Reservoir Operating Policies for Environmental Flows of Large Dams in the Zambezi River Basin

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Presentation Outline

- Introduction
- Background and study area
- Problem Statement
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- Conclusion
- Recommendations and further work

Introduction

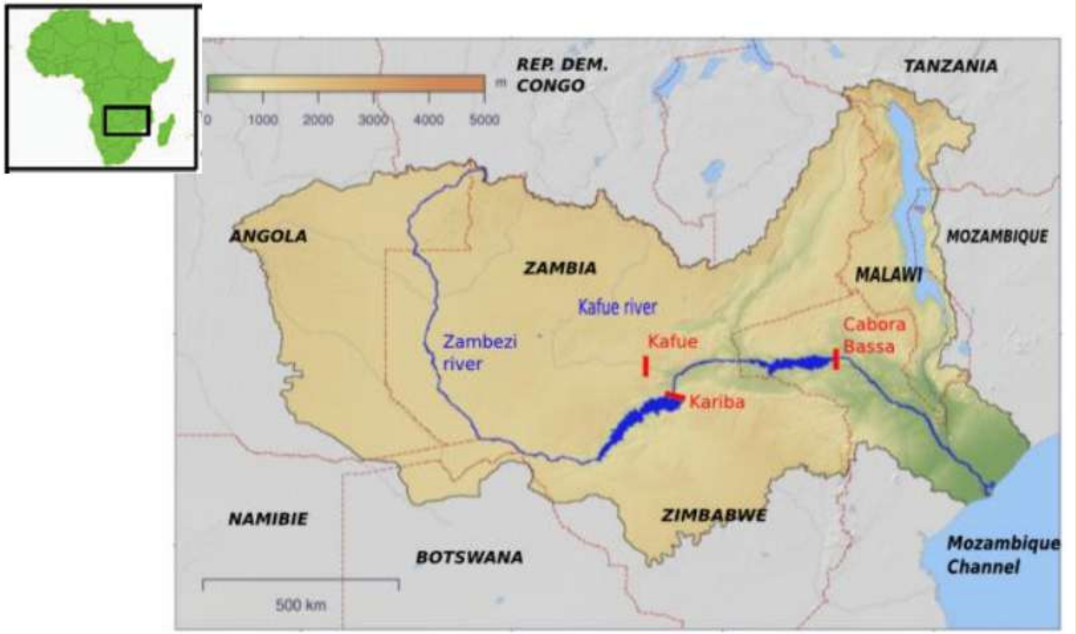
- The Zambezi basin is important to its riparian countries for food energy and ecological diversity (World Bank, 2010), with the Marromeu Complex and the Kafue Flats recognised as wetlands of world importance (Ramsar sites), the Mana Pools as a UNESCO World Heritage Site.

- The interference of large scale hydropower schemes in the Zambezi basin has disrupted the environment, especially in the lower Zambezi (Beilfuss, 1999)

- The alteration of flow to the lower Zambezi by the dams has resulted in ecosystem degradation in the delta and affected the fisheries (Hoguane, 2000)

BACKGROUND AND STUDY AREA

- Zambezi Basin is 390 000 km² and 2750km long
- 4 major reservoirs- Kariba, Cahora Bassa, Kafue and Itezhi Tezhi

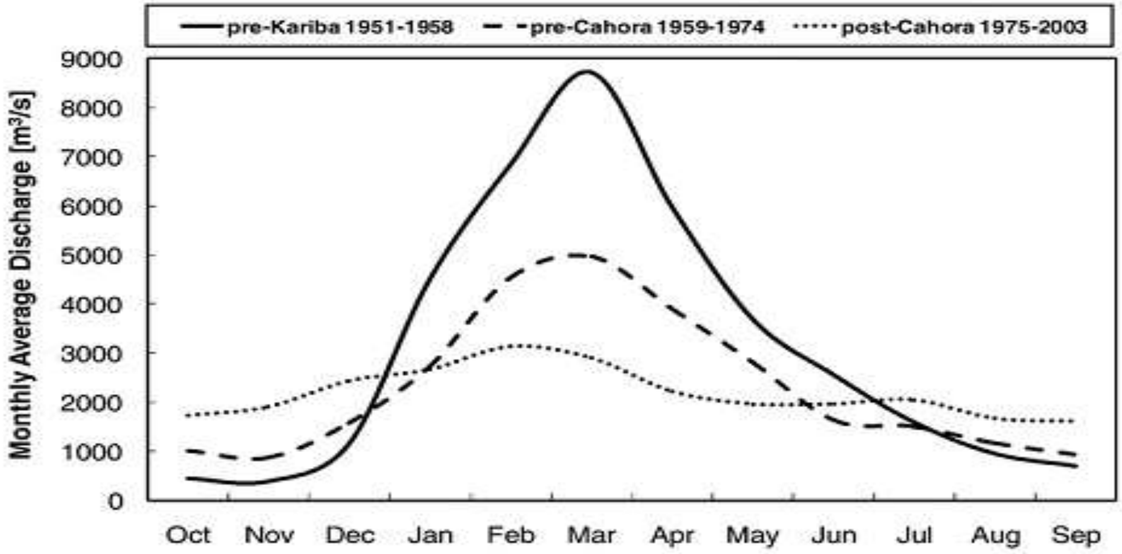


Parameter	Unit	Kariba	Itezhi Tezhi	Kafue	Cahora Bassa
Construction period		1955-1959			
Inflow(net)	m^3/s	1272	302	383	2376
	Mm^3/s	40114	9524	12078	74930
Live Storage	Mm^3	64744	5000	1178	51750
Reservoir Index (residence time)	Year	1.61	0.52	0.10	0.69
Installed power	MW	1350	Storage	900	2075

Source: Klassen, undated

PROBLEM STATEMENT

Illustration of the changes in the hydrograph at Tete, downstream of Cahora Bassa



Source: Ronco et. al, 2010

- Despite environmental flow studies in the basin, e-flows have not been implemented due to fear of opportunity costs (i.e. hydropower foregone) (Chen, 2010)
- Problem? Floods of 1978, though having a toll on human life and property, had unplanned benefits for the environment. And so were the emergency flood releases of1997 (Beilfuss, 1999)

Research questions

This study analyses current reservoir operating policies and investigates the possible effects of reoperation of the reservoirs by forcing Cahora Bassa and Kariba to release artificial floods in February and March on the hydropower production.

1. What are the current reservoir operating policies for Kariba, Itezhi tezhi, Kafue and Cahora Bassa reservoirs?
2. What is the impact of re-operating the reservoirs for environmental flows on hydropower production?

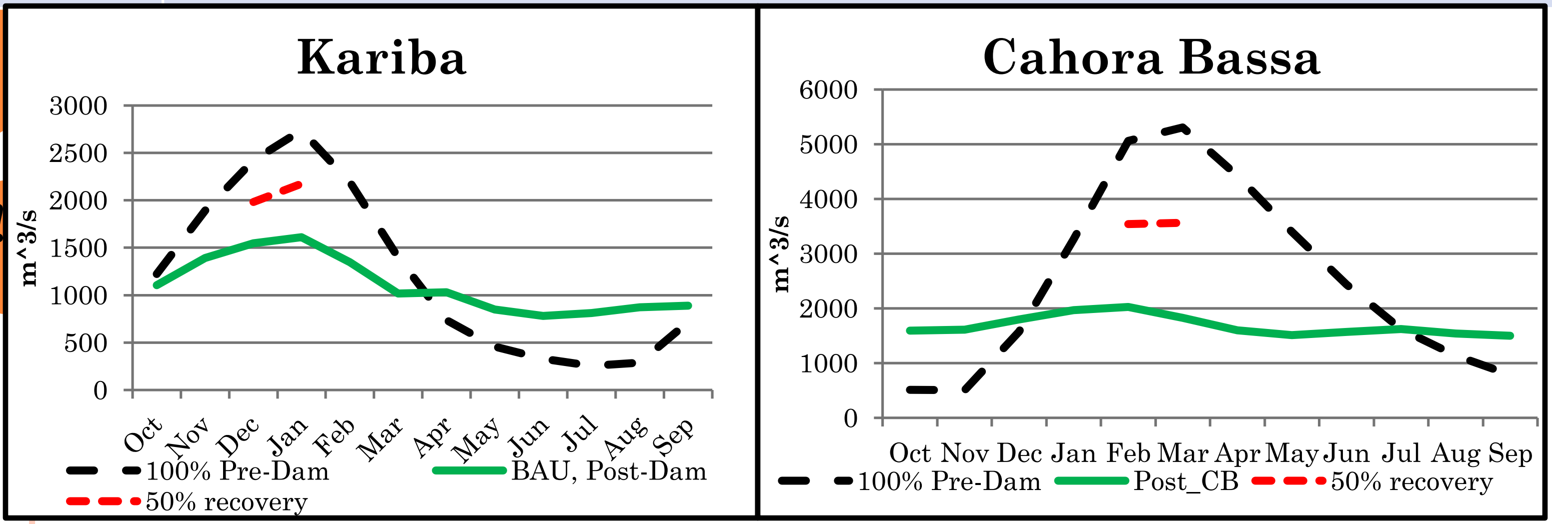
METHODOLOGY

- Data for the study was obtained through field visits in the basin in 2011
- Analysis of current reservoir operating policies using historical data (1980-2010)
- Reservoir simulation on a monthly timestep using Waflex (Savenije, 1995)
- Scenario analysis
  - Reductions in hydropower produced for Kariba are measured against historical production, and not actual demand. For HCB, they are measured against modeled production over the modeled period. This is because Cahora Bassa has only been fully operational since the late 90s.

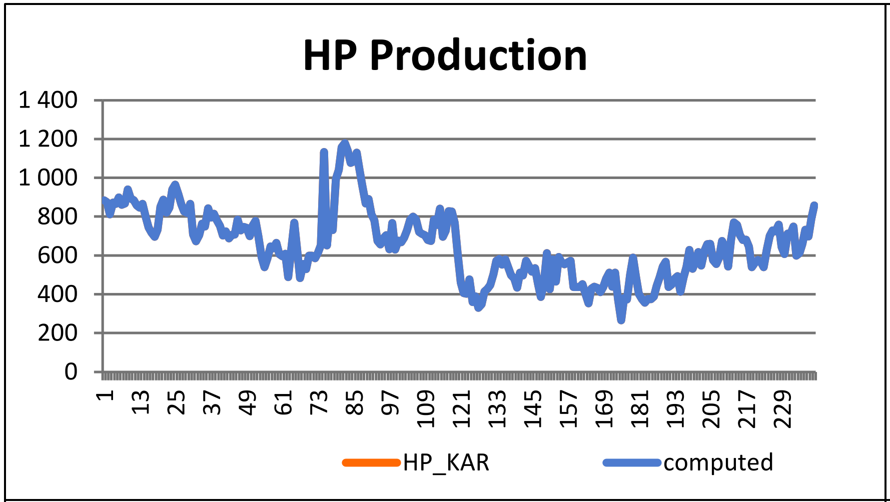
Scenario Description

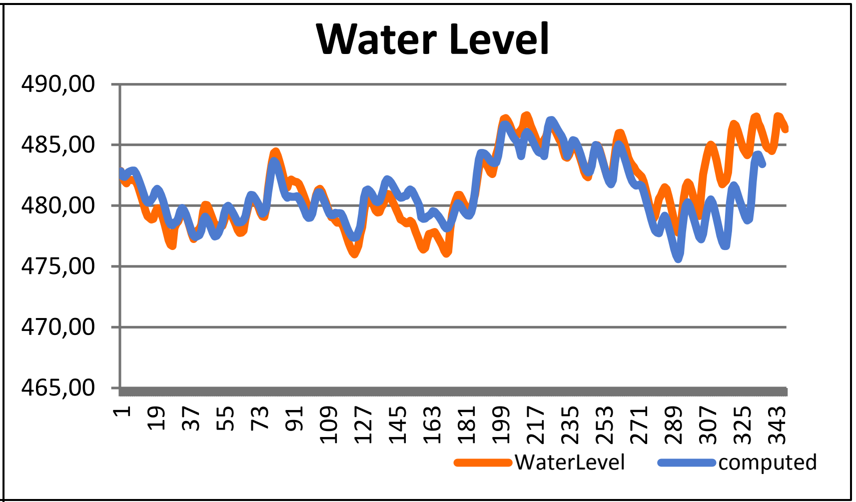
Scenario	Description
BAU	Current operating conditions with hydropower driving dam operation (BAU_FC for Cahora Bassa)
1	Recover the natural flows in Feb and Mar by 50% at Cahora Bassa
2	Recover the natural flows in Feb and Mar by 50% at Cahora Bassa & Kariba
3	Recover the natural flows in Feb and Mar at Cahora Bassa
4	Recover the natural flows in Feb and Mar by at Cahora Bassa & Kariba

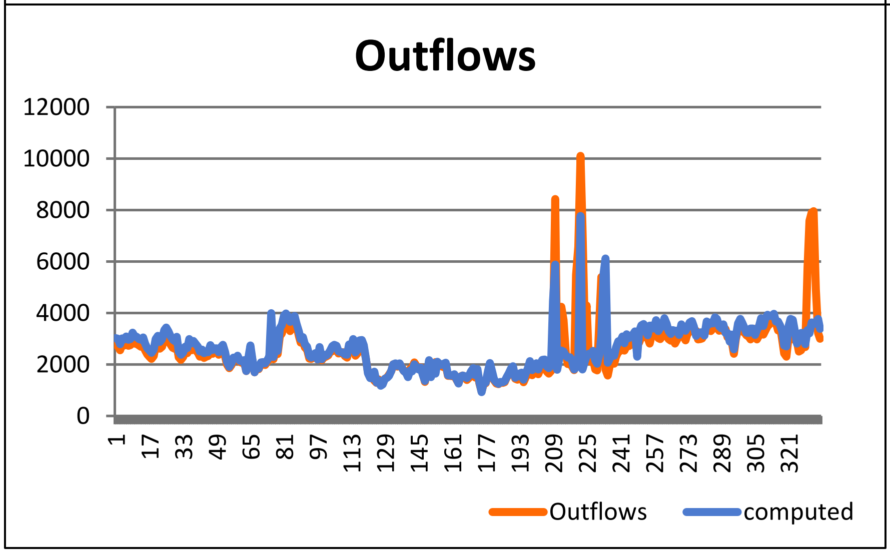
Illustration!



Model Calibration (Kariba)







	R2	NSC
HP	1	1
Water level	0.87	0.79
Outflows	0.49	0.48

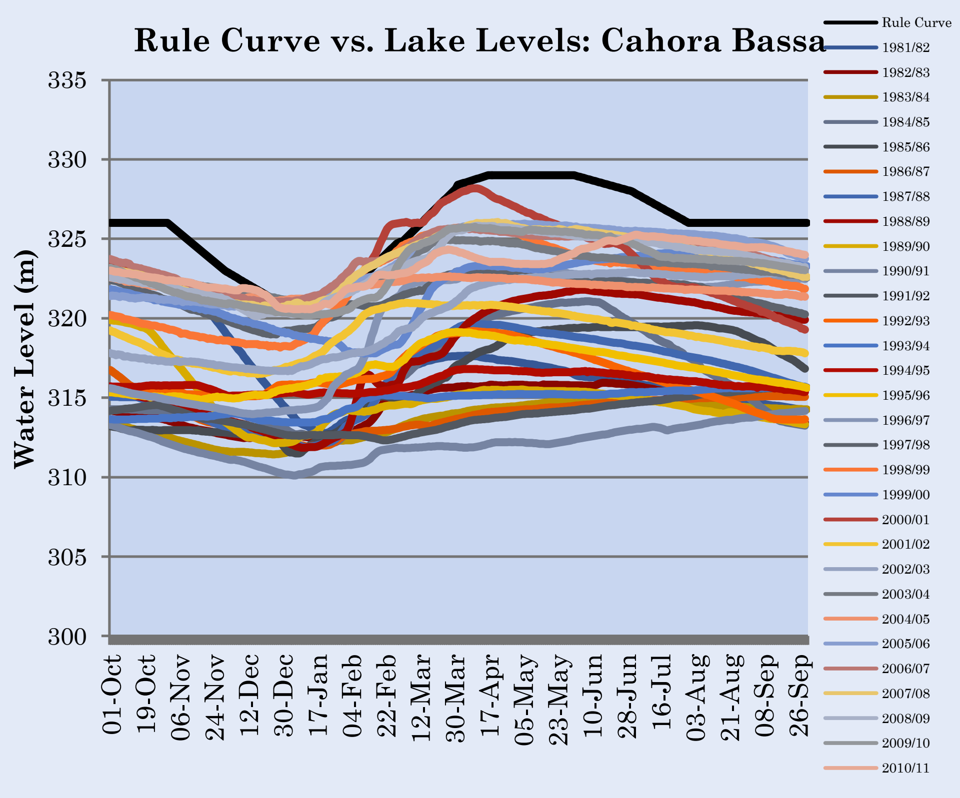
Results

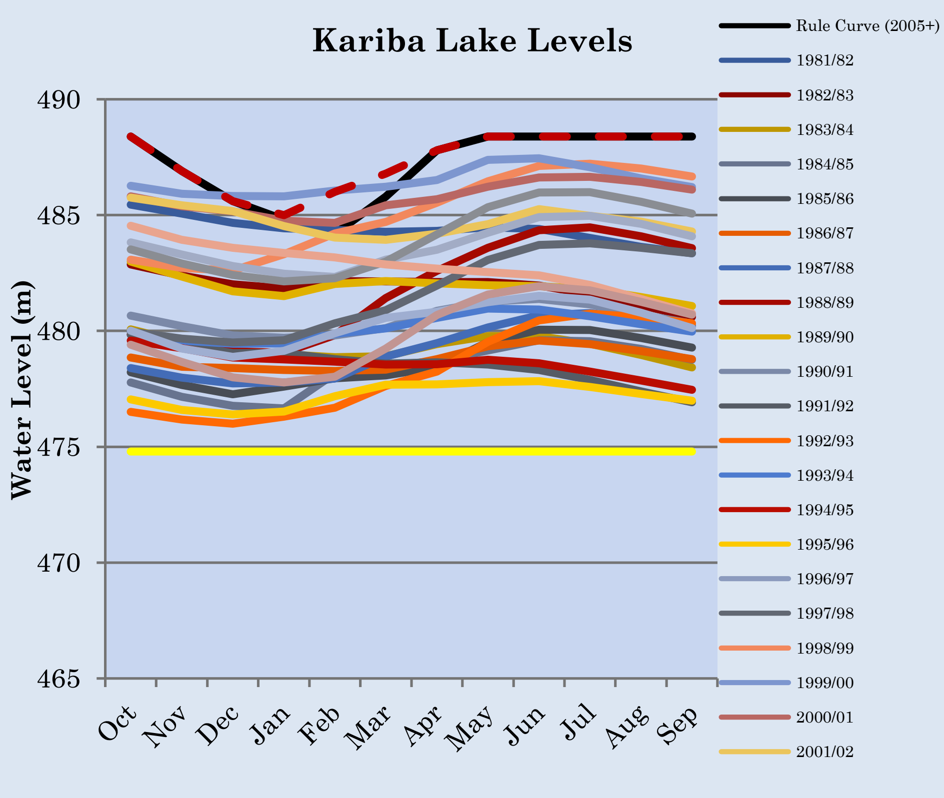
- The reservoirs operate based on rule curves:
  - Cahora Bassa and Kariba have maximum rule curves
  - ITT and Kafue have minimum rule curves

- The main operation objectives in the Zambezi basin are:
  - Maximizing hydropower production
  - Ensuring dam safety
  - Ensuring sufficient storage for flood water for flood protection (Kariba and Cahora Bassa)

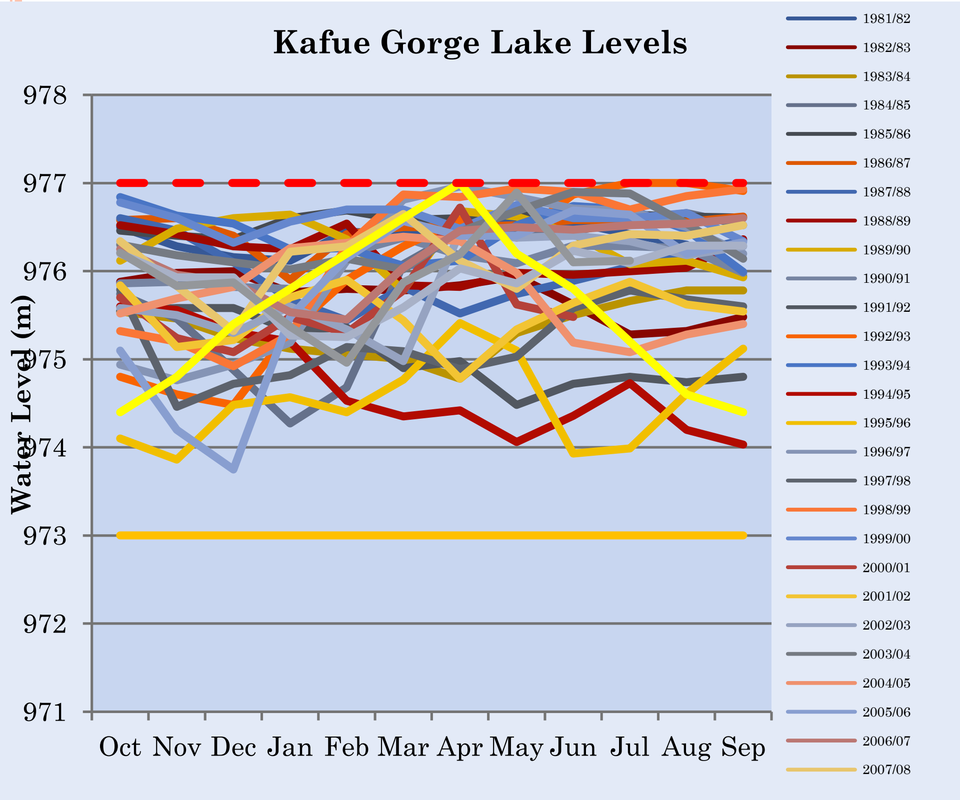
RESULTS

Comparison of historical water levels and the reservoir rule curves





Results



Kafue Gorge Lake Levels
Water Level (m)
978
977
976
975
974
973
972
971
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
1981/82
1982/83
1983/84
1984/85
1985/86
1986/87
1987/88
1988/89
1989/90
1990/91
1991/92
1992/93
1993/94
1994/95
1995/96
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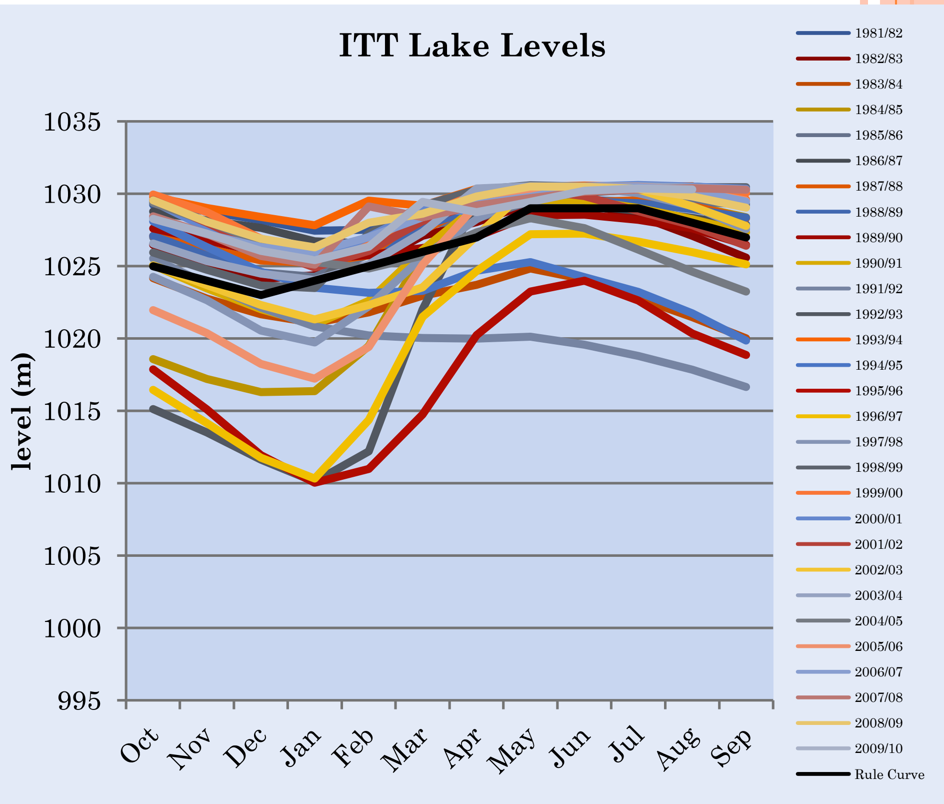
2005/06
2006/07
2007/08

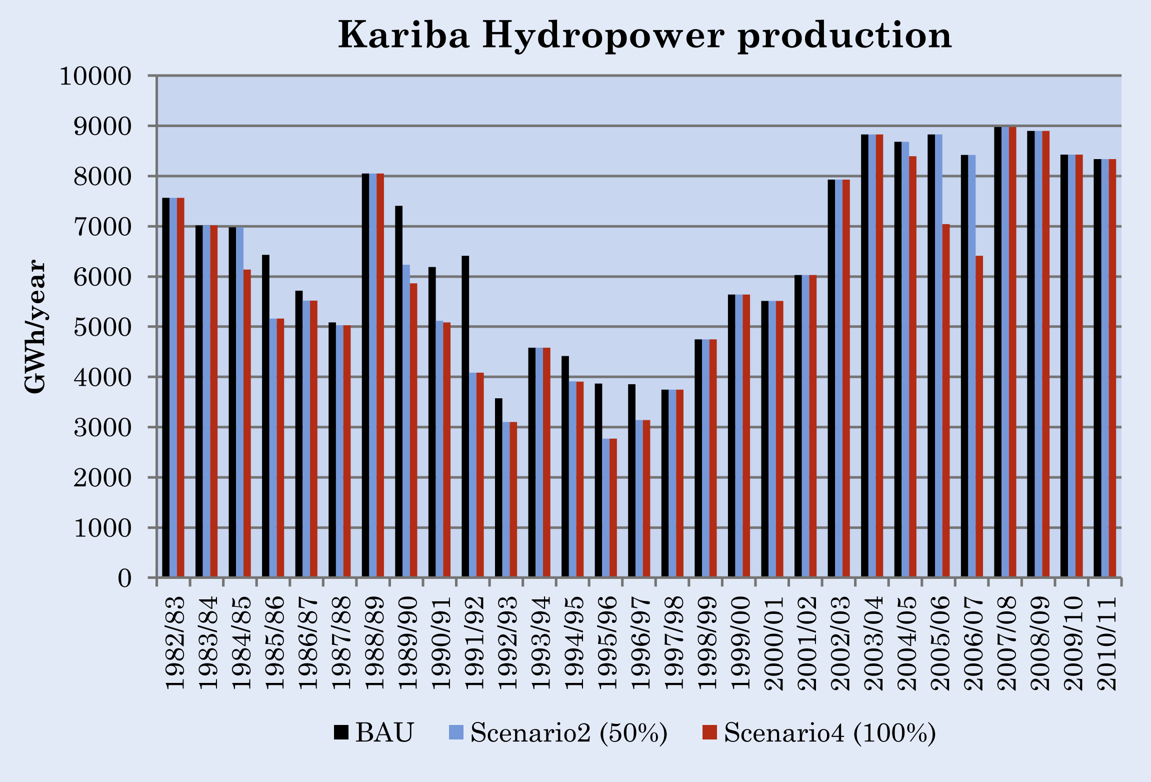


ITT Lake Levels
level (m)
1035
1030
1025
1020
1015
1010
1005
1000
995
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
1981/82
1982/83
1983/84
1984/85
1985/86
1986/87
1987/88
1988/89
1989/90
1990/91
1991/92
1992/93
1993/94
1994/95
1995/96
1996/97
1997/98
1998/99
1999/00
2000/01
2001/02
2002/03
2003/04
2004/05
2005/06
2006/07
2007/08
2008/09
2009/10
Rule Curve

RESULTS

Kariba

- No hydropower shortages in normal years for scenario 2
- Hydropower shortages of up to 36% in dry years for both scenarios (2 & 4)
- Hydropower shortages of up to 24% in normal years in scenario 4

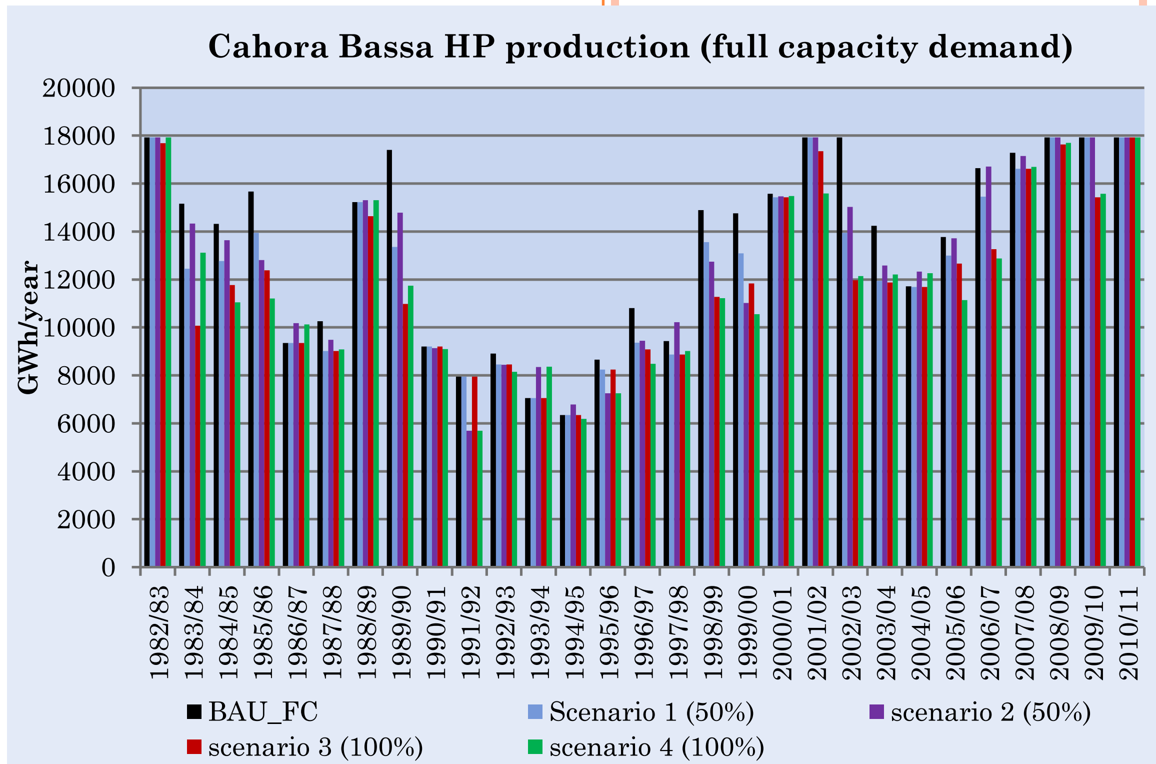


		Units	Max potential	BAU	Scen 2	Scen 4
KAR	HP	GWh/yr	11232	6556	6250 (4.7%)	6066 (7.5%)

Results

Cahora Bassa

- Cahora Bassa would be able to produce full power in normal years but not in dry years
- Shortages of up to 36%
- Reduced to 27% when Kariba releases for e-flows too (scenario 2),
- When Kariba fails, then the shortages are more (2005/06 & 2006/07)

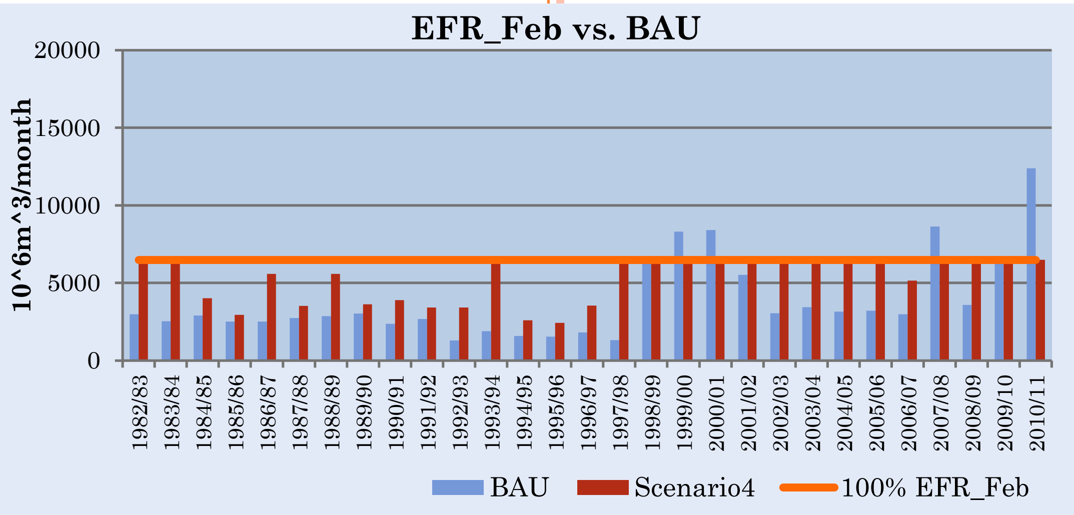


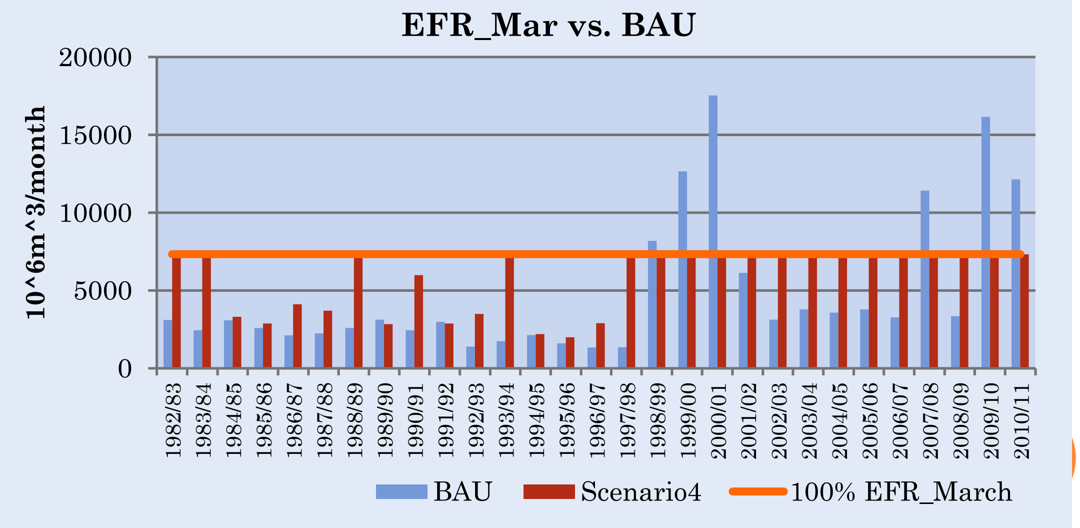
	Units	Max potential	BAU_FC	Scen 1	Scen 2	Scen3	Scen 4
CB	GWh/yr	17928	12334	12312 (0.2%)	12334	11933 (3.2 %)	11865 (3.4%)

Results

Example of flow results : Kariba Scenario 4.

- Shows the average natural flows for Feb and March can be met in normal years.
- However the frequency and magnitude of bigger floods is reduced.
- Although it may contribute to flood management, it is not known whether which flooding regime would be more beneficial (every year, or every few years)





Conclusion

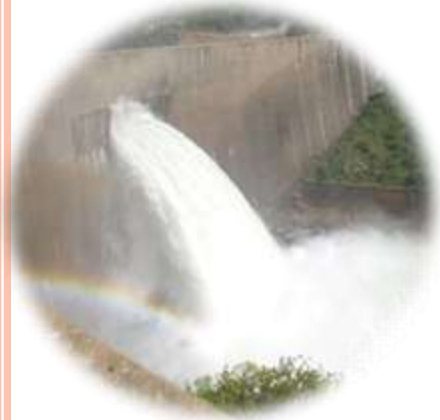
- The rule curves for Kafue and ITT are not strictly adhered to
- Cahora Bassa can release e-flows to recover the hydrograph by 50% or 100% in normal to wet years, without large negative impact on HP production. However, fewer shortages are experienced when Kariba also releases for EFR
- Therefore flood releases in February and March in the Zambezi are possible in normal to wet years without significantly affecting hydropower production (depends on the magnitude of EFR).
- However, the frequency and magnitude of very large floods is reduced by imposing these regular EFR flood releases.

RECOMMENDATIONS AND FURTHER WORK

- Further studies are needed to determine the environmental flow requirements and dynamics, especially inter-annual variations
- Compare environmental flow requirements at more locations in the basin, and find synergies between the operation of reservoirs
- Analyse *low* flow requirements and its trade-offs
- Study the economics of environmental flows in the Zambezi for tradeoff analysis and cost/benefit sharing policies between hydropower and the environment in the basin

Acknowledgements

- This work was part of the POWER2FLOW project financed by the UNESCO-IHE Partnership Research Fund (Netherlands). In addition, the authors would like to thank HCB, Fisheries Research-Songo, ARA Zambeze, ZRA, ZESCO Limited, DWA (Zambia), Meteorological Office (Zambia), WWF and WaterNet. Without these organisations and their staff, this piece of work would not have been possible.



Thank you!