Appendix 1

Quantitative Scoring and Classification Thresholds

To enhance the transparency and reproducibility of ecological risk classification, this study introduces two composite indices: The Ecological Sensitivity Index (ESI) and the FPV Disturbance Index (FDI) are constructed based on the principles of multi-criteria environmental assessment and semi-quantitative matrix scoring models, commonly applied in ecological planning and risk evaluation (Li et al., 2025; Wang et al., 2025), the latter being a new concept proposed in this paper in the context of FPVs. Each index integrates multiple key parameters, normalized to an ordinal scale (0 = low, 1 = moderate, 2 = high), and combined using a weighted additive formula. The parameter selection reflects critical ecological attributes (e.g., trophic status, biodiversity richness, and thermal sensitivity for ESI; surface coverage, transparency, and module clearance for FDI) that directly influence FPV-related ecosystem responses. The classification thresholds (0–2: Low, 3–4: Moderate, 5–6: High) are derived in alignment with risk stratification principles recommended in environmental impact assessment frameworks, such as the World Bank's ESS1, which emphasizes cumulative risk grading and multi-criteria evaluation (World Bank, 2018, ESS1). While no single prior study has proposed this exact framework, the structure follows established ecological risk matrix logic, with reference to adaptive scoring used in wetland conservation zoning, lake sensitivity evaluation, and FPV environmental guidelines. This semi-quantitative approach enables cross-site comparison, preliminary screening, and design optimization, especially in data-limited regions

where full quantitative modeling is impractical. Each is calculated as follows:

(1) Ecological Sensitivity Index (ESI)

$$ESI = w_1 \cdot S_{trophic} + w_2 \cdot S_{biodiv} + w_3 \cdot S_{stratification}$$

Where:

$S_{trophic}$: Score for trophic status (0 = oligotrophic, 1 = mesotrophic, 2 = eutrophic)

S_{biodiv} : Score for biodiversity richness (0 = low species count, 1 = moderate, 2 = high diversity)

$S_{stratification}$: Sensitivity to thermal disturbance (0 = deep-mixed, 1 = moderate layering, 2 = strong stratification)

w_1, w_2, w_3 : Weights, set as 1 by default

Classification Thresholds:

ESI 0-2 → Low

ESI 3-4 → Moderate

ESI 5-6 → High

(2) FPV Disturbance Index (FDI)

$$FDI = v_1 \cdot S_{\text{coverage}} + v_2 \cdot S_{transparency} + v_3 \cdot S_{clearance}$$

Where:

$S_{coverage}$:Water surface coverage by FPV (0 = <10%, 1 = 10 – 30%, 2 = >30%)

$S_{transparency}$:Module light transmittance (0 = >40%, 1 = 20 – 40%, 2 = <20%)

$S_{clearance}$:Vertical gap between module and water (0 = >0.5 m, 1 = 0.2 – 0.5 m, 2 = <0.2 m)

v_1, v_2, v_3 :Weights, also set to 1 by default

Classification Thresholds:

FDI 0–2 → Low

FDI 3–4 → Moderate

FDI 5–6 → High

The classification thresholds (0–2: Low, 3–4: Moderate, 5–6: High) follow common international semi-quantitative matrix scoring principles, as recommended in U.S. Army Corps of Engineers (2019), ISO (2018), and Australian/New Zealand Standard AS/NZS 31000 (2009).

(3) Final Risk Level Determination

Using a cross-tabulated risk matrix:

	FDI: Low	FDI: Moderate	FDI: High
ESI: Low	Low	Moderate	High
ESI: Moderate	Moderate	High	High
ESI: High	High	Very High	Very High

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