Quantifying the trade-offs in re-operating dams for the environment in the Lower Volta River

Afua Owusu[a b], Jazmin Zatarain Salazar[b], Marloes Mul[a], Pieter van der Zaag[a c], Jill Slinger[b d]

[a] Land and Water Management Department, IHE Delft Institute for Water Education, Westvest 7, 2611 AX Delft, The Netherlands
[b] Faculty of Technology, Policy and Management, TU Delft, Jaffalaan 5, 2628 BX Delft, The Netherlands
[c] Faculty of Civil Engineering and Geosciences, TU Delft, Stevinweg 1, 2628 CN Delft, The Netherlands
[d] Institute of Water Research, Rhodes University, Drosty Rd, Grahamstown, 6139, South Africa

Response to reviewers:
The authors thank the editor for their comment and hope the explanation below makes these statements clear.

Location	Comment and Response
	Comment: One final issue for Line 24-28: You said ‘leading to increased annual inflows to the Akosombo Dam’, then later stated ‘while climate change resulting in lower inflows’. This is confusing. Please explain. **Response:** The two statements refer to 2 situations: one where there is increased inflows and the other where there is decreased inflows. We have changed the wording in ‘*while climate change resulting in lower inflows*’ from “*lower*” to “*decreased*” to make the contrast clearer. Based on a literature review (Section 3.2) we designed 5 scenarios indicative of the range of climate-induced changes predicted for the Volta discharge for the mid to long term. These are listed in Table 1 and the effects of different climate futures on the Pareto approximate solutions for the Volta basin are presented in Figure 5 and section 4.2. In the abstract when we state: “*It is found that climate change* ***leading to increased annual inflows*** *to the Akosombo Dam reduces the trade-off between hydropower and the environment as this scenario makes* ***more water available for users****.”* we are referring to the scenarios that lead to an increase in annual inflows. We find that in these scenarios, there is more water compared to the current baseline so that the trade-off between water users is reduced. The second line: “*Furthermore, climate change resulting in* ***decreased annual inflows*** *provides the opportunity to* ***strategically provide dry season environmental flows****, that is, reduce flows sufficiently* ***to meet low flow requirements for key ecosystem services*** *such as the clam fishery”* refers to the scenario which leads to a decrease in annual inflows to the Akosombo dam. In this scenario, while there is less water for all users, it is still possible to reap some environmental benefits out of a ‘bad’ situation because it is possible to strategically release recommended dry season e-flows. In effect, if there is less water, there will be low releases from Akosombo Dam and the annual firm energy demand cannot be met, but some

Location	Comment and Response
	ecosystems like the clam fishery require these low flows at certain times of the year and in this scenario, we can meet this requirement without trading off against hydropower because we cannot meet the hydropower demand anyway (in Figure 5, this is most clearly illustrated in scenario 1-clam e-flows graph, where the best pareto solutions for the environment *is not* significantly different from the best hydropower solution on the Kpong (Kp) and Akosombo (Ak) axes). In the Discussion (Lines 426 to 443), an explanation of the two statements in the Abstract can be found: *"While the majority of climate predictions for the Volta River generally point to an increase in annual water availability (Kunstmann and Jung, 2005; Aerts et al., 2006; Jung et al., 2012; Abubakari, 2021; Jin et al., 2018; Sylla et al., 2018),* ***based on this study, an argument can be made that both an increase or a decrease in inflows to the Lower Volta enhance the potential for e-flows implementation compared to the current baseline****. On the one hand, an increase in inflows to the Akosombo dam as applied in scenario 3, reduces the amount of the firm energy requirement that would have to be supplemented by other sources for the implementation of 'fair environmental solutions' to about 3.9% (vs 11.6%) for clam e-flows, and then 23.2% (vs 32%) for e-flows 2 and 33.7% (vs 38%) for e-flows 3. On the other hand, a decrease in inflows to the Akosombo Dam, whereby at best only 2,774 GWh/year of hydropower can be generated, provides opportunity to strategically release recommended dry season e-flows to reap some environmental benefits out of a 'bad' situation where annual flow releases from the dam will be low anyway. This operation policy under dry climate scenarios could also be adopted in dry years, in essence modelling the Episodic E-flows Implementation approach, which is an opportunistic approach to dam re-operation that takes advantage of prevailing hydrological conditions (Warner et al., 2014; Yang and Yang, 2014; Owusu et al., 2021). This contrasts with the alternative approaches, Adaptive Management and Blanket Operation which represent more structural inclusion of e-flows in the dam operation policy (Warner et al., 2014)."* To elaborate on the requirement for low/dry season flows and why this is important for the clam fishery: this is because at certain times of the year (Nov to March), in the veliger larva life stage of the Volta clam, low water levels encourage salt intrusion to the Lower Volta and while adult clams are freshwater species with some tolerance for short term saline conditions, the larva of the clam require salinity. In Owusu *et al*., 2022, more details on the Volta clam, their lifecycle and habitat and the derivation of this environmental flow (clam e-flows) requirement can be found. Owusu, A., Mul, M., Strauch, M., van der Zaag, P., Volk, M., and Slinger, J.: The clam and the dam: A Bayesian belief network approach to environmental flow assessment in a data scarce region, Science of The Total Environment, 810, 151315, https://doi.org/10.1016/J.SCITOTENV.2021.151315, 2022.