Integrating Fish Ecology into Environmental Flow Assessments in Central Asia

Intégrer l'écologie des poissons dans l'évaluation des débits environnementaux en Asie centrale

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RÉSUMÉ

Le développement de l'hydroélectricité exerce une pression croissante sur les rivières de haute montagne encore préservées d'Asie centrale. Cette étude propose une approche l'écohydraulique pour évaluer les débits environnementaux (e-flows) d'un projet hydroélectrique de dérivation sur la rivière Koksu, en Ouzbékistan. Des modèles hydrodynamiques 2D à haute résolution ont été combinés aux besoins en habitats de la *Schizothorax eurystomus*. Des règles logiques floues ont été utilisées pour déterminer les débits nécessaires à trois stades de vie. Le régime d'e-flows recommandé, qui représente 10,6–17,7 % du débit annuel moyen, garantit une variabilité saisonnière et préserve les habitats critiques. Ces résultats, soutenus par les premiers résultats d'une étude de biotélémétrie, sont discutés dans le cadre de la gestion adaptative. Cette méthodologie offre un modèle reproductible pour les évaluations environnementales en Asie centrale et ailleurs.

ABSTRACT

Hydropower development poses increasing pressure on Central Asia's pristine high-mountain rivers. This study presents an ecohydraulics-based approach to assess environmental flows (e-flows) for a diversion hydropower project on Uzbekistan's Koksu River. High-resolution 2D hydrodynamic models were combined with habitat requirements of snow trout (*Schizothorax eurystomus*), using fuzzy logic rules to determine flow magnitudes for three life stages. The recommended e-flows regime, representing 10.6–17.7% of the mean annual flow, ensures seasonal variability and sustains critical habitats. We discuss these findings within an adaptive management framework supported by preliminary biotelemetry results. This methodology provides a replicable workflow for environmental assessments in Central Asia and beyond.

KEYWORDS

Eflows, Schizothoracinae, snowtrout, Syr Darya River, water management

Débits environnementaux, Schizothoracinae, truite des neiges, rivière Syr-Daria, gestion de l'eau

1 INTRODUCTION

Central Asia's rivers have been heavily regulated, especially during Soviet times, when large-scale water diversions transformed steppes into cropland. This caused severe environmental degradation, most notably the Aral Sea's shrinkage, disrupting ecosystems, economies, and public health (Micklin, 2010). While lowland rivers have been extensively modified, high-mountain regions remain relatively pristine. However, growing demand for renewable energy now threatens these areas through hydropower development.

Hydropower can endanger aquatic ecosystems, with around 25% of Central Asia's fish species already threatened and limited data hindering conservation (Gozlan et al., 2019; Mamilov et al., 2021). Environmental flows (e-flows) are crucial for preserving ecological processes, yet knowledge gaps on its use in Central Asia remain significant.

The European Hydro4U project is constructing a small hydropower plant on the Koksu River in Uzbekistan's Shakhimardan exclave. The project aims to minimize habitat loss and ensure ecological connectivity in the diverted river reach through sustainable e-flow regimes (Jorde et al., 2022). The Koksu River supports *Schizothorax eurystomus*, a snow trout species with limited ecological data. Initial assessments show viable populations across all life stages, emphasizing the river's ecological importance (Karimov et al., 2024). Using novel habitat preference data and CASiMiR modeling (Noack et al., 2013), this study proposes e-flows that ensure seasonal variability and sustainable habitat conditions, offering a replicable framework for hydropower assessments in the region.

2 STUDY SITE

The study area is located in the Shakhimardan exclave of Uzbekistan, within the Alai Mountain Range. The Koksu and Aksu Rivers form the Shakhimardan River, draining an 800 km² catchment with elevations from 1,388 to 5,235 m (mean: 3,280 m). The Koksu River, contributing 150 km², is influenced by a natural sediment dam created by a landslide in 1766, which formed Lake Kurbankul and Lake Yashilkul. These lakes, fed by snow and glacier melt water, act as sediment barriers and stabilize the river's flow and sediment transport. The Koksu River exhibits a nivo-glacial flow regime, with higher discharges in summer (4.2 m^3/s) and lower flows in spring (2.1 m^3/s), and water temperatures ranging from 8.0–10.6°C throughout the year. The river's near-natural morphology includes diverse habitats with step-pool and riffle-pool sequences, although an artificial 3.5 m waterfall from 1970s road construction blocks fish migration in its mid-section.

A 2 MW hydropower plant using Francis Container technology diverts water via a 2.3 km long pipeline (Jorde et al., 2022). This necessitates the assessment of environmental flows for the residual river reach.

3 METHODS

To evaluate the sustainability of the Koksu River's small diversion hydropower plant, we assessed environmental flows (e-flows) through a multi-step approach: (i) snow trout habitat assessments via electrofishing, (ii) 2D hydrodynamic modeling of four study reaches, (iii) habitat simulations to predict flow-dependent habitat quality and availability, and (iv) e-flow recommendations.

3.1 Habitat Assessment

The snow trout (*Schizothorax eurystomus*), the primary target species, was selected due to its ecological and commercial significance and vulnerability to hydropower impacts. Point electrofishing surveys were conducted in April 2022 across mesohabitats (e.g., pools, riffles) to record fish length, water depth, flow velocity, and substrate type. Habitat preferences for juvenile (<120 mm TL), sub-adult (120-200 mm TL), and adult (≥200 mm TL) life stages were derived to supply the input for e-flow determination.

3.2 Hydrodynamic Modeling

Digital elevation models (DEMs) for the four study reaches with diverse morphologies were obtained using a drone-based photogrammetry approach (Kopecki et al., 2024). Hydrodynamic simulations were performed using SRH-2D (Lai, 2010), calibrated with observed water surface elevations. Model outputs included water depths and flow velocities under different discharges.

3.3 Habitat Simulations

Habitat quality was assessed using CASiMiR, a fuzzy logic-based habitat modeling tool that integrates flow velocity, depth, and substrate type (Noack et al., 2013). Suitability indices (0 = unsuitable, 1 = optimal) were calculated for each mesh element, producing spatial maps of habitat quality for snow trout across life stages. Migration passability was also evaluated, with thresholds for water depth (<10 cm = impassable; >20 cm = fully passable).

3.4 Environmental Flow Recommendations

Seasonal e-flow regimes were designed to maintain natural flow variability while supporting snow trout habitat and migration needs. Flow requirements were tailored to distinct seasons – winter, spring, summer, and fall – ensuring ecological sustainability within the diverted river stretch.

4 RESULTS AND DISCUSSION

E-flow regimes for the Koksu River were designed to sustain *Schizothorax eurystomus* populations while ensuring instream migration and habitat quality. Minimum baseflows of 0.3 m³/s were identified to maintain year-round fish passability, with minimum water depths of 10–20 cm ensuring connectivity across the diverted stretch. Habitat suitability analyses revealed that sub-adult snow trout are the critical life stage for e-flow determination, as adult fish were hardly caught in Koksu River during the sampling campaign.

Seasonal e-flow regimes were proposed, ranging from 0.3 m³/s in winter to 0.5 m³/s in spring and summer, constituting 10.6–17.7% of the mean annual flow. Habitat suitability models predicted that these baseflows would preserve 60–80% of available habitat across critical seasons. Migration barriers, such as an artificial waterfall in the diversion stretch, were identified as significant constraints. Two fish passes are expected to mitigate the situation in the diversion reach and even enhance the connectivity upstream of the intake by approximately 1.5 kilometers.

Snow trout population assessments highlighted natural reproduction in the basin, with all life stages present except upstream of migration barriers. Fall surveys revealed higher densities of snow trout in the Koksu River, possibly due to its slightly warmer winter temperatures compared to the Shakhimardan River. Early telemetry data indicate upstream movement in fall for overwintering and downstream migration in spring, suggesting high site fidelity. Monitoring and adaptive management, including substrate assessment and habitat connectivity measures, will be critical to address residual impacts of hydropower operations.

The study underscores the importance of staggered e-flow regimes to balance ecological sustainability with hydropower demands. These flows, aligned with global best practices, also safeguard cultural ecosystem services such as recreation and tourism while setting a benchmark for future water infrastructure projects in Central Asia.

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