Supplementary methods and reconstruction tables

Station identifiers, component definitions and calculation results

This supplement documents FESI = 0.5FWQI + 0.3HI + 0.2BCI. Tables S1–S8 give component results, seasonal biological mapping, source correspondence and sensitivity scenarios. Tables S9–S10 provide indicator-level water-quality diagnosis and descriptive flow extremes. Supplementary Methods S7 and Tables S11–S13 document exported-record checks, full-risk memberships, F_1 sensitivity and source-reported water-level ranges.

Supplementary Methods S1. Fuzzy FWQI

The comparison values are DO c = 5 mg/L; NH_3-N c = 1 mg/L; TP c = 0.20 mg/L; TN c = 1 mg/L; CODMn c = 6 mg/L; and pH [6, 9]. The mapped cross-sections lie on river or tributary reaches. The main TP value is the GB 3838-2002 river Class III value of 0.20 mg/L, retained as a river-section diagnostic convention rather than a formal designation of hydraulic regime or regulatory water-body class. TN = 1 mg/L is borrowed from the standard's lake/reservoir Class III entry as an additional nitrogen-pressure screening benchmark; it is not presented as a river regulatory limit. TP = 0.05 mg/L is evaluated separately as a criterion-sensitivity scenario (Table S6). These distinctions also apply to the indicator-level results in Table S9; none of the comparison values or reported scores is changed by this clarification.

Let x be a valid observation, c its one-sided criterion, L = 0.8c and U = 1.2c. Define $f(t) = 0.5[t + t^2/(t^2 + (1 - t)^2)]$ for $0 < t < 1$. For a negative indicator, R = 0 if $x \le L$, $R = f((x - L)/(U - L))$ if $L < x < U$, and R = 1 if $x \ge U$. For DO, R = 1 if $x \le L$, $R = f((U - x)/(U - L))$ if $L < x < U$, and R = 0 if $x \ge U$. Thus R = 0.5 at x = c for these one-sided variables.

The raw excursion g is $\max(0, x/c - 1)$ for a negative indicator and $\max(0, c/x - 1)$ for DO with $x > 0$. For non-positive DO the implementation uses g = 10. The returned excursion e is Rg inside the transition band, g in the full-risk domain, and 0 in the zero-risk domain. The aggregation uses Re, so the band contribution is R^2g. For pH, R = e = 0 inside [6, 9]; below 6, R = 1 and e = (6 − x)/6; above 9, R = 1 and e = (x − 9)/9. The pH rule is therefore discontinuous in membership at its bounds.

For each indicator i, missing observations are removed and n_i is its valid count. An indicator with fewer than one valid observation is excluded. With M remaining indicators: $F_1 = (100/M)\Sigma_i \max_j R_{ij}$; $F_2 = (100/M)\Sigma_i[(\Sigma_j R_{ij})/n_i]$; $N = (1/M)\Sigma_i[(\Sigma_j R_{ij} e_{ij})/n_i]$; $F_3 = 100N/(1 + N)$. $FWQI = \max\{0, \min[100, 100 - \sqrt{(F_1^2 + F_2^2 + F_3^2)}/1.732]\}$. No valid indicators gives an unavailable score. F_1 is a maximum-risk summary, not the original CCME fraction of failed variables. F_2 averages indicators equally, not individual records. F_3 uses membership-weighted excursions. These departures require separate justification and are not validated by retaining the CCME aggregation shape.

Supplementary Methods S2. Hydrological-habitat score

WLS = max[0, min(100, 100(1 − ΔWL/60 m))], where ΔWL is the maximum minus minimum valid daily mean water level in the analysis window. Water-level and discharge records are grouped by calendar date and averaged arithmetically before HI calculation; missing days are not interpolated. At least two valid levels are required. The 60-m scale equals the stated normal-to-dead water-level difference (825–765 m) and is an illustrative normalization, not a locally calibrated ecological threshold or a verified amplitude at every source gauge. The score is invariant to a change of elevation datum. Table S8 tests 48-, 60- and 72-m reference scales.

For q = CV_Q, FVI = 100q/0.3 when $q < 0.3$; FVI = 100 when $0.3 \le q \le 0.7$; and FVI = max[0, 100(1 − (q − 0.7)/0.8)] when $q > 0.7$. The 0.3-0.7 interval is an uncalibrated scoring assumption.

For the supplied connectivity fraction C, CI = min[100, max(0, 100C)]. For sinuosity s, SI = 40 if $s < 1$; 50 + 80(s − 1) if $1 \le s \le 1.25$; 70 + 60(s − 1.25) if $1.25 < s \le 1.5$; 85 + 30(s − 1.5) if $1.5 < s \le 2$; 85 − 30(s − 2) if $2 < s \le 2.5$; and max[40, 70 − 20(s − 2.5)] if $s > 2.5$. The jump immediately above s = 2 is present in the supplied code and is disclosed rather than silently smoothed.

For gradient g, LGI = 100 − 20|g − 0.0175|/0.0125 for $0.005 \le g \le 0.03$; 60 + 20(g − 0.001)/0.004 for $0.001 \le g < 0.005$; 80 − 20(g − 0.03)/0.02 for $0.03 < g \le 0.05$; max[40, 60 − 1000(0.001 − g)] for $g < 0.001$; 60 − 20(g − 0.05)/0.05 for $0.05 < g \le 0.1$; and max[20, 40 − 100(g − 0.1)] for $g > 0.1$.

The common inputs s = 1.04, C = 0.995 and g = 0.011 produce SI = 53.2, CI = 99.5 and LGI = 89.6. Their weighted contribution to HI is fixed at 44.475 points for every station, equivalent to 13.3425 points in FESI after multiplication by the outer HI weight of 0.3. HI = 0.25WLS + 0.20FVI + 0.25CI + 0.20SI + 0.10LGI. Annual and quarterly FESI retain annual HI as a background; monthly exploratory FESI uses each month's own HI when both water-level and discharge inputs are present. S3 January and February are unavailable because water-level records begin in March. No water-level/discharge correlation enters HI. All five components are required in the reported monthly HI; missing components are not silently reweighted.

Supplementary Methods S3. Biological proxy score

D follows the Simpson definition in the source thesis [38] (Tian, 2024); reported values are used without conversion. J denotes Pielou evenness, c denotes Chl-a (μg/L), and A denotes abundance (cells/L). BCI combines four scores with weights 0.25 and enters FESI with weight 0.2. Source-definition consistency does not validate the scoring functions or establish ecological optima or universal trophic boundaries.

Simpson score: $S_D = 100D$ for finite D in the closed interval [0, 1], including D = 0 and D = 1. A missing D (including an absent entry or None), a non-finite D (NaN, +∞ or −∞), or an out-of-range D (D < 0 or D > 1) is treated as unavailable (NA; None in the code). Such inputs are neither replaced by zero nor clipped to the valid interval. The unavailable Simpson score is excluded from BCI, and the weights of the available component scores are renormalized to sum to 1: $BCI = \Sigma(k \in V)w_k S_k / \Sigma(k \in V)w_k$, where V contains the available scored components and the default w_k is 0.25. If no component score is available, BCI is unavailable. All four supplied seasonal D values are finite and within [0, 1]. This is the direct normalization of the supplied diversity values, not a locally calibrated ecological response function. Pielou score: $S_J = 100J$.

Chl-a score: $S_c = 100$ if $c \leq 1$; $100 - 30(c - 1)/9$ if $1 < c \leq 10$; $70 - 30(c - 10)/20$ if $10 < c \leq 30$; $40 - 30(c - 30)/20$ if $30 < c \leq 50$; and $\max[0, 10 - 0.2(c - 50)]$ if $c > 50$. This decreases with Chl-a above 1 μg/L; low values alone do not demonstrate whole-system ecological health.

Set $a = \log_{10}A$ for finite $A > 0$. Non-positive or non-finite abundance is treated as unavailable pending detection-limit and sampling metadata, rather than assigned a score. $S_A = 100$ if $a \leq 4$; $100 - 15(a - 4)$ if $4 < a \leq 6$; $70 - 30(a - 6)$ if $6 < a \leq 7$; $40 - 30(a - 7)$ if $7 < a \leq 8$; and $\max[0, 10 - 10(a - 8)]$ if $a > 8$. All four seasonal abundance values are positive, so the logarithmic transformation is defined for each observation. Missing component values are excluded and available weights renormalized; all four supplied rows have complete inputs. $BCI = 0.25(S_D + S_J + S_c + S_A)$.

Biological integration: source storage rows 1–4 are spring, summer, autumn and winter. Calendar quarters Q1–Q4 use source rows 4, 1, 2 and 3, respectively. The same reservoir-level seasonal score is applied to all three assessment datasets. Annual BCI is the arithmetic mean of the four seasonal BCI scores (61.86890063), contributing 12.37378013 FESI points at every station. Together with the fixed habitat contribution, the common annual contribution is 25.71628013 points. Annual FESI = 0.5FWQI + 0.075WLS + 0.06FVI + 25.71628013, so only FWQI, WLS and FVI create spatial differences; it is not BCI of the averaged raw indicators, not a measured 2024 annual value, and not a station-specific estimate. All seasonal inputs are complete; no imputation or alteration of source values is performed.

Table S1. Three-component annual and quarterly FESI

Site	Window	FWQI	Annual HI	BCI proxy	FESI
S1	Annual	57.99309	58.52532	61.86890	58.92792
S1	Q1	74.62392	58.52532	71.87685	69.24493
S1	Q2	68.59941	58.52532	51.81611	62.22052
S1	Q3	66.53455	58.52532	62.76167	63.37721
S1	Q4	74.51367	58.52532	61.02096	67.01862
S2	Annual	64.11155	76.66074	61.86890	67.42778
S2	Q1	84.96098	76.66074	71.87685	79.85409
S2	Q2	68.15886	76.66074	51.81611	67.44088
S2	Q3	69.51785	76.66074	62.76167	70.30948
S2	Q4	82.65679	76.66074	61.02096	76.53081
S3	Annual	45.90946	79.35661	61.86890	59.13549
S3	Q1	70.68067	79.35661	71.87685	73.52269
S3	Q2	57.60280	79.35661	51.81611	62.97160
S3	Q3	60.59316	79.35661	62.76167	66.65590
S3	Q4	56.50665	79.35661	61.02096	64.26450

All rows use weights 0.5/0.3/0.2. Annual FWQI and HI use pooled full-year inputs. Quarterly FWQI uses each quarter; HI remains annual. Annual FESI is not the mean of quarterly FESI. S1 quarterly FESI spans 62.22–69.24; S3 exceeds S1 in Q1–Q3 but is lower in Q4 (64.26 versus 67.02). FESI classes: Excellent ≥85, Good ≥70, Medium ≥55, Poor ≥40, Bad <40.

Table S2. Monthly three-component scores

Month	S1 FWQI	S2 FWQI	S3 FWQI	S1 FESI	S2 FESI	S3 FESI
1	79.87654	85.81485	77.94857	77.03908	84.05467	NA
2	80.57731	86.43777	79.93091	80.43652	84.25238	NA
3	75.07475	85.66658	70.67287	73.29520	81.16269	71.50557
4	75.33446	85.97125	64.64980	71.77670	80.14510	66.60930
5	68.15970	86.05114	61.29808	70.69682	80.15504	66.39623
6	79.95670	65.59051	66.08572	75.96657	69.80035	70.04858
7	73.00294	73.83186	60.97384	71.09100	76.15701	67.48379
8	81.04969	69.38405	73.39529	79.48343	72.98609	75.93373
9	75.20681	79.35860	73.42501	75.76574	78.94789	76.07109
10	80.64798	82.46639	53.19286	78.54443	80.15364	65.56062
11	74.63540	84.05191	72.62874	75.84189	80.95765	75.29731
12	80.44298	83.53595	75.44383	77.74323	78.60147	72.15254

FESI_month = 0.5FWQI_month + 0.3HI_month + 0.2BCI_season. Seasonal BCI is constant within each calendar quarter and identical at all sites; this table does not provide new monthly biological measurements or independent ecological validation. The exploratory Friedman comparisons use 12 common months for FWQI ($\chi^2 = 14.00$, df = 2, p = 0.0009, Kendall's W = 0.583) and 10 common months, March–December, for HI ($\chi^2 = 5.40$, p = 0.0672, W = 0.270) and FESI ($\chi^2 = 8.60$, p = 0.0136, W = 0.430). Serial dependence and shared proxies limit inference.

Table S3. Biological source mapping and scores

Target	Season	Source survey	D	J	Chl-a	PA*	BCI
Q1	Winter	January 2023	0.52	0.66	4.02	0.23	71.87685
Q2	Spring	April 2023	0.49	0.27	5.88	5.61	51.81611
Q3	Summer	July 2022	0.71	0.60	8.27	7.20	62.76167
Q4	Autumn	October 2022	0.55	0.50	5.84	3.11	61.02096

Chl-a: μg/L; PA*: 10^6 cells/L. Source: Tian (2024), four campaigns across 11 Baihetan sites. Figure 7 and the mapping above both follow Q1–Q4: winter, spring, summer and autumn. No new station survey is implied. The Simpson index uses the definition in the source thesis without conversion of the reported values. Ecological calibration of the scoring functions remains unresolved.

Supplementary Table S4. Comparison of two-component and three-component FESI calculations

Site	Two-component output	Three-component output	Difference
S1	66.06591	58.92792	-7.13799
S2	69.11307	67.42778	-1.68529
S3	58.86948	59.13549	0.26601

Calculation audit. Table S4 compares two calculation schemes for FESI. Scheme 1 omits biological-condition inputs and renormalizes the remaining weights to sum to unity. Scheme 2 explicitly incorporates seasonal BCI proxies, uses amplitude-based WLS derived from daily-mean water-level records, and applies linear Simpson-index scoring. Observed score differences arise from the combined set of modelling choices and cannot be attributed solely to inclusion or exclusion of biological inputs.

Figure 10 uses $\gamma = 0.2$, $\alpha \in [0, 0.8]$ and $\beta = 0.8 - \alpha$. It is a one-dimensional sensitivity check, not a complete three-weight uncertainty analysis. The manuscript figures use these same three-component results and S1–S3 identifiers.

Supplementary Methods S4. Biological scoring-function sensitivity

Additional one-at-a-time scenarios multiply each of the five HI weights or four internal BCI weights by 0.8 or 1.2, renormalizing the affected vector while keeping the other weights fixed. Two alternative FVI bands, 0.2–0.6 and 0.4–0.8, replace the default 0.3–0.7 band with the same upper penalty scale 0.8. These tests preserve all observations and outer FESI weights. Changing the FVI band gives annual FESI changes of −0.75 and +0.75 points, respectively, at all sites.

The Simpson values reported by Tian [38] were scored as S_D = 100D. To test the remaining biological scoring assumptions, the Chl-a input scale was multiplied by 0.8 or 1.2 before applying the existing piecewise function and the abundance log10 threshold was shifted by −0.2 or +0.2.. The resulting annual FESI changes were evaluated with the default outer weights and the same proxy season applied to all stations.

Across the four one-at-a-time biological-function scenarios, annual FESI ranged from 67.17–67.69 at S2, 58.87–59.40 at S3, 58.67–59.19 at S1. These ranges are bounded diagnostics of scoring assumptions, not confidence intervals, local ecological calibration or independent validation.

Supplementary Methods S5. Joint parameter perturbation and TP criterion scenario

We generated 2000 reproducible joint draws using seed 4650501. Each draw multiplied the five HI weights, four internal BCI weights and the three outer FESI weights by independent Uniform(0.8, 1.2) factors and renormalized each weight vector. The FVI high-suitability limits were sampled as lower U(0.2, 0.4) and upper U(0.6, 0.8), while the Chl-a scale and abundance log-threshold shift were sampled from U(0.8, 1.2) and U(−0.2, 0.2), respectively. Simpson scoring remained fixed at S_D = 100D. These ranges are sensitivity assumptions, not parameter distributions or ecological uncertainty estimates. The same draws were evaluated with TP = 0.20 and 0.05 mg/L.

Supplementary Table S5. Joint parameter perturbation results

TP (mg/L)	Station	FESI range	S2>S1>S3 fraction	Class fractions
0.05	S1	55.95–60.84	0.8780	Medium=1.0000
0.2	S1	56.47–61.33	0.4375	Medium=1.0000
0.05	S2	64.30–69.18	0.8780	Medium=1.0000
0.2	S2	65.03–69.78	0.4375	Medium=1.0000
0.05	S3	52.96–60.69	0.8780	Medium=0.9120; Poor=0.0880
0.2	S3	55.54–62.64	0.4375	Medium=1.0000

S2 remained highest in all 2000 joint draws. At TP = 0.20 mg/L, S2>S3>S1 occurred in 56.25% of draws and S2>S1>S3 in 43.75%; at TP = 0.05 mg/L, S2>S1>S3 occurred in 87.8%. All S1 and S2 draws remained Medium in both scenarios. S3 remained Medium at TP = 0.20 mg/L; at TP = 0.05 mg/L, 91.2% were Medium and 8.8% Poor. S1 and S3 are therefore treated as indistinguishable for ranking purposes under the tested assumptions; these draw frequencies are sensitivity results, not probabilities of ecological superiority or a formal equivalence test.

Supplementary Table S6. TP criterion scenario

Station	TP=0.20 FWQI	TP=0.20 FESI	TP=0.05 FWQI	TP=0.05 FESI
S1	57.99	58.93	56.83	58.35
S2	64.11	67.43	62.82	66.78
S3	45.91	59.14	41.33	56.85

The 0.05 mg/L value is the GB 3838-2002 Class III lake/reservoir TP criterion. The main diagnostic convention retains the river TP value of 0.20 mg/L. TN = 1 mg/L remains an explicitly supplementary nitrogen-screening benchmark, not a river regulatory limit. The mixed benchmark index is not a statutory classification under either a uniform river or lake/reservoir standard. Both TP scenarios retain the daily-mean HI and biological inputs; the S1–S3 order changes and is not considered robust.

Supplementary Table S2b. Monthly HI and valid daily mean water-level counts

Month	S1 HI	S1 nWL	S2 HI	S2 nWL	S3 HI	S3 nWL
1	75.751	31	89.240	31	NA	0
2	85.908	29	88.860	29	NA	0
3	71.275	28	79.847	28	72.646	28
4	79.154	30	89.321	30	79.737	30
5	87.513	31	89.221	31	84.613	31
6	85.417	30	88.806	30	88.808	30
7	73.457	31	88.963	31	81.482	31
8	88.021	31	85.806	31	88.946	31
9	85.367	30	89.054	30	89.354	30
10	86.721	28	89.054	27	89.200	28
11	87.733	30	89.092	30	89.262	30
12	84.392	31	82.098	31	74.088	31

Supplementary Methods S6. Source correspondence and WLS reference-scale sensitivity

Source correspondence. Assessment-site identifiers follow Figure 1: S1, Pudu River site; S2, Yili River site; and S3, Heishui River site. The same names identify each site and its corresponding water-quality, water-level and discharge series in Table S7. All hydrological and water-quality monitoring stations used in the study are located on tributaries within the Baihetan Reservoir area. The tributary names identify the assessment sites and their corresponding water-quality, water-level and discharge datasets. Approximate WGS84 positions read from the map axes locate assessment areas rather than surveyed monitoring gauges. Exact gauge coordinates, their reference systems and sampling depths are not reported in the available metadata. The monitored tributary reaches form part of the reservoir area and are affected by reservoir backwater; its magnitude and temporal variation have not been quantified at individual gauges. Reference [48] provides regional context on lower-Heishui backwater reaches.

Daily hydrological processing. Hydrological records originated from the Ministry of Water Resources Information Center [36], with secondary processing also identified in the discharge workbooks. Dates were parsed and sorted chronologically, invalid numeric observations were excluded, and valid water-level and discharge values were grouped by calendar date and averaged arithmetically. No missing day was interpolated. The 534, 532 and 415 valid intraday water-level observations at S1–S3 yielded 360, 359 and 300 daily means, respectively; each discharge series contained 366 daily means. S3 water-level records begin on 1 March 2024, leaving January–February monthly HI/FESI unavailable and restricting its Q1 water-level coverage to March. Annual daily-mean amplitudes were 52.920, 1.960 and 2.715 m. These daily series were used in the WLS and FVI calculations specified in Supplementary Methods S2.

Water-level elevation metadata. The source-reported daily means range from 779.650 to 832.570 m at S1, 775.360 to 777.320 m at S2, and 903.695 to 906.410 m at S3 (Table S13). The source records do not specify the water-level elevation datums or provide complete information linking the source gauges to the assessment sections; no transformation to a common datum was performed. These values cannot establish each gauge's water-surface elevation relative to the reservoir's 765–825 m operating range. WLS depends on within-series amplitude and is invariant to a constant datum offset; this property does not establish gauge equivalence or quantify backwater influence. Main-reservoir monitoring coverage is limited, so these tributary datasets do not represent the lacustrine zone or reservoir-wide ecological condition.

WLS reference-scale sensitivity. For each reference scale L = 48, 60 or 72 m, $WLS(L) = \max[0, \min(100, 100(1 - \Delta WL/L))]$ was calculated from the same annual daily-mean water-level amplitude. The default is L = 60 m. Only L was varied; water-quality and biological inputs, flow variability, fixed habitat scores and all weights were held constant. $HI(L) = 0.25WLS(L) + 0.20FVI + 0.25CI + 0.20SI + 0.10LGI$ and annual $FESI(L) = 0.5FWQI + 0.3HI(L) + 0.2BCI$ were then evaluated. Table S8 reports the resulting scores: at L = 72 m, S1 (60.03) slightly exceeds S3 (59.19), reversing their default order. This is a bounded normalization-sensitivity check, not local ecological calibration; gauge conditions and observation coverage can affect amplitude independently of ecological condition.

Supplementary Table S7. Assessment-site map positions (WGS84) and unified tributary names for hydrological and water-quality datasets

Site	Longitude °E	Latitude °N	Water quality	Water level	Discharge
S1	102.87	26.35	Pudu River site	Pudu River site	Pudu River site
S2	103.07	26.80	Yili River site	Yili River site	Yili River site
S3	102.82	27.05	Heishui River site	Heishui River site	Heishui River site

Table S7 gives approximate WGS84 map readings from Figure 1 (about 0.01° precision): S1, lower Pudu River; S2, Yili River confluence; S3, lower Heishui River. These locate assessment areas, not surveyed gauges. The site names Pudu River site (S1), Yili River site (S2) and Heishui River site (S3) are used consistently for the corresponding water-quality, water-level and discharge series. All source monitoring stations are located on tributaries within the Baihetan Reservoir area. Their tributary confluences follow S1 → S2 → S3 towards Baihetan Dam; the sites do not form a continuous sampled river transect. The unified tributary names are not surveyed gauge identifiers or evidence of identical sampling positions. Exact gauge coordinates, reference systems and sampling depths are not reported.

Hydrological source: Ministry of Water Resources Information Center (http://xxzx.mwr.gov.cn/); discharge workbooks also credit secondary processing. Available water levels at 08:00, 14:00 and other times are averaged by calendar date. The 534, 532 and 415 observations yield 360, 359 and 300 daily means at S1–S3. Each discharge series has 366 daily means. Missing water-level days, including S3 January–February, are not imputed. Annual daily-mean amplitudes are 52.920, 1.960 and 2.715 m at S1–S3; gauge regime and coverage can affect these independently of ecological condition.

Monitoring location: all hydrological and water-quality monitoring stations used in this study are on tributary reaches that form part of the Baihetan Reservoir area and are subject to reservoir backwater influence. The magnitude and temporal variation of this influence have not been quantified at individual gauges. Reference [48] provides regional context rather than gauge-specific quantification.

Supplementary Table S8. Annual FESI sensitivity to the WLS reference scale

Site	48 m	60 m	72 m
S1	58.04	58.93	60.03
S2	67.37	67.43	67.47
S3	59.05	59.14	59.19

The WLS reference scale is a normalization choice rather than a site-calibrated ecological threshold. At 72 m, S1 exceeds S3 slightly; therefore, these results do not support a stable S1–S3 ranking.

Supplementary Table S9. Indicator-level diagnosis for the annual water-quality datasets.

Site	Indicator	Valid n	Mean R	Max R	Mean Re
S1	DO	1440	0.00000	0.00000	0.00000
S1	NH3-N	1425	0.00000	0.00000	0.00000
S1	TP	1401	0.00276	1.00000	0.01661
S1	TN	1418	0.99859	1.00000	1.85902
S1	CODMn	1419	0.00420	1.00000	0.00118
S1	pH	1440	0.00069	1.00000	0.00000
S2	DO	1484	0.01356	0.82986	0.00014
S2	NH3-N	1437	0.00000	0.00000	0.00000
S2	TP	1412	0.01850	1.00000	0.01594
S2	TN	1456	0.85789	1.00000	0.93961
S2	CODMn	1381	0.00107	0.69658	0.00002
S2	pH	1484	0.00000	0.00000	0.00000
S3	DO	1354	0.17230	1.00000	0.02980
S3	NH3-N	1347	0.00218	1.00000	0.00054
S3	TP	1343	0.05037	1.00000	0.00606
S3	TN	1349	0.99998	1.00000	1.56013
S3	CODMn	1301	0.00045	0.33102	0.00000
S3	pH	1354	0.03397	1.00000	0.00063

R is risk membership (0–1); Re is the membership-weighted excursion used in F_3. DO is reverse-directional: larger R denotes greater low-oxygen risk. Counts are valid numeric records per indicator. The criteria are those in Supplementary Methods S1, including TP = 0.20 mg/L. Figure 4(b) displays these mean R values for all three sites. TN risk is high at every site, while additional DO, TP and pH risk contributes to the low FWQI at S3. Source correspondence follows Table S7.

Supplementary Table S9b. Annual FWQI factor decomposition.

Site	F_1	F_2	F_3	FWQI
S1	66.66667	16.77074	23.82706	57.99309
S2	58.77413	14.85027	13.73998	64.11155
S3	88.85040	20.98750	21.02321	45.90946

Supplementary Table S10. Annual daily-discharge extremes and extrema of 3-day and 7-day moving-mean discharge (m^3/s).

Site	Daily min	Daily max	3-day min	3-day max	7-day min	7-day max
S1	3.125	127.957	3.172	117.682	3.212	113.341
S2	3.656	660.156	3.792	634.375	4.049	502.984
S3	10.344	308.703	10.380	298.818	10.460	283.210

Each same-reach discharge series has 366 dated daily values from 1 January to 31 December 2024, with no missing or duplicate dates. Three-day and seven-day extrema are the minimum and maximum arithmetic means of complete consecutive daily windows within that year; no cross-year windows are used. The discharge series use the same tributary-based names as the corresponding water-quality and water-level datasets: Pudu River site (S1), Yili River site (S2) and Heishui River site (S3); Table S7 gives their correspondence with the assessment identifiers. These are descriptive summaries of the daily inputs to FVI and receive no additional HI weights.

Supplementary Methods S7. Export checks and maximum-risk sensitivity

Exported-record checks. The water-quality workbooks contain 1469, 1491 and 1395 rows at S1–S3. All monitoring dates parse within 2024. There are no exact duplicate complete rows, but 152, 167 and 176 rows, respectively, participate in repeated-timestamp groups. These rows remain separate exported records; counts do not represent independent events. Missing or non-finite values are removed for each indicator before risk calculation. The six indicator columns contain no non-missing non-numeric or infinite entries; per-indicator finite counts appear in Table S11. The main calculation applies no operational-status filter and does not remove a high value solely because it has high risk membership. Instrument calibration records, blank/standard checks and the provider's QC logs were not available, so no additional instrument-level validation is claimed.

Operational-status sensitivity. The source labels contain 1388/69/12 normal/maintenance/non-operational rows at S1, 1309/179/3 at S2 and 1283/97/15 at S3. A separate scenario retains only normal-status rows and repeats the same numeric screening and aggregation. This is a record-selection sensitivity rather than certification that all normal-status readings are valid or all maintenance readings are erroneous.

Full-risk counts. For each indicator, Table S11 reports the finite record count n, the count and proportion with exactly R = 1, and the empirical 95th percentile of R. The counts follow the implemented membership functions; for pH, any finite observation outside [6, 9] has R = 1. Repeated timestamps and serial dependence prevent interpreting these counts as independent excursions. At S3, the 66 DO, 16 TP and 46 pH full-risk records occur at 60, 14 and 44 distinct timestamps, respectively. At S1 all five CODMn full-risk records carry a maintenance flag. At S2, 12 of 17 TP full-risk records carry a maintenance flag. At S3, full-risk records include 3 maintenance DO and 1 maintenance pH reading; all 16 TP full-risk records have normal status.

Percentile-based F_1. For each indicator i and time window, $q_{0.95}(R_i)$ is the empirical 95th percentile calculated by linear interpolation between ordered observations (NumPy quantile, method="linear"). Set $F_{1,95} = (100/M)\Sigma_i q_{0.95}(R_i)$. Only the maximum term in F_1 is changed in the all-record comparison; F_2, F_3, comparison criteria, HI, BCI and component weights are held fixed. The normal-status scenario recomputes all three FWQI factors from its filtered inputs and then applies either F_1 definition. Annual results are in Table S12. Missing monthly HI remains missing.

Sensitivity interpretation. The percentile-based F_1 increases annual FESI to 70.24105, 77.49826 and 72.13066 at S1–S3 (all Good), compared with 58.92792, 67.42778 and 59.13549 (all Medium) under maxima. Absolute classes are therefore sensitive to F_1. S2 remains highest in these scenarios, while S1 and S3 should not be assigned a stable relative rank across all tested assumptions. The percentile choice is an explicit diagnostic alternative, not a locally calibrated ecological threshold.

Supplementary Table S11. Full-risk record counts and risk percentiles for each site and indicator.

Site	Indicator	Finite n	R = 1 n	R = 1 (%)	95th percentile R
S1	DO	1440	0	0.000	0.00000
S1	NH3-N	1425	0	0.000	0.00000
S1	TP	1401	2	0.143	0.00000
S1	TN	1418	1416	99.859	1.00000
S1	CODMn	1419	5	0.352	0.00000
S1	pH	1440	1	0.069	0.00000
S2	DO	1484	0	0.000	0.09751
S2	NH3-N	1437	0	0.000	0.00000
S2	TP	1412	17	1.204	0.00000
S2	TN	1456	1011	69.437	1.00000
S2	CODMn	1381	0	0.000	0.00000
S2	pH	1484	0	0.000	0.00000
S3	DO	1354	66	4.874	0.99328
S3	NH3-N	1347	1	0.074	0.00000
S3	TP	1343	16	1.191	0.31985
S3	TN	1349	1348	99.926	1.00000
S3	CODMn	1301	0	0.000	0.00000
S3	pH	1354	46	3.397	0.00000

Counts denote exported numeric records, not independent sampling events. Risk membership is calculated using the main mixed diagnostic benchmarks, including TP = 0.20 mg/L and TN = 1.0 mg/L. Percentages use the finite count for the corresponding indicator. Zero full-risk counts do not imply that all memberships are zero.

Supplementary Table S12. Annual sensitivity to F_1 definition and source operational-status filtering.

Site	Records / F_1	F_1	FWQI	FESI	FESI class
S1	All / max	66.66667	57.99309	58.92792	Medium
S1	All / p95	16.66667	80.61934	70.24105	Good
S1	Normal / max	60.57532	61.19713	60.52994	Medium
S1	Normal / p95	16.66667	80.63339	70.24807	Good
S2	All / max	58.77413	64.11155	67.42778	Medium
S2	All / p95	18.29176	84.25252	77.49826	Good
S2	Normal / max	49.56220	69.20966	69.97684	Medium
S2	Normal / p95	18.10797	84.55660	77.65030	Good
S3	All / max	88.85040	45.90946	59.13549	Medium
S3	All / p95	38.55225	71.89979	72.13066	Good
S3	Normal / max	88.85040	45.90362	59.13257	Medium
S3	Normal / p95	38.27511	72.01507	72.18830	Good

All: all finite indicator records in the exports. Normal: only rows flagged normal by the source. Max: per-indicator maximum membership in F_1. p95: per-indicator 95th percentile membership. HI, BCI and FESI weights are unchanged. The normal-status cases recalculate F_2 and F_3 from the same selected records as F_1. Classes use the study-specific FESI boundaries, including Good ≥ 70 and Medium ≥ 55 and < 70. Results printed to five decimals are classified using unrounded scores.

Supplementary Table S13. Source-reported daily mean water-level ranges and elevation-datum availability.

Site	Daily n	Minimum (m)	Maximum (m)	Amplitude (m)	Elevation datum
S1	360	779.650	832.570	52.920	Unspecified
S2	359	775.360	777.320	1.960	Unspecified
S3	300	903.695	906.410	2.715	Unspecified

S1 minimum/maximum dates are 22 May/17 October 2024; S2, 8 April/19 June 2024; S3, 22 March/30 July 2024. Elevation datums are not supplied and no common-datum conversion has been performed. The reported levels must not be treated as verified elevations relative to the reservoir's 765–825 m operating interval. Their within-series amplitudes enter WLS under the stated normalization; these amplitudes alone do not quantify backwater influence or establish ecological degradation. S3 covers 1 March–31 December only.