the 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 irrigation in the area can be expected to draw water away from ZESCO operations in the future. While the primary water demand is from agriculture, water needs for conservation, public uses, and industry uses also may 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.

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 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

TABLE 5-1: 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**
Water Efficiency, including 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; + consider further

TABLE 5-2: ADAPTATION 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

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.

Nine adaptation strategies were identified and evaluated to support Adaptation Goal #1: preventing losses to ZESCO from drought and precipitation variability. The results of this preliminary evaluation are presented in Table 5-1.

The six strategies for Adaptation Goal #2 include physical, organizational, social, and economic actions as indicated in Table 5-2. The strategies were evaluated using the STAPLEE criteria and the preliminary ranking results are shown in Table 5-2. Again, input from ZESCO and appropriate stakeholders at the local level are recommended to refine the evaluation of the adaptation strategies.

The four adaptation strategies for Adaptation Goal #3 include organizational, social, and economic actions as indicated in Table 5-3. The strategies were evaluated using the STAPLEE criteria and the preliminary ranking results are shown in Table 4-7. Here too, input from ZESCO and appropriate stakeholders at the local level are recommended to refine the evaluation of the strategies.

TABLE 5-3: GOAL #3 STRATEGY EVALUATION

Adaptation Strategy (Category)	S	T	A	P	L	E	E	Total
Assist the Government of Zambia 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

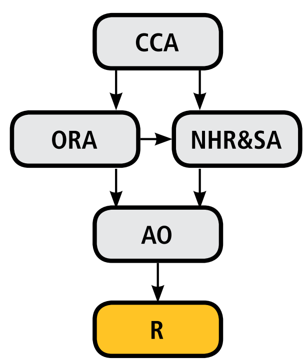
As discussed above, stakeholder input would be valuable to help check the rankings indicated above to ensure all promising strategies have been identified. Based on the preliminary rankings shown in Tables 5-1 through 5-3, some promising options were explored further. These include strategies that run across the three adaptation goals, such as: integrated water management (ties to Adaptation Goal #1), stabilization of slopes (ties to Adaptation Goal #2), and implementation of efficient irrigation methods (ties to Adaptation Goal #3).

To minimize reduced flows, four adaptation strategies were identified and evaluated to reduce water demand from development through improved agricultural methods.

Adaptation goals, descriptions and evaluations of the strategies, and other information are included in Section 5.0 of the full report. Recommendations regarding the promising adaptation strategies identified from this study's evaluation are presented in the recommendations of the full report and are summarized below.

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.



Climate change challenges highlight 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, in isolation, the hydropower system may be able to cope with 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 affect 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.

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.

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.

To improve the effectiveness of climate change adaptation efforts, it is needed to expand engagement with other Basin users and relevant stakeholders. These are generally lower cost strategies that can achieve significant positive results, and develop good-will with customers and other stakeholders.

For physical adaptation strategies, feasibility studies and benefit/cost analyses, **capital project planning would need to be completed to determine which options would 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 are needed for detailed analysis and to support management decisions.

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.

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. spawning cycles of fish, or interactions between plants and their pollinators,.), and have cascading impacts on the food chain. **Analyses of this type of climate change impacts are beyond the scope of this study but merit attention given the possible effects on the needs for different regimes of water releases.**

Climate changes that impact the flow of the Kafue River will have impacts on the financial performance of its 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.

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.

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. 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.

Sources: Data and Models

TEMPERATURE AND PRECIPITATION PROJECTIONS

Temperature and precipitation analyses were performed for the statistically downscaled results of six GCMs, across a base period and three future time periods (early-, mid- and late-century) of the 21st century, and two emissions scenarios (A2 and B1) developed by the IPCC. Outputs were provided as gridded data sets for both Zambia as a whole and for the Kafue River Basin study area. Downscaled datasets are available free of charge from the University of Santa Clara, California at: http://www.engr.scu.edu/~emaurer/global_data/. The data inputs and outputs for this step are provided in Appendix B of the full report.

HYDROLOGIC FLOW MODELING

To estimate the projected climate change impacts on flow in the Kafue River Basin study area, the Hydrologic Modeling System (HMS) from the Hydraulic Engineering Center (HEC) of the U.S. Army Corps of Engineers (USACE) was used. USACE HEC-HMS modeling software is available at no charge for download at: http://www.hec.usace.army.mil/software/hec-hms/index.html. The data inputs and outputs for this step are provided in Appendix B of the full report.

Of the original six GCMs, the three that produced high, low, and median climate change results were selected for further analysis. Scenarios developed from the three GCMs and two emissions scenarios were used to model flow for a base period and for the three future time periods. From these results, the scenario combinations that yielded the greatest increase and decrease in flow from their respective base periods were selected for further analysis using a U.S. Department of Agriculture WXGEN tool. The WXGEN tool can be downloaded at no charge from: http://epicapex.brc.tamus.edu/downloads/ model-executables/wxgn-v3020. The data inputs and outputs for this step are provided in Appendix B of the full report.

RESERVOIR (ENERGY) MODELING

A hydrodynamic and energy model (also available from the HEC at USACE), the HEC ResSim model, was used to evaluate power impacts for the flow results from the HEC-HMS and WXGEN modeling. In addition to the climate change impacts on flow, HEC ResSim was used to consider three conservation (freshet releases) scenarios (C-1, C-2, and C-3) and four development (consumptive water withdrawal) scenarios (I-3, I-6, I-9, and I-10), as shown in Figure ES-1. HEC ResSim modeling software is available for download at no charge from USACE HEC at: http://www.hec.usace.army.mil/software/HECRessim/. The data inputs and outputs for this step are provided in Appendix B of the full report.

FINANCIAL ASSESSMENT

A financial assessment was completed using the Renewable Energy Technology Screening (RETScreen) tool to consider the impacts of climate change on the financial viability of KGL. This tool was developed by Natural Resources Canada, with input from stakeholders such as the U.S. National Aeronautics and Space Agency. The financial analysis also considered the impacts of the conservation and development scenarios on power generation. RETScreen is available for download at no charge from Natural Resources Canada at: http://www.retscreen.net. The data inputs and outputs for this step are provided in Appendix B of the full report.

NATURAL HAZARD RISK AND SECTOR ASSESSMENTS

This study also considers the indirect risks of climate change to ZESCO through impacts on natural hazards (flood, droughts, landsides, wildfires, and disease) and potential impacts on select economic and environmental sectors that use water (agriculture, mining, urban demand, and conservation). The data inputs and outputs for this step are provided in Appendix B of the full report.

ADAPTATION OPTIONS

Based on modeling and analysis and review of recent literature, adaptation goals were identified. These goals and climate change risks were then evaluated to identify adaptation strategies for achieving two primary objectives: (1) address the most threatening and urgent concerns as promptly and effectively as possible and (2) identify those responses that have multiple benefits and/or are most cost-effective in order to minimize overall adaptation costs. The adaptation section identifies three primary adaptation goals, associated strategies, and promising adaptation options that are recommended for further consideration and potential implementation by ZESCO.

Uncertainty

Information to support assumptions and analysis in this study include previous reports prepared by (or for) the IFC, the World Bank Group or other entities, such as the European Commission and the United Nations Food and Agriculture Organization, as well as operational data shared by ZESCO, and financial assumptions shared by the IFC. In addition, a range of data sets were used to support modeling. Uncertainty associated with project steps is address below. While considerable uncertainty is associated with modeling steps and climate change projections, the study indicates that the risks are sufficient to warrant adaptation planning, even in the presence of uncertainty. Because there is considerable uncertainty associated with climate change risk assessment, adaptation goals and strategies in this report focus on those strategies that appear warranted given current conditions (past hazard events, projected water demand and electricity needs, etc.). The strategies proposed would be sound investments given current and future conditions without climate change impacts and become even more warranted given the climate change risks identified in this study.

TEMPERATURE AND PRECIPITATION PROJECTIONS

The uncertainties associated with GCM projections of climate change have been categorized as: (1) unknown future emissions of GHG gases; (2) uncertain response of the global climate system to increases in GHG concentrations; and (3) incomplete understanding of regional climatic changes and their impacts, that will result from global changes (IPCC, 2001). 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 sources is unquantifiable. Confidence bounds cannot be placed on any GCM projections.

Overall, the projected average annual precipitation changes are relatively small, but are associated with large uncertainty; the simulation of precipitation remains one of the principal challenges in global climate modeling. (Additional information is provided in Appendix A1 of the full report.) 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 (IISD, 2009).

In addition, the El Niño/La Niña-Southern Oscillation (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 and 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.

Limitations to GCM models are becoming better understood, allowing for further modification to improve performance. For example, recent analysis of GCM projections compared with observed precipitation data indicates that the models tend to underestimate climate change impacts on extreme precipitation events. For example, "[c]hanges in extreme precipitation projected by models, and thus the impacts of future changes in extreme precipitation, may be underestimated because models seem to underestimate the observed increase in heavy precipitation with warming" (Min, 2011).

Analysis of climate change risk requires frequent updates to ensure that it continues to reflect the most recent data inputs and outputs that are available from the international research community.

HYDROLOGIC FLOW PROJECTIONS

The hydrologic flow projections build on the temperature and precipitation projections from the selected GCMs, emissions scenarios, and time horizons. 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 publically 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 of the full report. 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 U.N. 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 conclusions from this study note 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" (Elasha, et. al., 2006). There are eight times fewer weather stations on the continent than the minimum recommended level 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 important 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 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 in the pilot study to evaluate the variability of flows among the GCMs (see Section 3.3.2, Rainfall Variability and Impacts on Flow Projections). 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.

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 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 publically available information regarding power unit locations, sizes, efficiencies and operational rules. Numerous assumptions were made based on the available data to establish the model. Where assumptions differ from actual operational parameters and 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 A3 of the full report.

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.

NATURAL HAZARD RISK AND SECTOR ASSESSMENTS

The average annual loss estimates were developed with limited loss data across a limited time period. These limited sets of data do not allow the development of a very comprehensive view of potential loss and should be reviewed and refined over time, either with new loss events or additional modeling.

The hazard frequencies were developed using national datasets and not local, Kafue River Basin data. Local loss data would have to be collected in the future to better represent flood frequency potential. Also, a detailed hydraulic analysis should be conducted for the entire basin to support estimates of potential flood frequency.

ADAPTATION OPTIONS

The adaptation goals and strategies are based on the literature, an understanding of climate change risks based on this study, and implementation of an evaluation framework (POSE and STAPLEE). The adaptation goals and strategies focus on "no regrets" options that appear merited based on current and anticipated conditions with or without the exacerbating impacts of climate change. While the study team used available information and professional knowledge to identify and rank appropriate goals and strategies, uncertainty remains regarding actual local conditions and needs. Therefore, local stakeholder input would be valuable to ground truth the goals, strategies and rankings to ensure they address local priorities, goals, and needs. This information also would assist in reviewing and refining preliminary loss data and cost/benefit analysis approaches and data included in this report.

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