International Association for Impact Assessment Conference: IAIA'23
Kuching, Malaysia, 8-11 May 2023

ENSURING THAT ENVIRONMENTAL FLOWS FROM DAMS WILL SUSTAIN BIODIVERSITY

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Abstract: Environmental flow (e-flow) releases from hydropower and other dams are now recognized as a key environmental impact mitigation measure. Yet e-flows are often determined without sufficient attention to biodiversity, resulting in excessive loss of aquatic life and harm to riverine ecosystems. For e-flows to sustain aquatic and riparian biodiversity, they need to mimic (at least somewhat) the natural flow variation to which these species and ecosystems are finely adapted. Adequate e-flow releases from dams are more than just ensuring enough water downstream during dry periods; they also mean providing enough seasonal variation (wet enough in the wet season, yet dry enough in the dry season), keeping hydro-peaking flow variation within acceptable limits, and keeping flow changes from being too abrupt. Even without considering species-level information, e-flows will be more biodiversity-friendly if they can maintain key riverine habitat features such as floodplain forests and grasslands, marshes and lagoons, river islands with successional vegetation, sand and gravel bars, steep riverbanks, emergent boulders, and seasonal pools. Making biodiversity-friendly e-flows a reality may require incorporating specific boundary conditions within dam operating rules, followed by diligent compliance monitoring. Biodiversity outcomes should also be monitored, with adjustments to e-flow releases where needed as part of adaptive project management.

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Introduction--Aquatic Biodiversity is at Great Risk Worldwide:

1. **Biodiversity Loss: The Other Global Environmental Crisis.** The ongoing loss of biodiversity-- the variety of life on Earth, including different ecosystems, species, and genes—has become a global environmental crisis. Although it receives less attention overall than climate change, the biodiversity loss crisis is no less severe--owing to its global scale, rapid rates of change, and largely irreversible consequences. Natural ecosystems and wild species sustain human survival and well-being in numerous and often irreplaceable ways. There is thus a compelling, worldwide need to take the actions required to maintain biodiversity, natural habitats, and the associated ecosystem services upon which human society depends.

2. **Freshwater Biodiversity is at Highest Risk.** Based on the proportion of species at risk, freshwater biodiversity worldwide is even more acutely threatened than terrestrial or coastal/marine biodiversity. The reasons for this precarious situation are readily apparent. Around the globe, freshwater ecosystems have been—and continue to be--degraded, diminished, or destroyed by a multitude of threats. These include:

a. **Pollution** from numerous industrial, agricultural, and other human sources, resulting in eutrophication and oxygen depletion from excess nutrients, along with poisoning from a broad range of toxic substances.

b. **Water abstraction and diversion**, for agriculture and other human uses, result in the shrinkage or even disappearance of lakes, marshes, and other freshwater ecosystems.

c. **Invasive species**: Many non-native aquatic animals and plants have been (and continue to be) introduced—deliberately or accidentally—to lakes, rivers, and other freshwater ecosystems. Some invasive species spread rapidly and result in the extinction or severe decline of native aquatic species.

d. **Overharvesting** of freshwater fish and other aquatic organisms, whether through direct harvest or bycatch.

e. **Dams** and related infrastructure can harm aquatic biodiversity through (i) upstream inundation by reservoirs; (ii) river fragmentation, blocking the movements of fish and other aquatic life; and (iii) and **alteration of downstream flows**—the impact specifically addressed by this paper.

Environmental Flows as a Key Tool for Conserving Biodiversity:

3. **Available Tools for Biodiversity Conservation in Dam Projects.** Managing downstream water releases based on environmental considerations including biodiversity (known as **environmental flows**, or **e-flows**) is a fundamentally important tool for managing the environmental impacts of dams. Besides e-flows, other key tools for managing the biodiversity-related impacts of dams are (i) **project site selection** (considering the location and surface area of upstream inundation, along with which river segments merit permanent protection from dams or similar infrastructure); (ii) **reservoir and catchment area management**; and (iii) **off-site compensatory measures** (including biodiversity offsets).

4. **E-flow considerations are relevant to all dams with some water storage capacity**, i.e., those dams that are not entirely run-of-river. (In run-of-river dams, the water outflow volume approximately equals the inflow volume at any time except during initial reservoir filling, if any.) Water storage dams for which e-flows are an important consideration include **many hydropower dams, along with most irrigation, water supply, and multi-purpose dams**—whenever there is any meaningful ability to influence downstream flows.

5. It is important to recognize that there are **multiple objectives for downstream water releases from dams**. These objectives can include power generation, irrigation, water supply, inland navigation, pollution or sediment management, recreational water use, or other downstream human uses. While these are all legitimate objectives for managing dam water releases, **biodiversity also needs to be duly considered**—either (i) as a **direct objective** of an e-flow regime or (ii) as a **binding constraint** to a flow regime being driven by one or more other objectives.

There are Different Types of Environmental Flows:

6. The author has found a common misconception among development practitioners and even some environmental advisors--that "environmental flows" simply means ensuring that there will be enough water downstream of the dam, especially during dry periods. While this is indeed an important e-flow category, there exist at least **four distinct e-flow categories.**

7. **E-flow Type #1: Enough Water in Dry Periods.** This what many people consider "environmental flows" to mean--not letting the river run too dry. For water supply, irrigation, or multi-purpose dams--with consumptive water uses--this concern might cover the entire downstream waterway (or until the confluence with another river or large tributary). For hydropower projects (which use but do not consume water), the risk of insufficient downstream flows exists largely for (i) de-watered stretches of downstream river (between the dam wall and the tailrace water outflow) or (ii) rivers or tributaries that are diverted to increase water availability for power generation.

8. For downstream river segments that experience reduced water availability, it is important to remember that **year-round release of the dry season "base flow"** (if substantially less than the wet season flows) typically **will not be sufficient to sustain most downstream biodiversity.** Many aquatic species can survive low-flow (high stress) periods during part of the year, but not over the course of the entire year. This situation is analogous to high-latitude terrestrial species that can survive a cold winter, but only because they can recover during the warmer spring and summer seasons.

9. **E-flow Type #2A: Enough Seasonal Variation--Wet Enough in the Wet Season.** To sustain biodiversity, e-flow water releases need to consider the seasonality of natural river flows. This includes releasing enough water during wet periods to maintain specialized habitats such as **floodplain forests; lakes, lagoons, marshes, and seasonal wetlands; floodplain grasslands; and river islands with successional vegetation**. High seasonal flows are also needed to maintain the **reproductive cycles of fish and other aquatic life**; high flow pulses stimulate the breeding or migratory behaviors of many fish species.

10. **E-flow Type #2B: Enough Seasonal Variation--Dry Enough in the Dry Season.** The flip side of e-flow seasonality is that much river-dependent biodiversity also requires having not too much water during naturally dry periods. Many key riverine habitat features need lower dry season flows to persist. These include **sandbars, gravel bars, shingle** (rock cobble), and **steep riverbanks**; these features provide nesting, resting, or foraging habitats for a wide range of birds, turtles, and other wildlife. Seasonally **emergent boulders and rocky outcroppings** provide essential habitat for specialized biodiversity; this includes, for example, highly localized *Podostemaceae* aquatic plants in West African rivers, along with birds such as the Rock Pratincole *Glareola nuchalis*. **Seasonal pools** that form when rivers recede in dry periods provide important breeding or foraging habitat for amphibians, aquatic insects, and a wide range of other wildlife. **All these types of habitats may be reduced or lost completely when rivers are regulated to maintain unnaturally high dry season flows**; this is sometimes the case with baseload hydropower, large-scale irrigation, or inland navigation projects.

11. **E-flow Type #3: Peaking Flows within Acceptable Limits.** Those hydropower projects that are operated for peaking generation result in twice-daily fluctuations in downstream flows; this normally corresponds to daily electricity demand changes, with morning and evening peak loads. This fluctuation, if significant, can severely affect aquatic biodiversity downstream of the hydroelectric dam. Most freshwater species are adapted to **seasonal changes** in water flows and levels, **but not daily ones**; in this respect, they are unlike coastal species that are adapted to natural, twice-daily tidal fluctuations.

12. **From a biodiversity standpoint, run-of-river flows** (often used for baseload power generation) **are preferable to peaking power flows.** Nonetheless, peaking power is often attractive to power sector planners, who may wish to complement other sources of baseload (hydro, nuclear, geothermal, or fossil fuel) or intermittent (wind or solar) power generation. Accordingly, **where peaking hydropower generation is selected, options for making it more biodiversity-friendly include:**

a. Keep peaking ratios low, such that the difference between peak (high) and off-peak (low) flows is not more than about 2 to 1. As an example, recent fish monitoring from the Uganda Bujagali Dam shows that peaking flow fluctuations of around 2 to 1 have led to measurable, but not drastic, reductions in downstream fish abundance.

b. Choose lower conservation value waterways and compensate for the losses. For example, to compensate for aquatic and terrestrial habitat losses associated with the Ingula Pumped Storage Scheme, an important South African wetland is now protected as a biodiversity offset, benefiting globally threatened birds such as the Wattled Crane *Bugeranus carunculatus*.

c. Build a downstream regulating dam to absorb the peaking flow variation. For example, the new Mpatamanga Hydropower Project on the Shire River in Malawi will have a peaking power dam (309 MW) but also a regulating dam (41 MW) some 7 km downstream. The regulating dam will replicate run-of-river flows to protect the biodiversity of the Majete Wildlife Reserve and Elephant Marsh, along with downstream flood-recession farming areas.

13. **E-flow Type #4: Flow Changes Not Too Abrupt.** Abrupt flow changes—during peaking generation, reservoir flushing, dam maintenance, or equipment testing—can unnecessarily harm downstream biodiversity. **Sudden flow drops** can leave fish stranded; they may also pose a human safety hazard (at recreational swimming areas). **Sudden flow increases** can wash away and drown terrestrial wildlife, along with livestock and even people. Accordingly, **dam operating rules** should specify more gradual flow release changes, known as **ramping**.

Environmental Flow Decision-making involving Biodiversity:

14. **Emphasize Species of Conservation Interest.** If the downstream native species are of conservation concern (e.g., IUCN Red List), or of special management interest (such as for fishing), their requirements should receive special attention in e-flow decision-making.

15. **Species-level Knowledge Gaps.** Decision-making about whether a proposed e-flow regime would be adequate for sustaining biodiversity is often constrained by scientific uncertainty. Not enough may be known about the affected downstream species to confidently predict whether they would thrive (or even just survive) under a proposed flow regime. Some of the aquatic species in question might not even be scientifically described, much less studied enough to know how they would respond to downstream flow changes. Moreover, decision-making about how to operate a dam normally cannot wait until the downstream biodiversity has been sufficiently studied.

16. **Focus on Key Habitat Features.** Since species-level information may be inadequate for e-flow decision-making, it is useful to focus on downstream riverine habitat features. Specifically, to what extent would each of these habitat features remain under a proposed flow regime? Conversely, what changes to the flow regime would likely be needed for these habitat features to persist over time? Paras. 9-10 (above) provide examples of special habitat features that are important for biodiversity and depend on sufficiently high, low, or seasonally variable e-flows. Even with minimal available data on downstream aquatic species, it is feasible to assess the extent and condition of these riverine habitat features. By modeling the water levels associated with different e-flow options, it is then possible to predict the impacts of proposed flow regimes on the affected habitat features and thus to select an e-flow regime that adequately considers biodiversity. Many of the downstream species of conservation interest will depend on these habitat features.

Making It Happen—Project Planning, Design, Construction, and Operation:

17. **Obtaining good biodiversity outcomes from e-flows** typically implies close attention to each of the following dam project stages:

a. **Project (and River Basin) Planning.** Biodiversity-friendly E-flow plans can usefully be expressed as **boundary conditions for dam operating rules**. Such boundary conditions might specify, for example, e-flows with not less than X cubic meters per second (m3/s), nor more than Y m3/s, during [indicate which dry months] and not less than Z m3/s during [indicate which wet months].

b. **Project Design.** Because the engineers designing the dam might not be aware of the e-flow requirements, it is important to ensure that the dam design (including outflow dimensions) is fully capable of delivering the agreed e-flows during operation.

c. **Project Construction.** Construction supervision should ensure that the dam is built and tested in accordance with the agreed e-flow releases.

d. **Project Operation.** Making biodiversity-friendly e-flows a reality often requires diligent compliance monitoring. Biodiversity outcomes should also be monitored, with adjustments to e-flow releases where needed as part of adaptive project management.

18. **Legally Binding Requirements.** It is important to turn e-flow agreements (as specified in the Environmental and Social Management Plan, Biodiversity Management Plan, or similar technical documents) into binding requirements in the project legal documents, including financing agreements.

References:

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