Annex H

Climate Change Risk Review

H1 CLIMATE CHANGE RISK REVIEW

H1.1 INTRODUCTION

A high-level climate risk assessment was undertaken of the Batoka Gorge Catchment to understand the likely implications of future climate change on the Gorge, and specifically on water availability, which has direct implications for the functioning of the proposed BGHES. The assessment included a review of publically available reports and scientific papers, as well as an analysis of downscaled climate data for the catchment to look specifically at water availability.

H1.2 HISTORIC CLIMATE

H1.2.1 Overall

The Zambezi River Basin is subjected to one of the most variable climates of any major river basin in the world, experiencing extreme conditions across the catchment through time (1). A high level summary of temperature, precipitation and flooding patterns in the Basin is discussed below.

H1.2.2 Temperature

Temperature variation across the Basin across seasons is not high (i.e. estimated to be in the region of 4 °C) (2). The coolest temperature is experienced in July and winter temperatures range from 13 °C (higher elevation areas to the south) to 23 °C (lower elevation areas in the delta) (3). Mean daily temperatures in the summer months range between 23 °C in the highest elevation areas, to 31 °C for the lower parts of the Zambezi valley (4). Temperatures are warmest along the border of Zambia and Zimbabwe.

H1.2.3 Precipitation

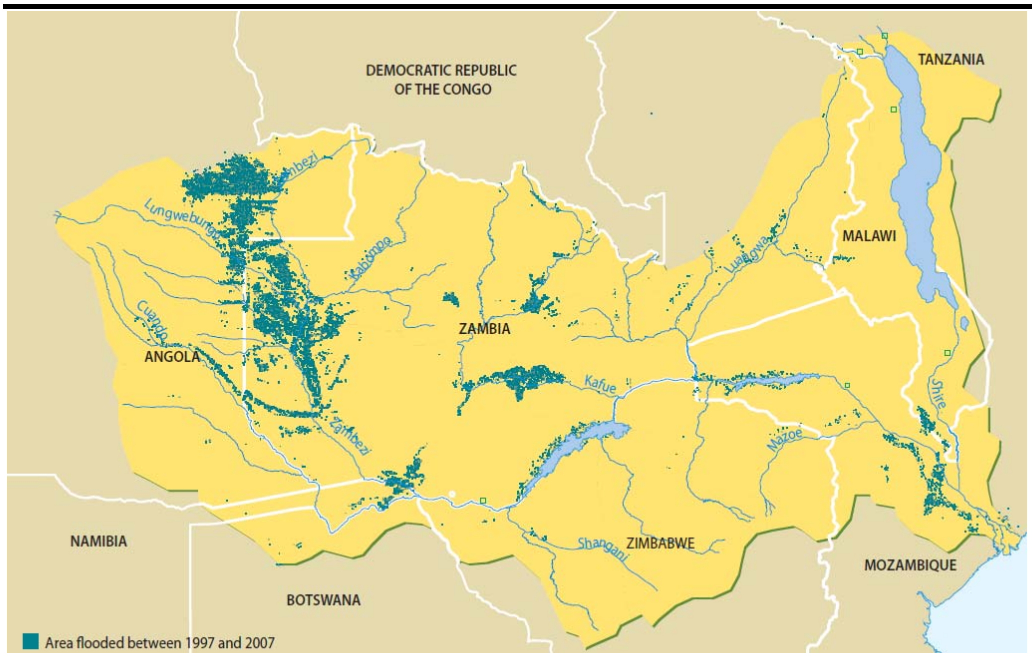
Average annual rainfall in the Basin is approximately 950 mm/year, although this average is unevenly distributed with the northern and eastern portions of the Basin receiving the highest proportion of rainfall (5). For example, annual rainfall varies from more than 1600 mm in the northern highland areas to approximately 550 mm in the southern portion of the basin (6).

(1) Beilfuss, Richard. 2012. A risky climate for southern African hydro: Assessing hydrological risks and consequences for Zambezi river basin dams. International River.
(2) Schlosser, C. Adam; Strzepek, Kenneth (2013): Regional climate change of the greater Zambezi River Basin: A hybrid assessment, WIDER Working Paper, No. 2013/040.
(3) SADC/SARDC and others 2012. Zambezi River Basin Atlas of the Changing Environment. SADC, SARDC, ZAMCOM, GRID-Arendal, UNEP. Gaborone, Harare and Arendal.
(4) Ibid.
(5) Ibid.
(6) Beilfuss, Richard. 2012. A risky climate for southern African hydro: Assessing hydrological risks and consequences for Zambezi river basin dams. International River.

The Zambezi River Basin experiences robust seasonality with regards to precipitation, with a dry season from June to August (average precipitation of less than 0.05 mm/ day), and a wet season from December to February (average precipitation of more than 5 mm/day) [7].

Flooding is problematic in the Basin, occurring nearly every decade resulting in numerous socio-economic impacts. Between 1997 -2001, the Basin has experienced extreme floods during the rainy seasons of 1999 – 2000, 2005 - 2006 and 2007 [8]. Tropical cyclones originating in the Indian Ocean are the main driver behind the flood cycles. The areas of the Basin flooded between 1997 and 2007 are shown in *Figure H1.1* below.

Figure H1.1 Flooding in the Zambezi River Basin between 1997 and 2007 [9]



H1.2.4 Drought

Multi-year droughts are observed in the Basin, with implications for river flows and hydropower production. For example, the effect of the 1991/92 drought on hydropower potential in the Kariba Dam resulted in a regional impact that included a reduction of GDP of US$ 102 million, US$ 36 million reduction in export earnings and the loss of 3 000 jobs [10].

(7) Schlosser, C. Adam; Strzepek, Kenneth (2013): Regional climate change of the greater Zambezi River Basin: A hybrid assessment, WIDER Working Paper, No. 2013/040, ISBN 978-92-9230-617-5.

(8) SADC/SARDC and others 2012. Zambezi River Basin Atlas of the Changing Environment. SADC, SARDC, ZAMCOM, GRID-Arendal, UNEP. Gaborone, Harare and Arendal.

(9) SADC and ZRA 2007. Rapid Assessment Report: Integrated Water Resources Management Strategy for the Zambezi River Basin. SADC Water Division. Gaborone.

(10) Beilfuss, Richard. 2012. A risky climate for southern African hydro: Assessing hydrological risks and consequences for Zambezi river basin dams. International Rivers.

H1.3 *PROJECTED FUTURE CLIMATE CHANGE AND POSSIBLE IMPLICATIONS*

H1.3.1 *Overall*

The Zambezi River Basin has been classified by the Intergovernmental Panel on Climate Change (IPCC) as the river basin to be subjected to the 'worst' potential effects of climate change among 11 major African river basins reviewed. This classification is largely based on the climate change-induced increased temperature and decreased precipitation in the Basin [(11)], which is discussed below.

The literature suggests that there are four main ways in which climate change can affect hydropower operations, namely [(12)]:

- Reduced reservoir inflows as a result of a projected decline in Basin runoff and more prolonged drought conditions. This will reduce overall power output.

- Increased risks in the form of uncontrolled releases and dam safety risks due to a projected increase in extreme flooding events, following higher rainfall intensity and more frequent tropical cyclones.

- A potential reduction in the reliability and predictability of hydropower production due to both a delayed onset of the rainy season, and general reduction in the water budget.

- A likely decline in reservoir capacity and risks to flood management operations because of the projected increase in rainfall and flooding intensity increasing sediment loads to reservoirs.

H1.3.2 *Temperature*

Overall, temperatures in the Basin are expected to increase as a result of climate change, the degree to which differs across studies. Beilfuss (2012), for example, report a projected warming trend of 0.3 – 0.6 °C per decade until the end of the century [(13)]. Beck and Bernauer (2011) report on an annual temperature increase in the Basin of as great as 2.9 °C [(14)]. Temperature increases will likely result in concomitant increases in evaporation rates, with implications for water availability (see sub-section on 'water availability' below). In addition, climate change is expected to result in prolonged dry periods and enhanced drought conditions (driven largely by the increased temperatures and reduced rainfall, discussed below) [(15)].

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(11) Ibid.
(12) Ibid.
(13) Ibid.
(14) How will combined changes in water demand and climate affect water availability in the Zambezi river basin? Global Environmental Change: 21: 1061 -1072.
(15) Beilfuss, Richard. 2012. A risky climate for southern African hydro: Assessing hydrological risks and consequences for Zambezi river basin dams. International Rivers.

H1.3.3 *Rainfall*

Across the Basin, rainfall is expected to decline by 10 - 15% by the end of the century [16]. In addition to this, alterations in the seasonal rainfall patterns are projected (including a delay in the onset of the rainy season, which is corroborated by evidence provided in the 'water availability' section below), with implications for hydropower generation [17].

Climate change is expected to result in tropical cyclones of increased intensity, with higher peak wind speeds and heavier rainfall (as a result of increasing sea surface temperatures), with implications for the flooding regime in the Basin [18].

Even in the absence of changes in temperature, the projected reduction in rainfall will have consequences for river and lake levels [19].

H1.3.4 *Water Availability* [20]

Precipitation minus evaporation (P-E) was used as a proxy to determine the water budget of the Bakota Gorge catchment (i.e. water availability and annual river flow). Note that this does not take into account subsurface flow and groundwater, which are both expected to be a small and probably constant fraction of the water budget. P-E was determined using the ensemble mean of multiple models [21] supporting the latest (5th) IPCC assessment (IPCC, 2013 [22]).

The best estimate of projected P-E is a reduction of approximately 1.7% per decade compared to the baseline climatology (1980-2010) (*Figure 1.2*).

Figure 1.2 Annual Mean Precipitation Minus Evaporation (mm/day) of Multi-model Mean for Scenario 1850-2100. Solid Line is the 10 Year Moving Average.

(16) Ibid.

(17) Ibid.

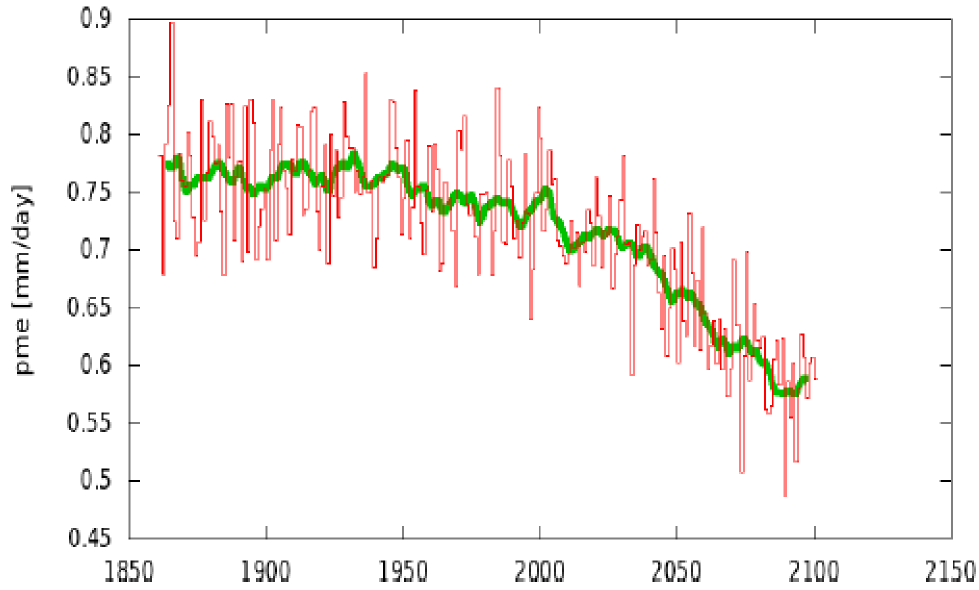
(18) Emanuel, K., Sundararajan, R. and Williams, J. 2008. Hurricanes and global warming: Results from downscaling IPCC AR4 simulations. Bulletin of the American Meteorological Society. Vol.89 (3), 347.

(19) SADC/SARDC and others 2012. Zambezi River Basin Atlas of the Changing Environment. SADC, SARDC, ZAMCOM, GRID-Arendal, UNEP. Gaborone, Harare and Arendal.

(20) Analysis conducted by Professor Ralf Toumi of the Imperial College London. Results presented here are based on the multi-model mean of the CMIP5 program used by the 5th Assessment of the Intergovernmental Panel on Climate Change (IPCC, 2013). The greenhouse gas emission scenario is a business as usual case (called RCP8.5) which is in line with current emission and causes a radiative forcing of 8.5 Wm-2 by 2100.

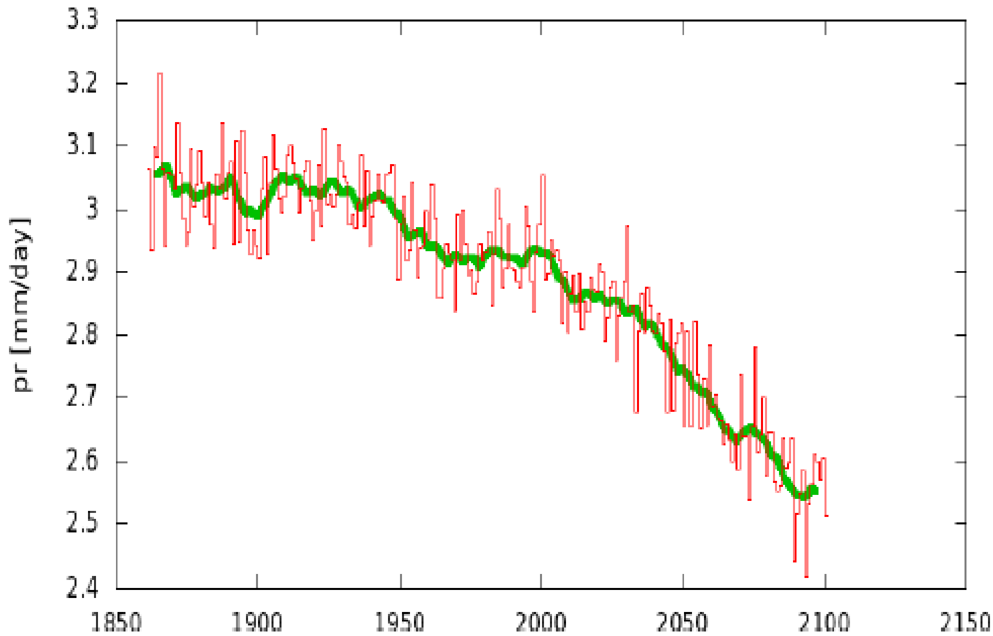
(21) The ensemble mean of multiple models involves running parallel model simulations of multiple climate models to include the impact of model differences. Variations in the results of the different models utilised provide some indication of the level of uncertainty inherent in the results (IPCC, 2007).

(22) IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.



If climate change was accelerated (e.g. if 2100's climate was experienced by the 2050s) then the worst case scenario of a reduction in the water budget of approximately 3.5% per decade is likely. A lower rate of climate change (i.e. 2030's climate by the 2050s) would suggest a reduction in the water budget of approximately 0.9% per decade. The reduction in the water budget is driven largely by projected declines in precipitation levels (*Figure* **1.3**) with a best estimate decline of 1.2% per decade and a high /low of -2.4%/-0.6% per decade, respectively.

Figure 1.3 ***Annual Mean Precipitation (mm/day) for Multi-model Mean for 1850-2100. Solid Line is the 10 Year Moving Average.***



There is a strong seasonality of the water budget. The seasonal peak of available water in the Batoka Gorge is from November to March. Climate change projections indicate a reduction in both P-E and precipitation during the peak months (*Figure* **1.4** and

Figure **1.5**). The largest relative decrease during the seasonal peak is projected for November, implying a future delay in the onset of the peak season. The end of the peak season is only slightly earlier as the March decline is more modest compared to November. This suggests an overall shortening of the rainfall season as well as decline in water volumes during the season. In addition, a deficit in water budget is expected between April and September, with excess evaporation over precipitation. The seasonal deficit is projected to decline largely as a result of an overall reduction in available water. The monthly precipitation trends highlight declines in all months with large relative declines exceeding 50% by 2100 in already dry months.

H1.4 CONCLUSIONS AND RECOMMENDATIONS

Based on the assessment, the following recommendations have been made:

- Undertake a more in-depth climate risk assessment looking to:
    - Ground-truth the P-E analysis using historical flow records in order to test the relationship and confirm the use of P-E as a proxy;
    - Bolster this analysis with additional downscaled climate change data to improve the understanding of the likely future changes in climate; and
    - Identify possible adaptation measures where possible (i.e. measures to reduce the risk).

- Based on the analysis of future water availability, it is recommended that planners take into account both the potential worst case scenario of an up to 3.5% reduction in the water budget per decade compared with baseline climatology (subject to additional studies) and the projected shortening of the peak flow season into their water budget calculations.

- Undertake a greenhouse gas (GHG) inventory in order to review:
    - The potential GHG emissions associated with land use change in the project area as a result of the BGHES (i.e. flooding will remove/ reduce vegetation in the area);
    - The potential GHG emissions associated with the operation of the BGHES (and possible mitigation measures to reduce GHG emissions); and
    - The GHG emission benefits associated with hydropower.

Figure 1.4 Monthly Mean Precipitation Minus Evaporation (mm/day) of Multi-model Mean for Scenario 1850-2100. Solid Line is the 10 Year moving average.

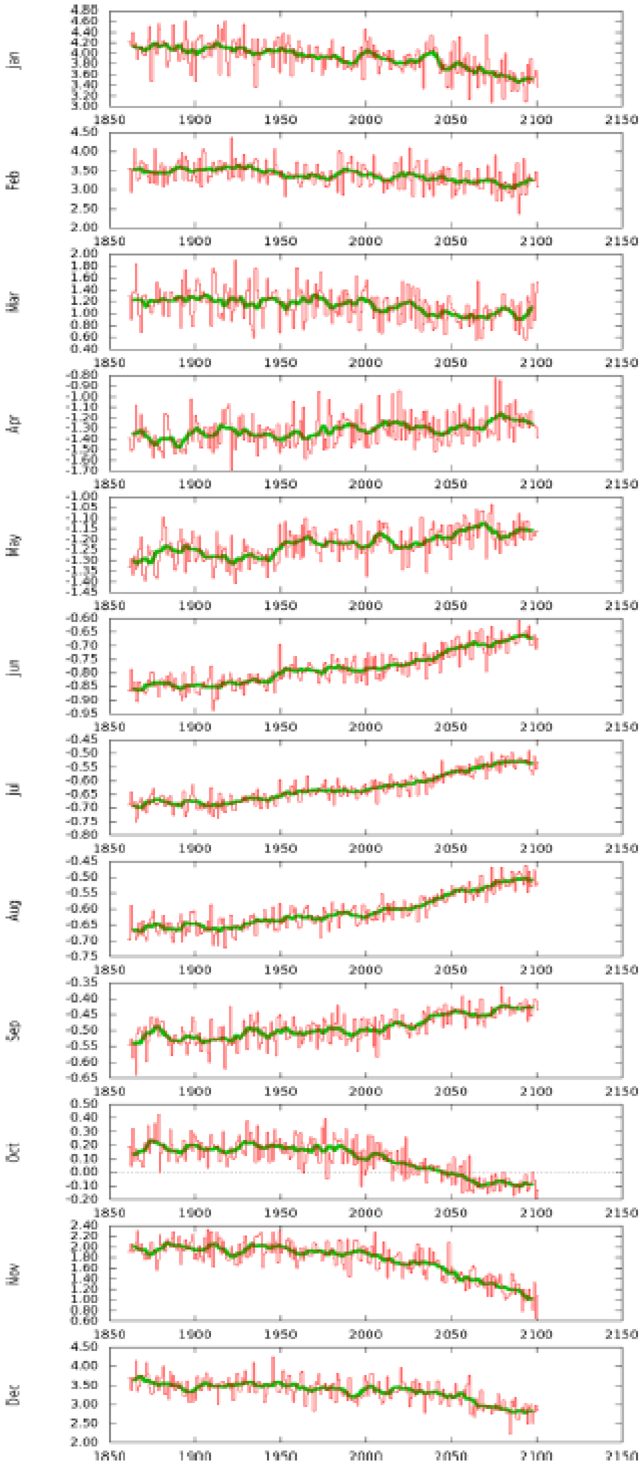


Figure 1.5 Monthly Mean Precipitation (mm/day) for Multi-model Mean for 1850-2100. Solid Line is 10 Year Moving Average.