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The Operation of the Grand Ethiopian Renaissance Dam under Future Climate Scenarios

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Objectives

- Simulate hydrological parameters for the reservoir management in the Upper Blue Nile (UBN) basin for future climate projections using CREST-SVAS.
- Predict the inflow at Eldiem outlet close to the dam, Grand Ethiopian Renaissance Dam (GERD).
  - GERD Configuration:
    - Volume :74 Billion Cubic Meter (BCM)
    - Area: 1760 km^2
- Analyze effect of climate change on the streamflow at Eldiem.
- Analyze hydropower generation and dam operation for future climate projection.

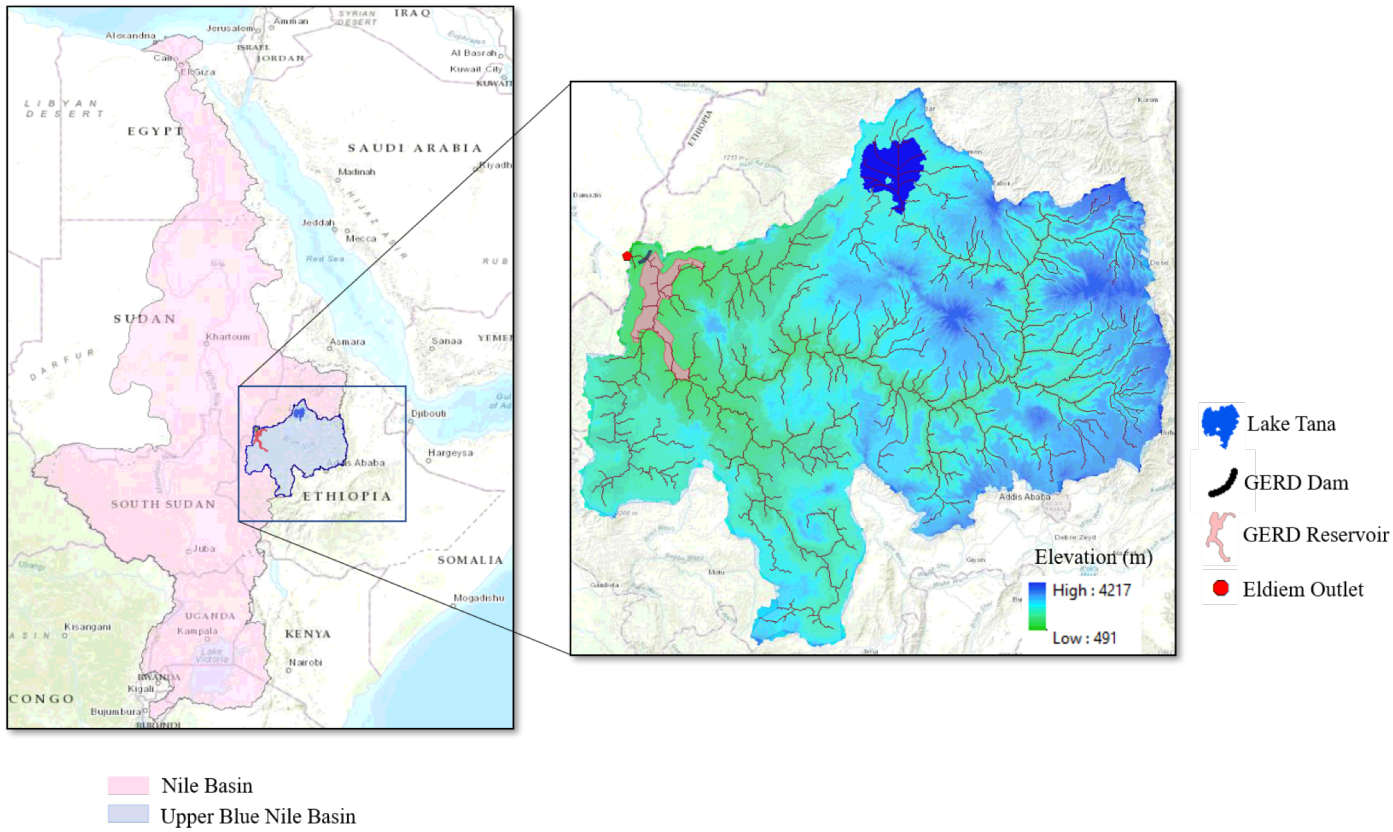


Fig 1: Study Area, Upper Blue Nile Basin

CREST-SVAS Hydrological Model

- Coupled Routing and Excess Storage (CREST), Soil-Vegetation-Atmosphere-Snow (SVAS) is a fully distributed hydrological model that strictly couples energy and water balances and imposes closed energy balance.

- It can simulate for small to large watersheds (a few 100 km^2 to 176,000 $km^{2)}$ at a fine spatiotemporal resolution (500 m and 3-hourly).

- Meteorological variables that are required to force the model include precipitation, air temperature, shortwave solar radiation, longwave solar radiation, wind speed, humidity, and air pressure.

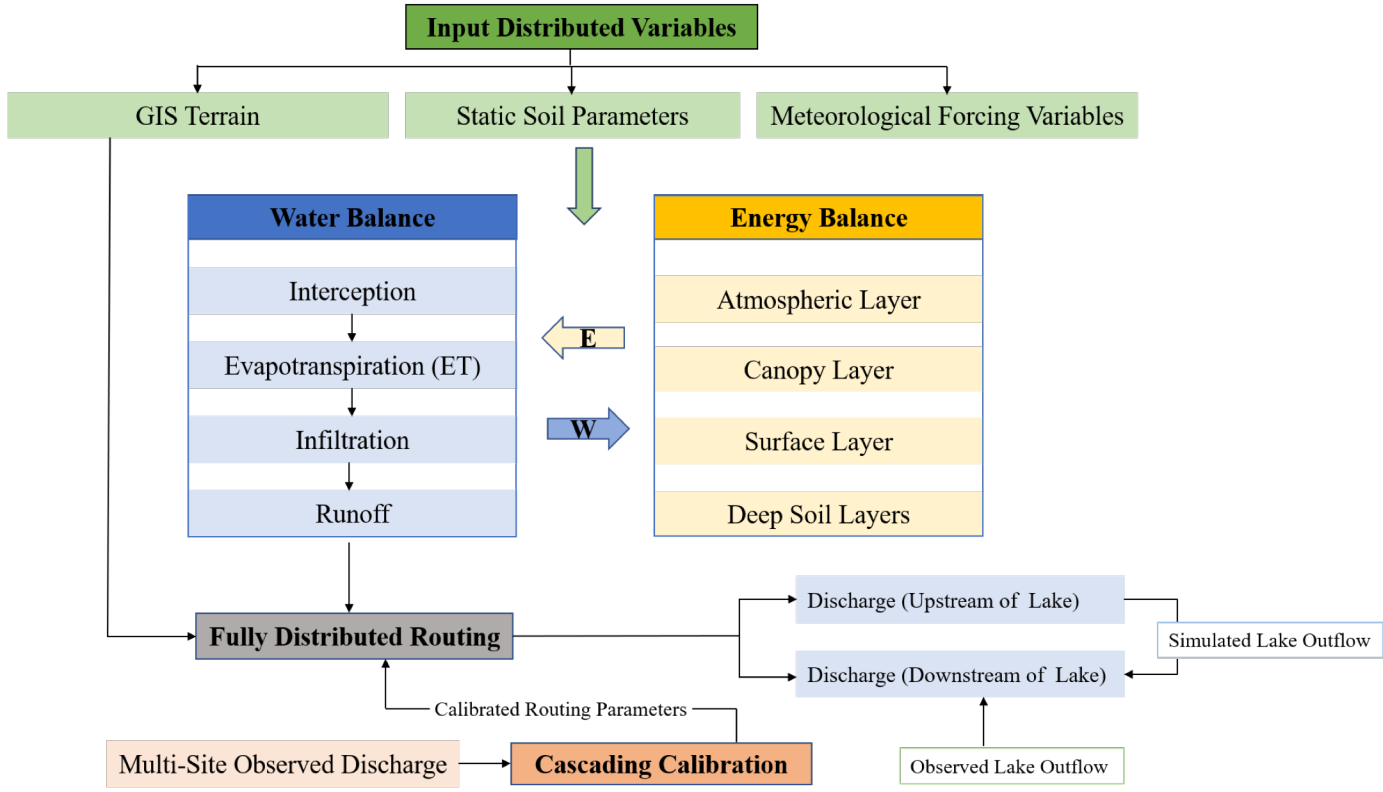


Fig 2: CREST Framework (*Shen and Anagnostou, 2017*)

Meteorological Forcing Data Source

- Climate Projection Data

Regional Climate Model (RCM)	Global Circulation Model (GCM)	Representative Concentration Pathway (RCP)	Temporal Extent	Spatial Resolution	Temporal Resolution
Rossby Centre regional Atmospheric model (RCA4)	Model for Interdisciplinary Research On Climate (MIROC5)	4.5	2006 - 2100	50 km	3-Hourly
		8.5			

- Baseline Data
  - We consider 1981-2010 as baseline period and compared the climate data for three time windows, 2011-2040, 2041-2070, and 2071-2100.

Variables	Data Source
Precipitation	MSWEP
Temperature	ECMWF
Flow	Observed

- Reference Flow for the Recent Years
  - For recent years (2001-2019), we used ERA Land and MSWEP forced flow as reference

Model Calibration

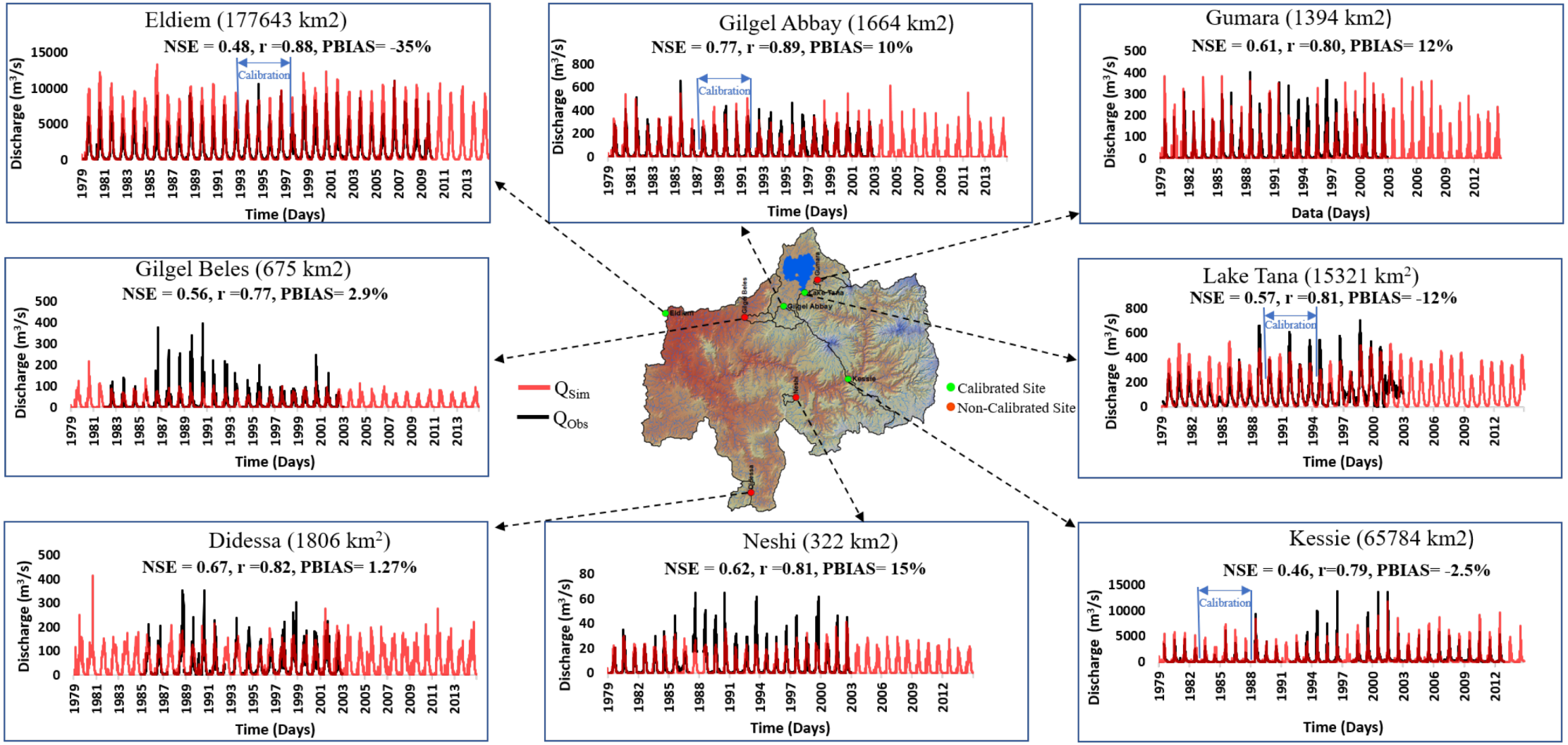
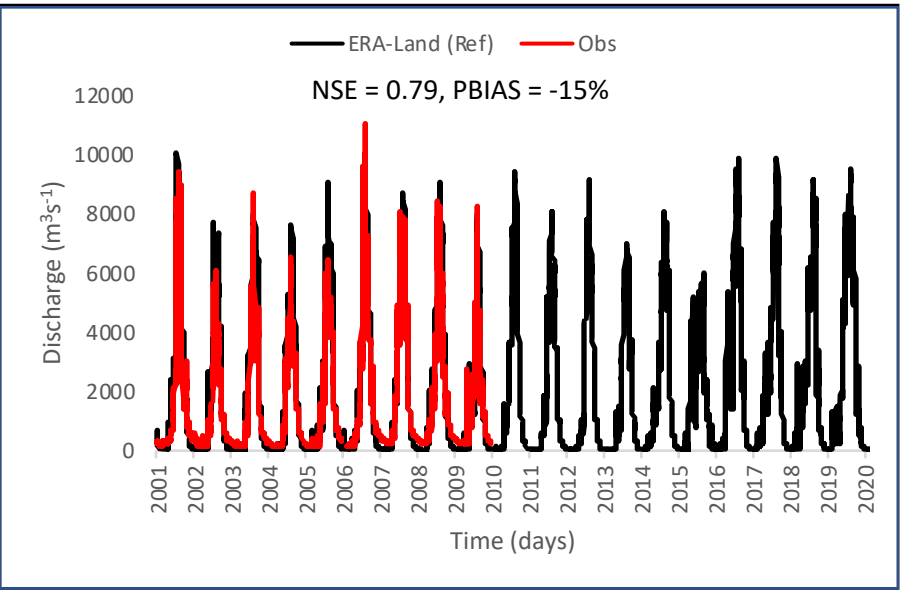
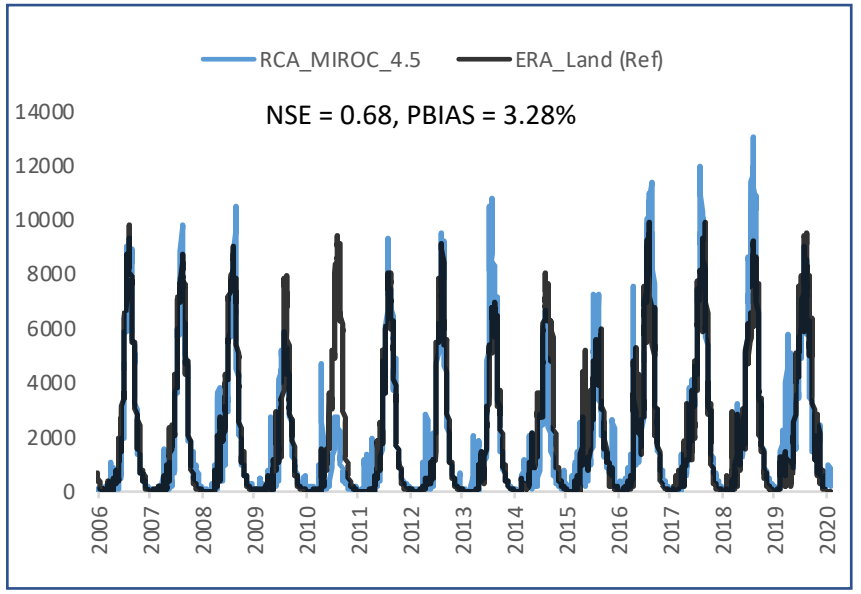


Fig 3: Multi Site Cascade Calibration of Daily Streamflow (*Lazin et al., 2020*)

Validation of Discharge From Reference and Climate Projection Simulation

Discharge at Eldiem





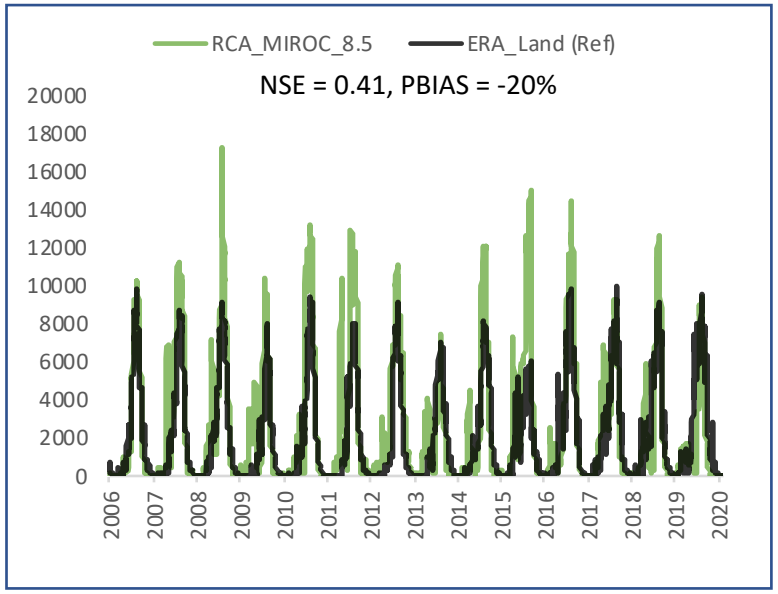


Fig 4: (Left) Validation the ERA Land and MSWEP forced discharge with respect to the observed discharge which is later used as reference discharge to evaluate Climate Projection simulations of RCP 4.5 (middle) and RCP 8.5 (right) for the recent years.

Climate Projection Analysis

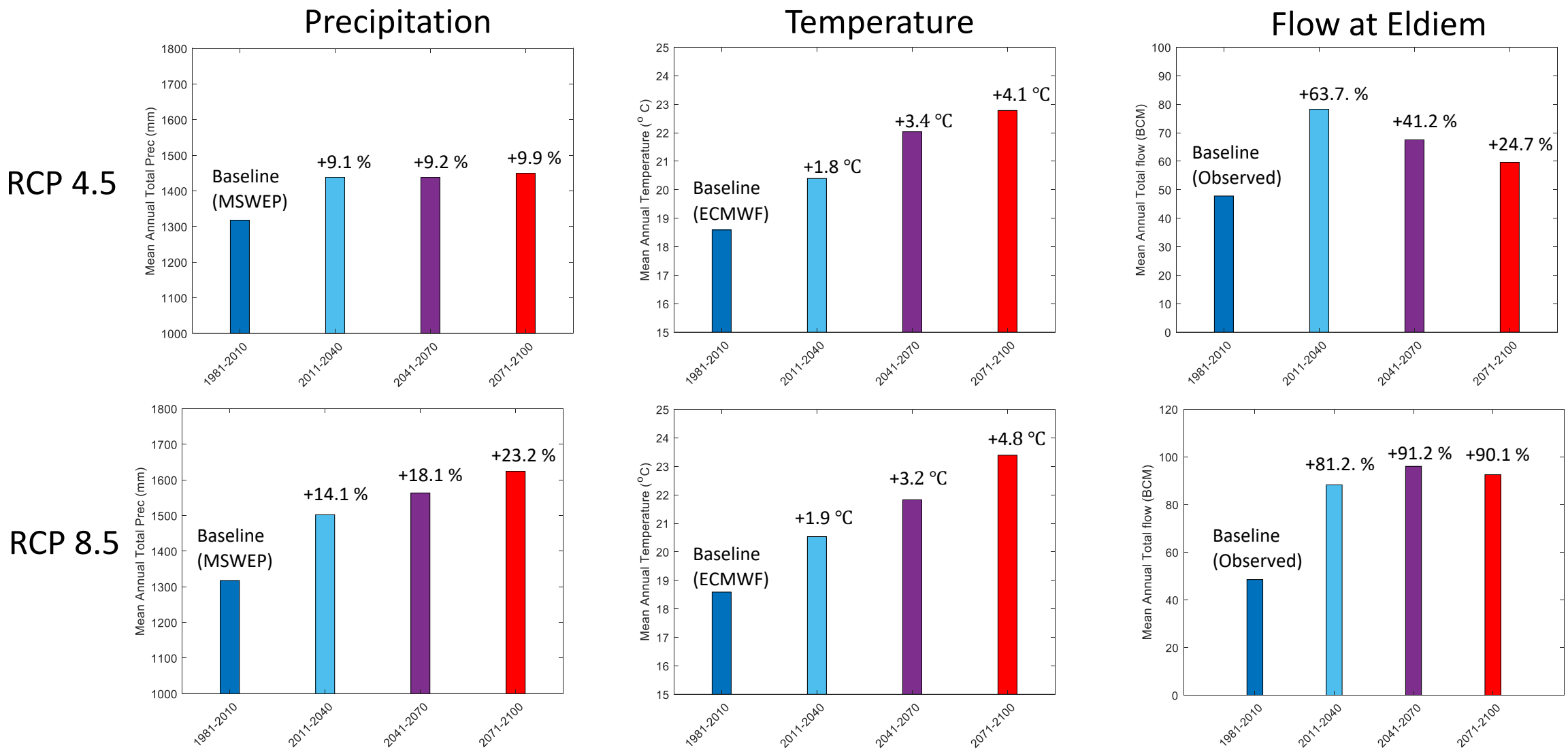


Fig 5: Climate Projections for Temperature, Precipitation and Flow for RCP 4.5 and RCP 8.5

GERD Proposed Annual Filling Volume

Number of Years	Retained Amount in the Dam (BCM)
1	4.9
2	13.5
3	10.4
4	10.5
5	10

In 5 years the dam will be filled up to 49.3 BCM at the end of the dry season. The dam is intended to be filled up to the capacity of 74 BCM for higher performance of power generation.

Reservoir Mass Balance and Hydropower Generation

- The mass balance equation for GERD can be represented as,
  - $S_{GERD_i} = S_{GERD_{i-1}} + Q_{in} - Evaporation\ loss_{GERD} - Q_{out}$.....(1)
  - $Q_{out} = Q_{spillway} + Q_{Turbines}$
  - $Evaporation\ loss_{GERD} = Prec_{GERD} - 0.8 \times ET_{pot_{GERD}}$ *(Kevin et al. 2007)*
  - $Q_{Turbines} \leq 0.373\ (km^3/day)$ [When Elevation > 590]
  - $Q_{Spillway} \leq 1.573\ (km^3/day)$ [When Elevation > 640]
- $Reservoir\ water\ level_i$ is determined from Elevation-Storage Curve (Fig 7)
- Hydropower production is formulated as,
  - $HP = \gamma \times \eta \times Q_{Turbines} \times H_{GERD}$.....(2)
  - γ = Specific Weight of Water (98 07 N/m³)
  - H_{GERD} = $Reservoir\ water\ level_i - Turbine\ level\ (560\ m)$
  - η = Efficiency of the turbine

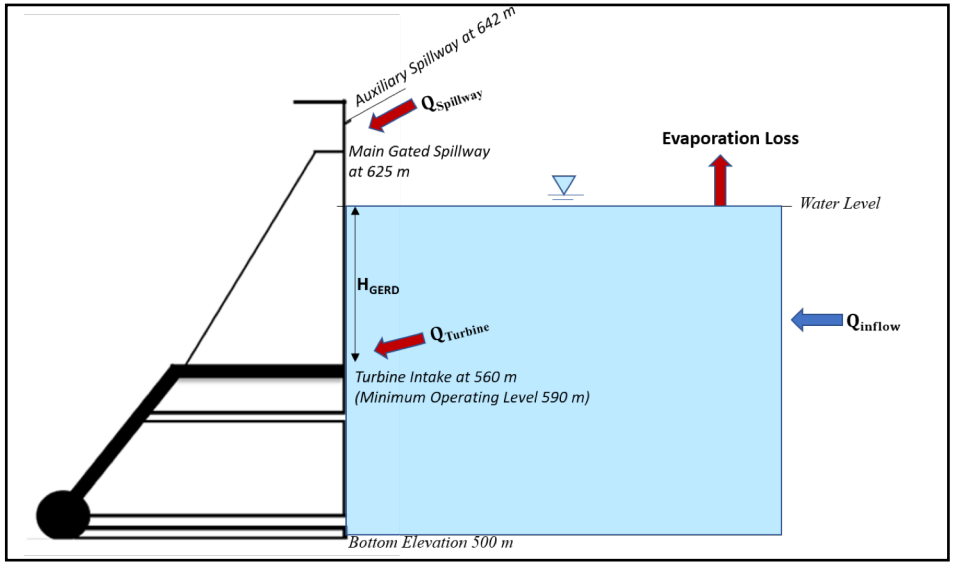


Fig 6: Mass Balance in the GERD Reservoir

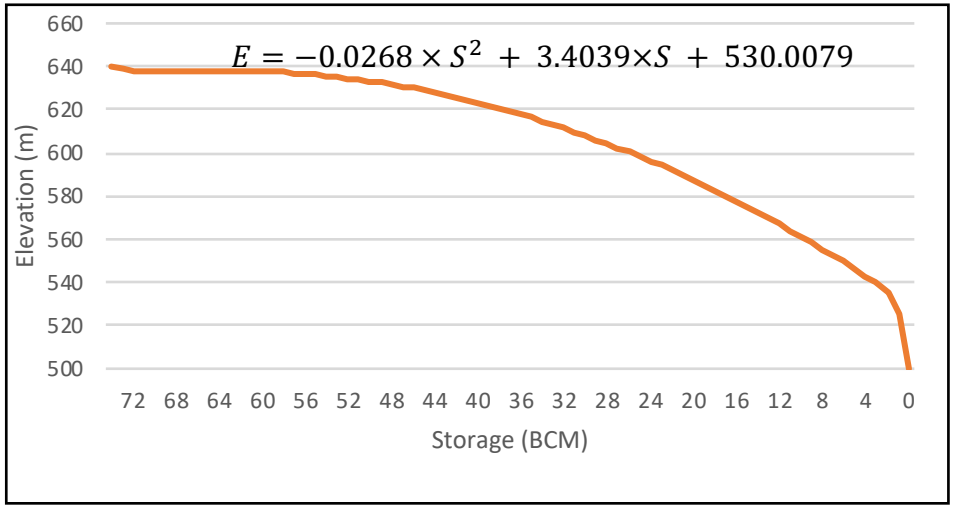


Fig 7: Elevation Storage Curve

GERD Storage and Annual Flow Volume (RCP 4.5)

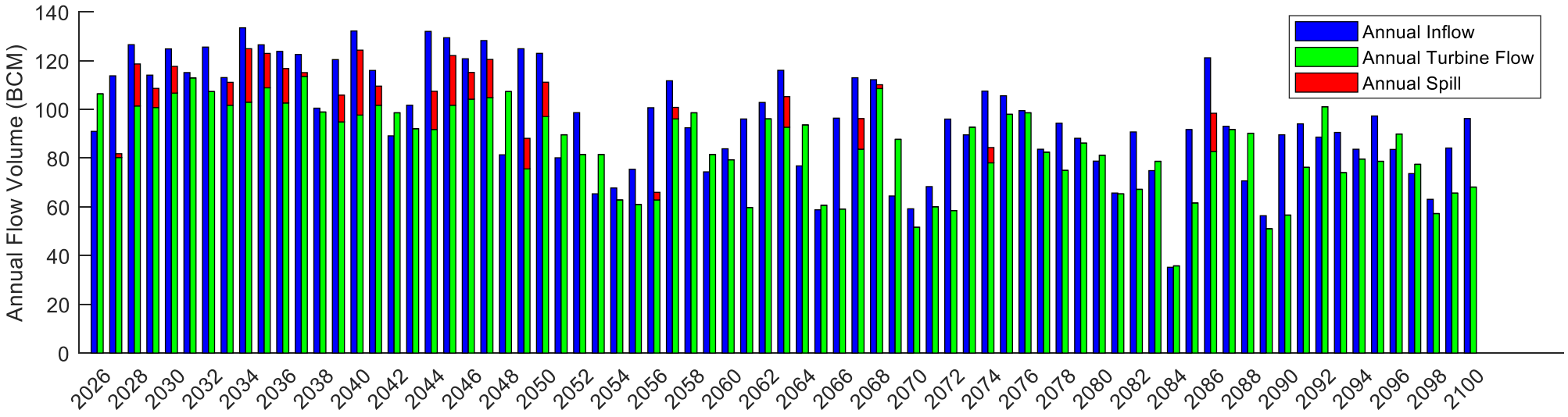


Fig 8: Annual Flow in the Reservoir. The flow through the Turbine and Spillway represent the Total Outflow

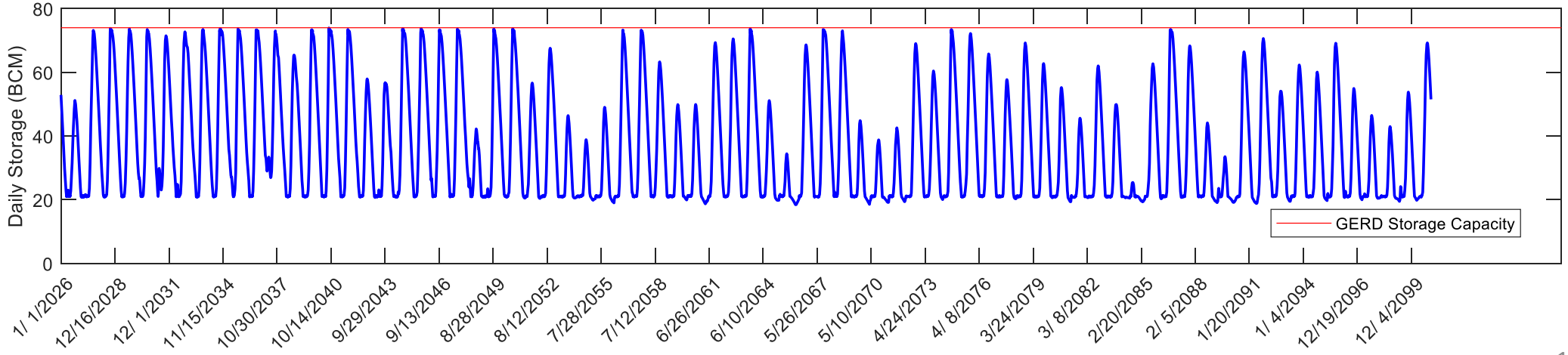


Fig 9: Daily Storage in the GERD Reservoir

GERD Storage and Annual Flow Volume (RCP 8.5)

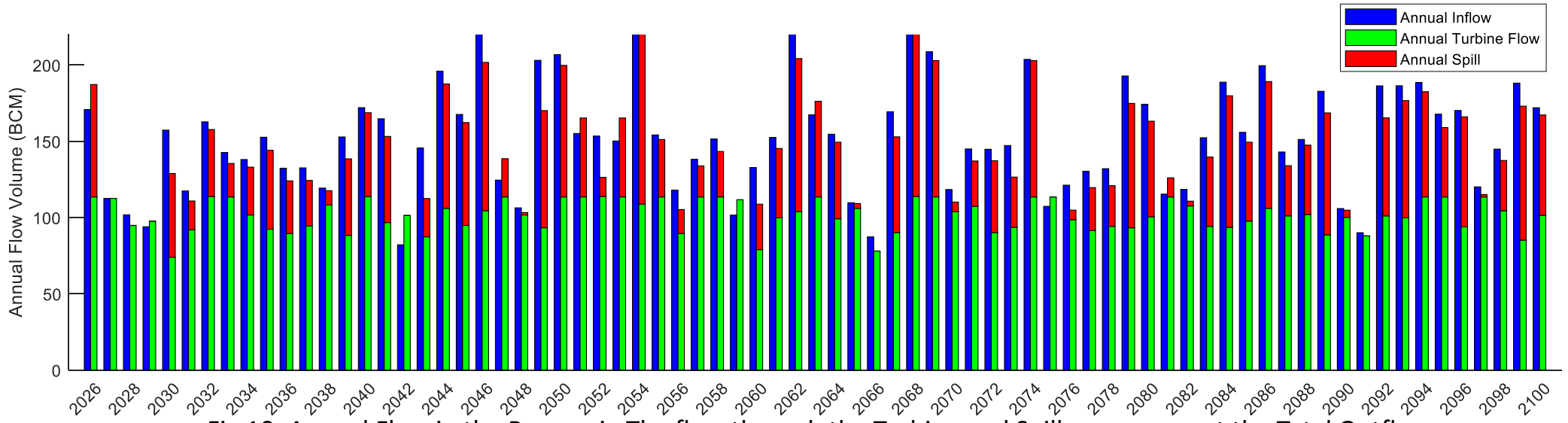


Fig 10: Annual Flow in the Reservoir. The flow through the Turbine and Spillway represent the Total Outflow

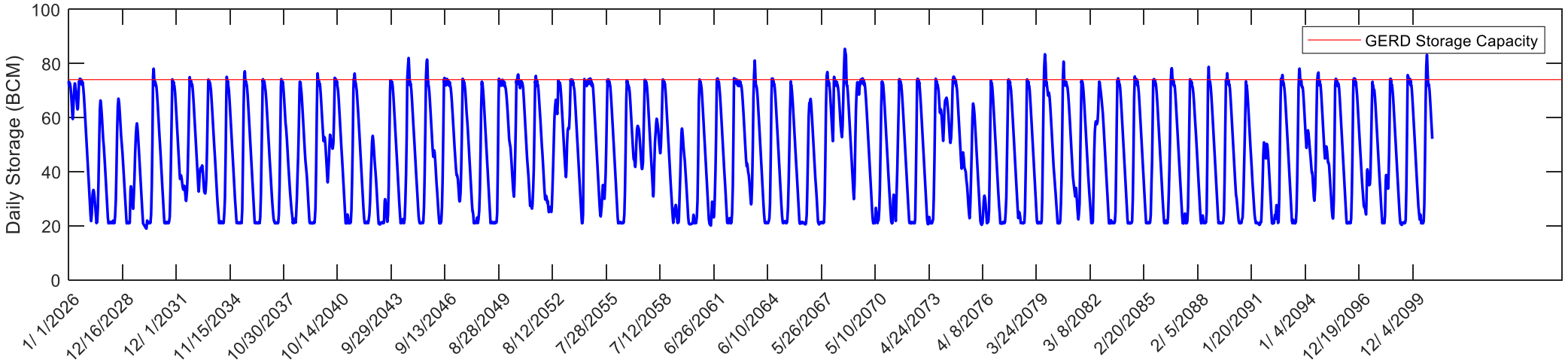
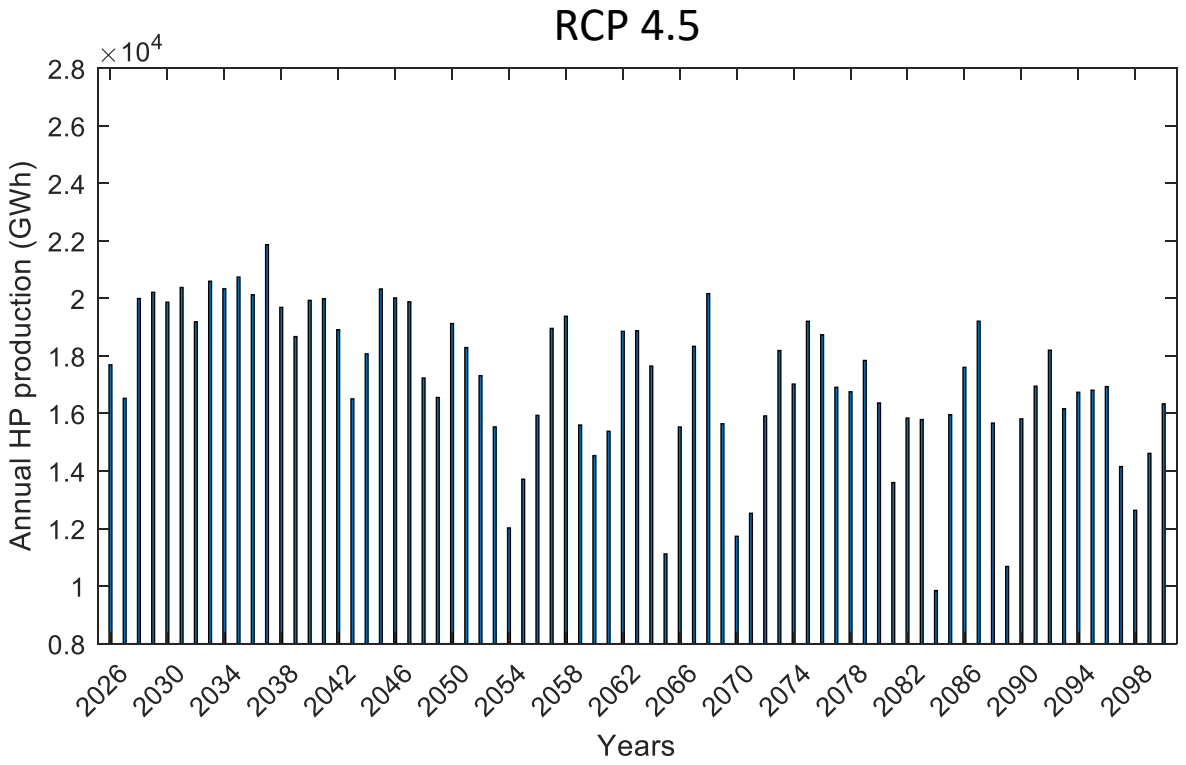


Fig 11: Daily Storage in the GERD Reservoir

Hydropower Generation

- The hydropower plant is expected to generate 15,000 GWH of power per year.
- $HP(Energy) = \sum_{1}^{365} \gamma \times \eta \times Q_{Turbines} \times d_{GERD} \times 24$ (GWH)



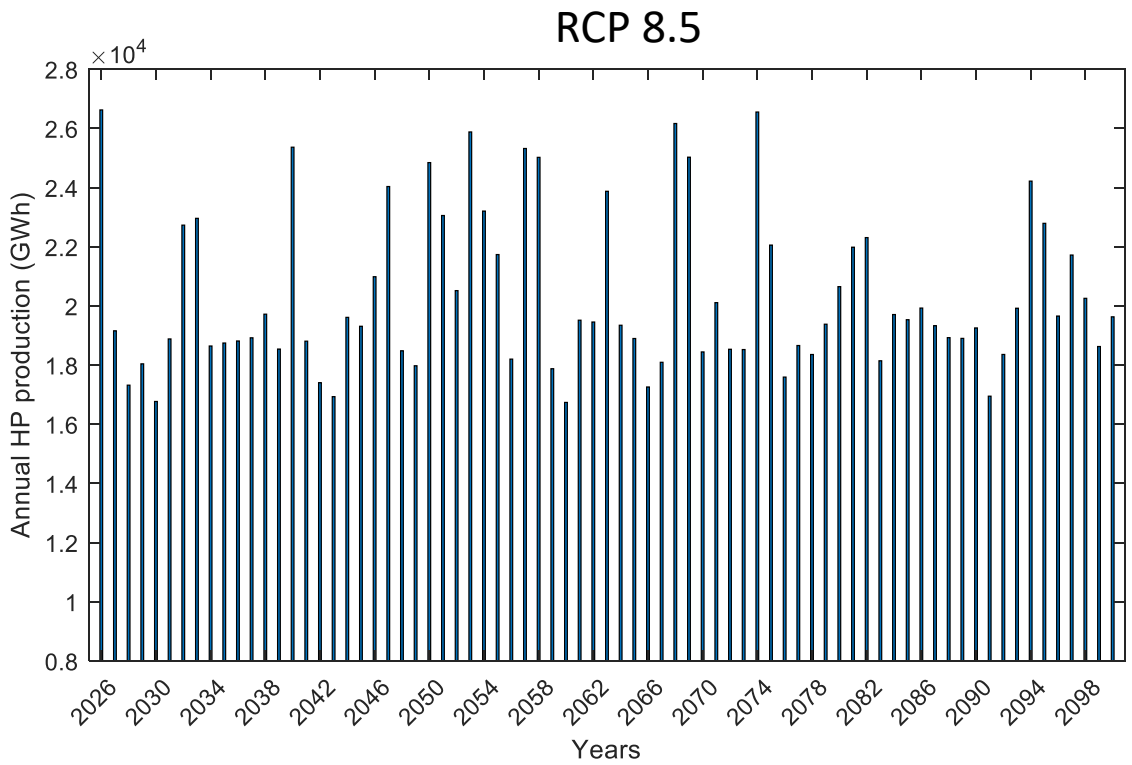


Fig 12: Hydropower Generation Under Future Climate Projections

Conclusions

- Climate Projections from RCA MIROC 5 model (RCP 4.5 and RCP 8.5) indicate an increasing trend in terms of precipitation and temperature that results in a similar increasing trend of streamflow.

- From RCP 4.5 projections, since during the 2050 s the flow is high, the dam will frequently reach to its capacity and spillway need to be activated whereas for the later part of the century, the spillway is rarely activated. For RCP 8.5 projections the flow is so high for some years that the storage exceeds the dam capacity of 74 BCM even after activating the spillway at 640 m

- The mass balance and hydropower production framework represents that the dam can produce the expected energy (15000 GWH). For high inflow (RCM 8.5 and during 2050 s of RCP 4.5) the hydropower generation can be higher. However, during the dry years it can drop below 10,000-12,000 GWH.

Limitations and Future Work

- The projections of the climate model can be uncertain which might cause the inconsistent future hydrological performance.

- Evaluation of the impact of climate change on the Evapotranspiration and Soil Moisture and the consideration of irrigation release from the GERD can be analyzed in future studies.

Thank You!