Development and application of the Ecological Risk due to Flow Alteration (ERFA) methodology in Cambodia – Progress on the TEFRIC Project

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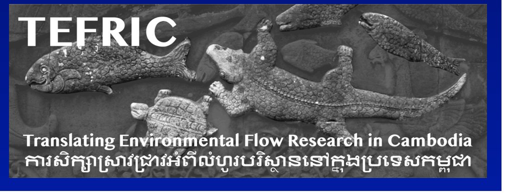

1. Introduction: Environmental Flows

The hydrological characteristics of a river exert critical controls on aquatic ecosystems. A river's flow regime (characterised by variability, magnitude, frequency, duration, timing and rate of change of discharge) is central to sustaining aquatic biodiversity and ecosystem integrity. All elements of this regime influence some aspect of riverine ecosystems. Changes in river discharge due to climate change or water resources management have the potential for ecological impacts. The science of environmental flows has developed in order to determine flow regimes necessary to maintain economically, socially and ecologically important ecosystem services.

2. ERFA

A range of methods is available to assess environmental flow requirements and potential impacts of hydrological change. The Ecological Risk due to Flow Alteration (ERFA) method is based on the Range of Variability Approach that uses Indicators of Hydrological Alteration (IHA), for comparing natural and altered flow regimes. ERFA was originally applied to Europe-wide climate change assessments (Laize *et al.*, 2014; Figure 1).

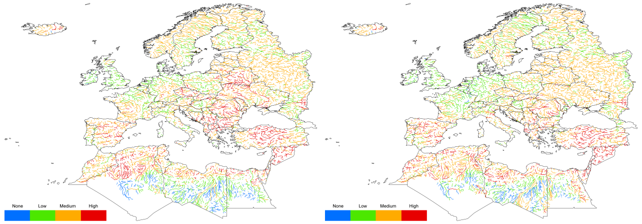

Figure 1. European-wide application of ERFA based on river discharges simulated by the WaterGAP hydrological model for 1961-1990 baseline and 2040-2069 scenario periods. Climate projections are for the SRES A2 scenario simulated by the IPCM4 (left) and MIMR (right) GCMs (Laizé *et al.*, 2014).

Thompson *et al.* (2014) modified ERFA for use with large-scale hydrological model results for the Mekong River Basin. This modified ERFA uses eight Monthly Flow Regime Indicators (MFRIs), three for high flows and five for low flows (Table 1). MFRIs capture the magnitude (described by the median) and variability (interquartile range, IQR) of hydrological variables calculated for each year of a baseline and scenario period. Indicators associated with timing of high and low flows are described by the mode of the month in which extreme flows occur.

Table 1. Monthly Flow Regime Indicators (MFRIs) used within modified ERFA (Thompson *et al.* (2014).

Hydrological variables (one per year)	MFRI[c] (one per period)	Flow type	Regime characteristics
Number of months above threshold[a]	Median (1) IQR[d] (2)	High	Magnitude; Frequency
Month of maximum flow / flooding (1-12)	Mode (3)	High	Timing
Number of months below threshold[b]	Median (4) IQR (5)	Low	Magnitude; Frequency
Month of minimum flow / flooding (1-12)	Mode (6)	Low	Timing
Number of periods of at least two months duration with flow / flooding below threshold[b]	Median (7) IQR (8)	Low	Magnitude; Frequency; Duration

a. Threshold: Q5 (95th percentile) from the baseline period; b. Threshold: Q95 (5th percentile) from the baseline period; c. Indicator identification number between brackets.

For MFRIs based on the median and mode, significant departures from baseline conditions are assumed when baseline-scenario differences exceed 30%. The corresponding threshold for significant changes for the two mode-based MFRIs is 1 or more months. A traffic-light based colour coding system is used to classify the overall risk of ecological change in high and low flows. Risk classes from no risk, through low and medium to high risk are based on the number of MFRIs undergoing significant change (Table 2, Figure 2).

Table 2. Risk classes based on MFRI changes.

Risk	Number of MFRIs High Flows	Number of MFRIs Low Flows
High	3	4-5
Medium	2	2-3
Low	1	1
No	0	0

Beyond the Mekong, ERFA has been applied to assess climate change-driven impacts on environmental flows in the West Africa's Upper Niger Basin (Thompson *et al.*, 2017) and India's Narmada Basin (Robinson *et al.*, 2018). These applications have included approaches for summarising where changes in individual MFRIs exceed thresholds as well as the overall risks of change for large numbers (>40 for the Upper Niger) of scenarios (Figure 3).

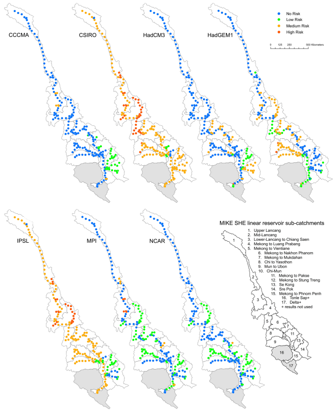

Figure 2. ERFA risk of ecological change in low flows for the Mekong derived from MIKE SHE/MIKE 11 modelling for a 2°C increase in global mean temperature for 7 GCMs (Thompson *et al.*, 2014).

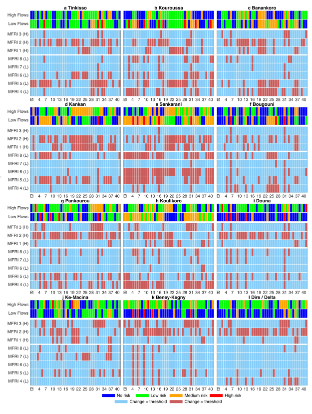

Figure 3. Risk of change in high / low flows and MFRI change compared to thresholds for 12 stations on the Upper Niger for 41 GCMs and the RCP4.5 scenario (E = ens. mean) (Thompson *et al.*, 2017).

3. Translation of Environmental Flow Research in Cambodia

TEFRIC is funded by the NERC Innovation Follow-on Programme. The project is a collaboration between UCL Geography, the Centre for Ecology and Hydrology (CEH), the Institute of Technology of Cambodia (ITC) and the Tonle Sap Authority (TSA).

Cambodia's freshwater resources are key to the livelihoods of the nation's population, especially the rural poor. They include the Tonle Sap (Figure 4), the great lake alternatively fed by and draining to the Mekong, as well as river systems in which the seasonal flood supports agriculture and extensive fisheries. Cambodia's and the wider Mekong's water resources are under increasing pressure from dams, rapid development, population growth and land use change. Climate change will also impact river flows although there is uncertainty in projected impacts (Thompson *et al.*, 2014). TEFRIC aims to introduce environmental flow approaches to Cambodia by developing and tuning ERFA so that impacts of these pressures can be established and mitigation measures developed.

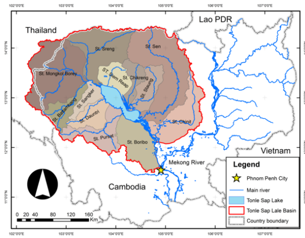

Figure 4. Cambodia, Lower Mekong River, the Tonle Sap and the primary Cambodian river catchments

4. Development of ERFA

The original ERFA code comprised a series of R scripts whose use required intimate knowledge of their operation. A new interface has been developed (TEFRIC-ERFA) using `shiny` which provides a "front end" to the ERFA code (Figure 5). The interface:

1. Interrogates a results directory containing baseline and scenario discharges enabling the user to select a site (gauging station) and any number of scenarios.
2. Plots scenario and baseline data, river regimes and flow duration curves as well enabling definition of the start of the hydrological year used in ERFA calculations.
3. Enables modification of ERFA settings including percentiles used in defining high and low flows (95th and 5th percentiles are the defaults; Thompson *et al.*, 2014). Thresholds used to define significant changes in MFRIs can also be modified (defaults = 30% and 1 month).
4. Enables user-defined settings to be saved for future use.
5. Summaries ERFA calculations for each scenario in terms of overall risks of change in high and low flows as well as the significant changes in each of the MFRIs (i.e. replicating the approach shown in Figure 3).

5. Tuning ERFA for Cambodia

The settings used in ERFA can in principle be changed so that the ERFA-derived risks of change match the opinion of experts with knowledge of a given river system.

ITC hosted a workshop in July 2018 attended by experts from different academic, governmental and conservation organisations (Table 3). Workshop participants collectively explored alternative TEFRIC-ERFA settings comparing results against expert assessment of risks to aquatic ecosystems and fisheries within the Lower Mekong. This was undertaken using results from Mekong-wide modelling initially for scenarios involving a 2°C increase in global mean temperature (Thompson *et al.*, 2014; Figure 2) but with access to projections from 41 CMIP5 GCMs for the RCP4.5 scenario (equivalent to the data in Figure 3; Robinson, 2018).

Refinements to TEFRIC-ERFA were also suggested. These included the use of different thresholds for high and low flows (incorporated into the current version – Figure 5) and new MFRIs to reflect risks associated with changes in the timing of the seasonal rise in river flows. Future versions of TEFRIC-ERFA will incorporate these additional metrics. Suggestions for minor refinements to the interface have been addressed.

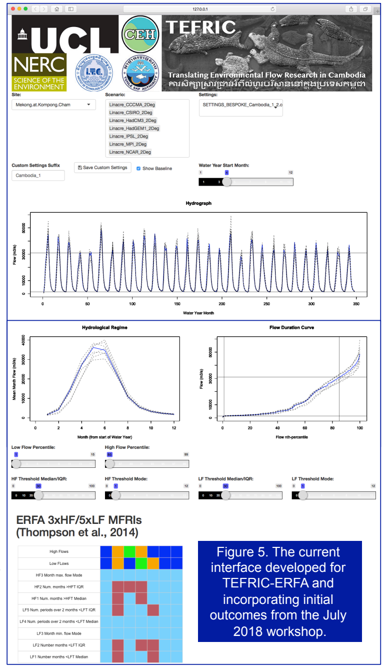

Figure 5. The current interface developed for TEFRIC-ERFA and incorporating initial outcomes from the July 2018 workshop.

6. The Next Steps

A final version of TEFRIC-ERFA will be developed incorporating all of the workshop outcomes.

Cambodian-specific scenarios are to be investigated using higher-resolution models developed by ITC of catchments draining to the Tonle Sap (Figure 4). These are likely to include climate change, water resource management and land cover modification.

Table 3. TEFRIC 2018 Workshop Participants

Cambodian Ministry of Water Resources and Meteorology
Cambodian Ministry of Environment
Tonle Sap Authority
Institute of Technology of Cambodia
Royal University of Phnom Penh
Battambang University
Royal University of Agriculture.
International Union for Conservation of Nature (IUCN)
Conservation International
Worldfish

These new scenarios, as well as those investigated to-date, will be re-assessed using the final version of TEFRIC-ERFA. As necessary, the existing Cambodia settings will be fine-tuned to reflect the new MFRIs and additional scenarios using a Cambodian expert group.

A major dissemination meeting in Cambodia will be held in the first half of 2019 coinciding with the release of TEFRIC-ERFA to the global environmental flows community. The meeting will include scientists, environmental practitioners and decision / policy makers in Cambodia as well as representatives of National Mekong Committees of other Mekong riparian states.

References

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