

Type

Nitrogen and Phosphorus Diffusion Fluxes: Insight from High-Resolution Technology and Hydrodynamic Modeling

Qingqing Sun ¹, Fu-Jun Yue ^{1,*}, Jing-An Chen ², Jingfu Wang ^{2,*}, Yulin Li ³, Xiaozheng Li ¹, MohdAadil Bhat ¹, Jing Liu ⁴ and Si-Liang Li ¹

¹ Institute of Surface Earth System Science, School of Earth System Science, Tianjin University, Tianjin 300072, China; sunqingqing17@tju.edu.cn (Q.S.); lxz1998@tju.edu.cn (X.L.); aadilgeo@tju.edu.cn (M.B.); siliang.li@tju.edu.cn (S.-L.L.)

² State Key Laboratory of Environmental Geochemistry, Institute of Geochemistry, Chinese Academy of Sciences, Guiyang 550081, China; chen-jingan@vip.skleg.cn

³ Environmental Protection Monitoring Station of Two Lakes and One Reservoir in Guiyang, Guiyang 551400, China; 36170589@qq.com

⁴ School of Management Science, Guizhou University of Finance and Economics, Guiyang 550025, China; liujingaiskl@hotmail.com

* Correspondence: fujun_yue@tju.edu.cn (F.-J.Y.); wangjinfu@vip.skleg.cn (J.W.)

Text S1

The forms of P were determined on dry samples by chemical sequential extraction [1]. Specifically, 500 mg sediment was 1) 1 M NH₄Cl (NH₄Cl-P, loosely adsorbed P), 2) 0.11 M Na₂S₂O₄/0.11 M NaHCO₃ (BD-P, P forms sensitive to redox potentials, such as P bound on the surface of Fe(III) and Mn oxides and hydroxides), 3) 1 M NaOH (NaOH-SRP, exchangeable with hydroxide ions), which extracts the P fraction adsorbed on the surface of aluminum hydroxides and the interior of ferric oxides of the sediment particles, 4) The extract in Step 3) was digested with K₂S₂O₈ to measure TP, and the difference between 3) and 4) was NaOH-NRP, Microbial phosphorus, including detritus of organophosphorus and poly phosphorus, and humic acid compounds binding P, 5) 0.5 M HCl (HCl-P, Ca-bound fraction), which represents the amount of P found in Ca and Mg minerals, 6) The residual-P, consisting mainly of refractory P of the Si crystal lattice and organic P fraction. The extraction efficiency was 87% ~ 94%. The continuous extraction solution of Fe forms in sediment was selected as follows, including exchangeable form, carbonate bounded form, ferric and manganese oxide form, organic matter bounded form, and residual form [2].

Phosphate, NH₄⁺, and NO₂⁻, NO₃⁻ concentrations in surface water, overlying water, pore water, and sediment in the extract were measured by molybdenum blue method [3], salicylic acid-

Text S2

hypochlorite photometric method, N-(1-naphthalene) ethylene-diamine photometric method, ultraviolet spectrophotometry using Epoch Microplate Spectrophotometry (Biotech, USA), respectively [4, 5]. Fe^{2+} , Mn^{2+} , and S^{2-} concentrations in pore water in O-Phenanthroline spectrophotometric method, potassium periodate oxidation photometric method, and p-aminodimethylaniline photometric method [5].

There are four main kinds of sediment material diffusion and migration: molecular diffusion, dispersion, hydrodynamic wind and wave disturbance, and disturbance. In the mathematical model describing the material balance of modern lake sediments, molecular diffusion is the most important way for the dissolved components below the disturbed layer of sediments to be transported through pore water [6].

The porosity of sediments below the surface φ , Equation (S1).

$$\varphi = W_{wet}\omega / \rho V \quad (\text{S1})$$

Where w_{wet} is the wet weight of 5 cm surface sediment, ω is moisture content, ρ is water density, 1g/cm^3 , V is the volume of 5 cm surface sediment core (core diameter 5.9 cm). It had values between 0.90 and 0.96.

D_s denotes the effective diffusion coefficient of ion in sediments, Equations (S2 and S3) [7].

$$D_s = D_o / \varphi f \quad (\text{S2})$$

$$f = 1 / \varphi^m \quad (\text{S3})$$

Where D_o is the ideal diffusion coefficient of the infinite dilution solution. The D_o value used in this study were 17.65 (NH_4^+), 16.39 (NO_2^-), 16.93 (NO_3^-), 6.54 (HPO_4^{2-}), $10^{-6} \text{ cm}^2/\text{s}$ [7]. f is the morphological hindrance factors in surface sediments, when $\varphi \geq 0.7$, $m=2.5-3$, in this paper, $m=3$, $\varphi < 0.7$, $m=2$ [8].

There is a linear relationship between D_o and temperature, Equations S4.

$$D_o(\text{HPO}_4^{2-}) = 7.34 + 0.16(T - 25) \quad (\text{S4})$$

Where T is the temperature at SWI, the unit was K.

Diffusion flux from SWI, $R_{diffusion}$, Equations (S5):

$$R_{diffusion} = \sum F_i \cdot A_i \quad (\text{S5})$$

Settling flux, $R_{settling}$, Equations (S6):

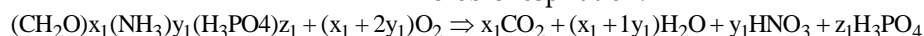
$$R_{settling} = \sum A_i \cdot k_s \cdot C_{s,i} \quad (\text{S6})$$

Where F_i is the i th diffusion flux represented by the i th sampling point, A_i is the area represented by the i th sampling point, $C_{s,i}$ was the C, N and P concentration at the surface sediment of the i th sampling point.

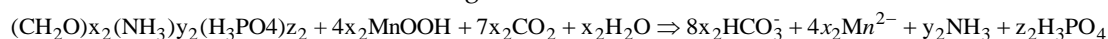
Text S3

Some main reactions among OM, O₂, P, N, Fe, Mn, S [9].

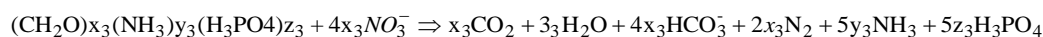
Aerobic respiration:



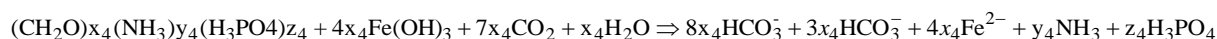
Manganese reduction:



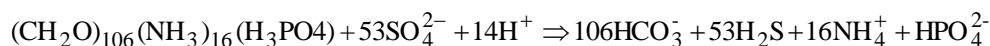
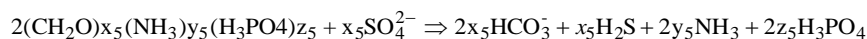
Nitrate reduction:



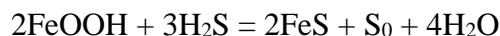
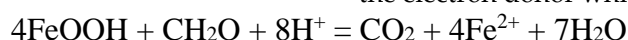
Iron reduction:



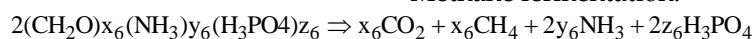
Sulfate reduction:



When NO₃⁻, NO₂⁻ and Mn(IV) are depleted, Fe(III) are reduced by the microbial iron reduction coupled with OM as the electron donor and chemical iron reduction coupled with S²⁻ as the electron donor which is produced by SO₄²⁻ reduction [10].



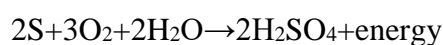
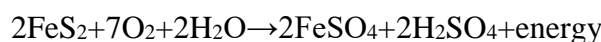
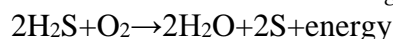
Methane fermentation:



FeS dissolved product smaller than MnS, OM decomposition H₂S priority and Fe(II) in combination with FeS is generated, the top 4 cm dissolved Fe content is close to zero, the dissolved iron was unused, the excess H₂S with Mn(II), Fe content increased from 4cm, the bivalent iron overload, hydrogen sulfide, and iron combination generated FeS, small solubility product, hydrolysis of S²⁻ cannot be checked out.

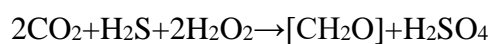
Sulfurization (sulfur oxidation):

Colourless sulfur bacteria, e.g., filamentous sulfur bacteria, *Beggiata*, *Thiothrix*, *Thiospira*, *Sulfolobus*, *Thiovulum*.



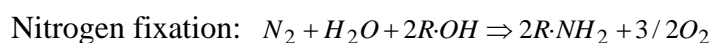
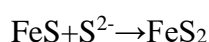
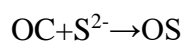
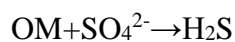
Colored sulfur bacteria, which contains chlorophyll and can carry on the photosynthesis, e.g., *Chromatiaceae*, *Chlorobiaceae*, *Rhodospirillaceae*, *Rhodobacter spheroides* and *R. palustris*.





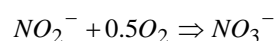
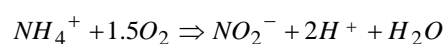
Sulfur reduction

The chemical iron reduction process produces solid



Ammonification: Proteins in granular organic nitrogen are mineralized to peptides and amino acids under the action of heterotrophic bacteria.

Nitrification:



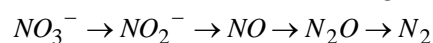
Nitrite bacteria and nitrate bacteria are both aerobic autotrophic bacteria.

Michaelis-Menten Equation is the basic expression of enzyme reaction [11], Michaelis constant of nitrate bacteria is $16\mu\text{M O}_2$, that of nitrite bacteria is $62\mu\text{M O}_2$. Heterotrophic nitrifying bacteria nitrogen-oxidizing organic compounds and inorganic ammonia compounds that require additional organic matter [12] and could react when oxygen is very low, and are more important than autotrophic nitrifying bacteria. Denitrification can occur when sufficient organic matter is present.

Denitrification is an important source of greenhouse gases in the atmosphere, N_2O especially.

The optimum pH is 7-8 and the limit is 6 ~ 9.5.

Denitrification: Facultative anaerobic heterotrophic microorganisms



Nitrate nitrogen reduced to ammonia nitrogen: obligate anaerobic bacteria.

Table S1. Characteristics of the 24 water sampling sites and 6 sediment sampling sites.

Sites	Longitude (° E)	Latitude (° N)	Water depth (m)	Sediment thickness (m)
24 water sampling sites				
1	106.3878	26.45111	13	
2	106.3872	26.45028	12	
3	106.3772	26.44861	11	
4	106.3775	26.44278	9	
5	106.3847	26.43861	1	
6	106.3892	26.46667	10	
7	106.3939	26.47611	19	
8	106.4028	26.48306	12	
9	106.4211	26.4725	1	
10	106.4175	26.48944	7	
11	106.4236	26.48944	21	
12	106.4253	26.50250	9	
13	106.4253	26.51111	23	
14	106.4244	26.52306	30	
15	106.4242	26.52639	1	
16	106.3997	26.54611	31	
17	106.3942	26.54611	11	
18	106.3994	26.54722	16	

19	106.3894	26.54889	13	
20	106.4106	26.54472	24	
21	106.4208	26.54806	12	
22	106.4194	26.55000	22	
23	106.4194	26.55028	35	
24	106.4194	26.53361	33	
6 sediment sampling sites				
HF1	106.412	26.481	17	0.44
HF2	106.405	26.546	18	0.76
HF3	106.44	26.507	4	1.05
HF4	106.425	26.515	28	0.6
HF5	106.423	26.523	10	0.44
HF6	106.414	26.550	36	0.34

Table S2. Hydrodynamic and temperature modules parameter of Hongfeng Lake in EFDC[13-18].

Index	Parameter
Turbulent diffusion	
Horizontal kinematic eddy viscosity and diffusivity	Smagorinsky with Wall Drag and WC Diffusion (Wall Z0=0.002)
Background/constant horizontal eddy viscosity (AHO, m ² /s)	10
Horizontal momentum diffusivity (AHD, dimensionless)	0.15
Wall roughness	0.002
Large cell aspect ratio (m/m)	0
Vertical eddy viscosity and diffusivity	
Time advance filter	Square root $T=((t-1)*t)^{0.5}$
Vertical eddy viscosity(AVO, m ² /s)	10 ⁻⁶
Vertical molecular diffusivity (ABO, m ² /s)	10 ⁻⁸
Max. kinematic eddy viscosity(AVMX, m ² /s)	10 ⁻⁶
Max. eddy diffusivity(ABMX, m ² /s)	10 ⁻⁸
Vertical turbulent limiting options	Limit length scale and limit RIQMAX
Wall Proximity Function	No wall proximity effects on turbulence
Sub-options for standard scheme	Galperin et al., stability functions
Roughness	0.035
Wetting and drying options	Use wetting/drying with non-linear iterations and face masking
Dry depth (m)	0.04
Dry step	10

Boundary condition withdrawal wet depth(m)	0.15
Timing/linkage	
Time step(seconds)	0.754
Dynamic time step options	
Safety factor	0
#Ramp-up loops	1000
Maximum dH/dT	0
Growth step	2
Maximum time step	30
Initial condition for water temperatures (°C)	26.23 on 1 July, 10.5 on 1 January
Initial condition for bed temperatures	
Uniformbed temperature (°C)	16
Uniform thermal thickness (m)	12
Surface heat exchange sub-model	equilibrium temp (CE-QUAL-W2 method)
Solar radiation absorbed in the surface layer Minimum fraction absorbed in the top layer	0.3
Light extinction coefficients in units of 1 m per g/m ³ unless otherwise specified (EFDC+) Background	0.45
General	
Bed heat exchange coefficients,heat transfer coefficient W/m ² /°C	0.3
Convective heat transfer coefficient	0

Evaporation Options (water balance only)

Using evaporation and rainfall from ASER

Table S3. Sample points information for verification and input data.

Reservoir/inflow	Name	Part	Site name	Latitude (° N)	Longitude (° E)	Distance from dam/m
Reservoir area	Hongfeng Lake	North part	H1	26.508	106.425	6500.9
Reservoir area	Hongfeng Lake	North part	H2	26.523	106.438	6232.65
Reservoir area	Hongfeng Lake	North part	H3	26.53	106.431	2441.05
Reservoir area	Hongfeng Lake	South part	H4	26.55	106.422	451.42
Reservoir area	Hongfeng Lake	South part	H5	26.549	106.387	4091.95
Reservoir area	Hongfeng Lake	South part	H6	26.555	106.348	9258.47
Inflow	Taohuayuan River	South part	HZ1	26.532	106.331	11676.84
Inflow	Yangchang River	North part	HZ2	26.433	106.360	19062.28
Inflow	Houliu River	North part	HZ3	26.436	106.432	19712.2
Inflow	Maxian River	North part	HZ4	26.410	106.377	20988.88
Inflow	Maibao River	North part	HZ5	26.570	106.395	4277.3

Table S4. Verification of temperature module of Hongfeng Lake by EFDC and measured data.

		Surface water				Middle water				Bottom water			
		April	April	July	July	April	April	July	July	April	April	July	July
H1	S			25.9	26.1							25.9	26.1
H1	M			25.2	25.0							24.8	24.8
H2	S			25.1	26.1								
H2	M			25.2	25.								
H3	S	16.9	16.6	26.0	26.6	16.9	16.6	26.0	26.6	16.9	16.6	26.0	26.6
H3	M	15.3	15.3	25.4	25.6	15.7	15.3	25.2	25.3	13.8	15.2	25.0	25.3
H4	S	15.3	15.9	25.8	26.1	15.3	15.9	25.8	26.1	15.3	15.9	25.8	26.1
H4	M	15.5	15.4	25.3	25.3	15.3	15.4	25.2	25.3	15.4	15.3	24.8	24.5
H5	S	16.7	17.0	26.5	26.5	16.7	17.0	26.5	26.5	16.7	17.0	26.5	26.5
H5	M	15.6	15.4	25.3	25.3	15.4	15.4	25.2	25.2	15.2	15.3	25.3	25.3
H6	S	15.8	15.0	25.1	26.2					15.8	15.0	25.1	26.2
H6	M	15.8	15.8	26.2	25.4					15.8	15.8	25.9	25.1
Deviation													
H1				-0.026	-0.042							-0.042	-0.050
H2				0.006	-0.029								
H3		-0.094	-0.078	-0.023	-0.03	-0.070	-0.078	-0.031	-0.049	-0.183	-0.084	-0.038	-0.049
H4		0.016	-0.029	-0.018	-0.031	0.003	-0.029	-0.022	-0.031	0.010	-0.036	-0.037	-0.061
H5		-0.067	-0.094	-0.046	-0.046	-0.079	-0.094	-0.050	-0.050	-0.091	-0.100	-0.046	-0.046

H6	0.000	0.051	0.045	-0.029		0.000	0.051	0.033	-0.040
----	-------	-------	-------	--------	--	-------	-------	-------	--------

Note: S means simulation value, M means measured value. There are some missing measured data.

Table S5. Concentration in sediment, deposit rate, enrichment degree in sediment, release flux of N and P at the sediment-water interface in Hongfeng Lake.

Elements	Hongfeng reservoir									
	Concentra- tion in sedi- ment [19]/% (min- max(mean))	Degree of en- rich- ment [19]*	Total amount in sedi- ment/ Mmol	Average Deposit rate mol/(m ² ·ye ar)	Average Deposit rate Mmol/ye ar	Concentration in surface sediment in front of the dam/ %	Degree of en- richment in front of the dam ^(a)	Flux release from SWI 10 ⁻⁹ nmol/cm ² /s	Release amount of DAM from SWI at sum- mer ^(b) mol	Flux at 5 cm depth sediment 10 ⁻⁹ nmol/cm ² /s
TN	0.25-0.36 (0.28)	4.45	1,341.7	1.56 [19], 0.34	19.448	0.48-0.70 (0.56)	8.90			
TP	0.10-0.22 (0.14)	2.6	287.8	0.077	4.391	0.18-0.19 (0.18)	3.34	3,321.36	547.98	3,656.46

Note:(a) means the ratio of the average value of lake sediments to the soil background value in China. (b) means area=207,5601 m².

Table S6. Porosity ϕ , diffusion coefficient D_s , diffusion flux of NH_4^+ , NO_3^- , labile P surface sediment concentration, deposited fluxes of N and P, and the contribution rate of diffusion flux on the overlying water and sediment in Hongfeng Lake.

Parameter	July						
	HF1	HF2	HF3	HF4	HF5	HF6	Total
t_w (yr ⁻¹)	0.82	0.82	0.82	0.82	0.82	0.82	
H (m)	17	18	4	28	10	36	
ϕ	0.788~0.967	0.780~0.947	0.805~0.966	0.785~0.942	0.675~0.810	0.943~0.980	
k_s (ng cm ⁻² s ⁻¹)	16.211	6.274	4.86	11.495	8.579	8.917	
k_s (g cm ⁻² yr ⁻¹)	0.512	0.198	0.153	0.3625	0.271	0.281	
A_i (km ²)	7.6	4.13	5.84	6.1	3.84	6.61	
C_o (NH ₄ ⁺ , mg/L)	1.279	1.785	0.710	1.769	0.271	4.014	
$D_{s-NH_4^+}$ (10 ⁻⁶ cm ² s ⁻¹)	10.96	10.987~15.829	11.438~16.470	10.876~15.662	8.042~11.58	10.904~15.695	
$F_{w-NH_4^+}$ (10 ⁻⁶ nmol cm ⁻² s ⁻¹)	-36.95	229.976	17.666	-95.993	4.251	-270.688	
$F_{s-NH_4^+}$ (10 ⁻⁶ nmol cm ⁻² s ⁻¹)	-36.950~110.844	-20.254~229.976	-20.060~23.270	-95.993~5.843	-24.324~4.251	-270.688~164.767	
$F_{Diffusion-NH_4^+}$ (10 ⁻⁶ nmol cm ⁻² s ⁻¹)	-36.950~110.844	-20.254~229.976	20.060~18.447	-95.993~1.300	-24.324~64.105	-270.688~519.968	
Total NH ₄ ⁺ -N diffusion flux(kg/summer)	2,232.001	2,735.964	248.399	-2,295.722	448.002	4,106.684	7,475.327
$C_{NH_4^+}$ (%)	0.0102	0.1425	0.01245	0.00705	0.0405	0.2175	
$F_{deposited-NH_4^+}$ (nmol cm ⁻² s ⁻¹)	0.0118	0.0639	0.00432	0.00579	0.0248	0.138	

Total NH_4^+ -N deposited flux(kt/summer)	0.714	2.096	0.201	0.281	0.758	7.279	11.327
<i>Contribution</i> _{Overlying, NH_4^+}	-0.0050~-0.015	-0.0019~-0.021	-0.0210~-0.0193	-0.0058~-0.000078	-0.027~-0.070	-0.0056~-0.011	
<i>Contribution</i> _{Sediment, NH_4^+}	-0.00313~-0.00938	-0.000317~-0.0036	-0.00464~-0.00427	-0.0166~-0.000225	-0.000980~-0.00258	-0.00195~-0.00375	
$C_o(\text{NO}_3^-, \text{mg/L})$	5.790	2.055	5.596	4.350	5.790	5.520	
$D_{s-\text{NO}_3^-}$ ($10^{-6} \text{ cm}^2 \text{ s}^{-1}$)	10.513~15.820	10.539~15.183	10.971~15.798	10.423~15.023	7.714~11.108	10.459~15.055	
$F_{w-\text{NO}_3^-}$ ($10^{-6} \text{ nmol cm}^{-2} \text{ s}^{-1}$)	-4,621.552	175.657	-12.615	-183.863	-2,557.02~-589.694	-700.636	
$F_{s-\text{NO}_3^-}$ ($10^{-6} \text{ nmol cm}^{-2} \text{ s}^{-1}$)	-1,138.729~1,591.854	-155.52~1,665.424	-11.562~692.79	-525.659~-15.468	-81.995~1,418.177	-811.256~458.451	
$F_{\text{Diffusion}-\text{NO}_3^-}$ ($10^{-6} \text{ nmol cm}^{-2} \text{ s}^{-1}$)	-5,111.985~1591.854	20.138~1,665.425	-24.178~692.79	-525.659~-199.23	-2,585.350~1,418.177	-953.585~458.451	
Total NO_3^- -N diffusion flux(kg/summer)	-93,815.217	21,099.627	15,228.267	-17,576.517	-14,217.468	-22,879.926	-112,161.234
$C_{\text{NO}_3^-}$ (%)	0.0026	0.0597	0.0086	0.0050	0.0872	0.0041	
$F_{\text{deposited}-\text{NO}_3^-}$ ($\text{nmol cm}^{-2} \text{ s}^{-1}$)	0.0031	0.0268	0.0030	0.0041	0.0534	0.0026	
<i>Contribution</i> _{Overlying, NO_3^-}	-0.15~-0.048	0.0016~-0.13	-0.00321~-0.09188	-0.0049~-0.013	-0.13~-0.073	-0.014~-0.0068	
<i>Contribution</i> _{Sediment, NO_3^-}	-1.670~-0.520	-0.0922~-0.00112	-0.00811~-0.232	-0.129~-0.0489	-0.0484~-0.265	-0.0062~-0.129	

C_{IN} (%)	0.0128	0.2022	0.0210	0.0120	0.1277	0.2216	
$F_{deposited-IN}$ (nmol cm ⁻² s ⁻¹)	0.0149	0.0906	0.0073	0.0099	0.0783	0.1411	
$Contribution_{Overlying,IN}$	-0.1784	0.0855	0.0392	-0.0482	-0.0531	-0.0421	
$Contribution_{Sediment,IN}$	-0.1019	0.0080	0.0457	-0.0416	-0.00576	-0.00253	
C_{ON} (%)	0.0860	0.3963	0.0739	0.0804	0.2023	0.5030	
$F_{deposited-ON}$ (nmol cm ⁻² s ⁻¹)	0.0995	0.1776	0.0256	0.0660	0.1240	0.3204	
C_{TN} (%)	0.0988	0.5985	0.0949	0.0924	0.3300	0.7246	
Total NO ₃ ⁻ -N deposited flux(kt/summer)	0.185	0.878	0.138	0.198	1.631	0.137	3.167
Total ON deposited flux(kt/summer)	6.013	5.830	1.190	3.200	3.784	16.833	36.851
Total N deposited flux(kt/summer)	6.911	8.805	1.529	3.679	6.172	24.249	51.345
C_o (PO ₄ ³⁻ , mg/L)	0.186	0.196	0.213	0.188	0.171	0.215	
D_{s-P} (10 ⁻⁶ cm ² s ⁻¹)	4.061~6.111	3.984~5.865	4.238~6.103	4.030~5.803	4.415~4.291	4.040~6.276	
$F_{w-HPO_4^{2-}}$ (10 ⁻⁶ nmol cm ⁻² s ⁻¹)	-3.015~3.401	-8.183~4.871	1.721	-	10.336~95.092	7.468~9.691	

$F_{s-HPO_4^{2-}}$ (10^{-6} nmol cm^{-2} s ⁻¹) 1)	1.771~4.482	-2.043~61.096	0.111~0.936	1.766	-6.906~2.563	2.131~8.199	
$F_{Diffusion-HPO_4^{2-}}$ (10^{-6} nmol cm^{-2} s ⁻¹)	1.247~1.771	-3.329~65.967	0.111~2.657	0.59~5.167	0.857~88.188	-0.262~15.667	
Total P release flux(kg/summer)	90.717	501.620	59.697	139.572	778.751	426.585	1,996.942
C_{DIP} (%)	0.0469	0.0340	0.0233	0.0553	0.0266	0.00531	
$F_{deposited-IP}$ (nmol cm^{-2} s ⁻¹) 1)	0.0245	0.00688	0.00365	0.0205	0.00736	0.00153	
C_{TP} (%)	0.136	0.145	0.0721	0.193	0.0798	0.0620	
$F_{deposited-TP}$ (nmol cm^{-2} s ⁻¹) 1)	0.0712	0.0294	0.01131	0.0717	0.0221	0.0179	
C_{OP} (%)	0.0889	0.11121158	0.0488	0.138	0.0532	0.0567	
$F_{deposited-OP}$ (nmol cm^{-2} s ⁻¹) 1)	0.0465	0.0225	0.00766	0.0511	0.0147	0.0163	
$Contribution_{Overlying, HPO_4^{2-}}$	0.0026~0.0038	-0.0016~0.025	0.00085~0.020	0.00074~0.0064	0.00042~0.339	-0.0002~0.0133	
$Contribution_{Sediment, HPO_4^{2-}}$	$5.08 \times 10^{-5} \sim 7.22 \times 10^{-5}$	-0.000484~0.00959	$3.04 \times 10^{-5} \sim 0.000299$	$2.87 \times 10^{-5} \sim 0.000251$	$1.48 \times 10^{-5} \sim 0.0120$	-0.000171~0.0102	
Total PO_4^{3-} deposited flux(kt/summer)	1.482	0.226	0.169	0.996	0.225	0.080	3.178

Total OP deposited flux(kt/summer)	2.812	0.740	0.356	2.479	0.450	0.858	7.694
Total TP deposited flux(kt/summer)	4.301	0.964	0.525	3.475	0.675	0.938	10.878

Note: Diffusion fluxes were calculated (1) the pore water tested is obtained by centrifugation and filtration after cutting sediments at 1 cm intervals, (2) the pore water tested is obtained by DGT technique at 0.2 cm intervals. + means the molecule released from pore water to overlying water, - means the molecule diffused from overlying water to pore water.

Table S7. Velocity and total bed shear at HF1~HF6, Hongfeng Lake, in winter (W) and summer (S) (mean±standard deviation).

Sites	Year	Season	HF1	HF2	HF3	HF4	HF5	HF6
Velocity of water at depth of 0.5 m (10^{-2} m/s)	2013	W	5.24±3.42	7.40±5.53	4.04±1.92	3.60±2.41	5.43±2.44	4.82±5.62
	2017	W	4.20±3.13	8.16±4.32	4.79±1.61	3.60±1.61	5.64±2.90	4.43±2.72
	2013	S	12.42±3.31	11.21±5.32	4.74±2.43	8.31±4.30	16.42±3.45	16.90±10.52
	2017	S	8.86±3.55	14.65±6.12	5.09±0.30	11.48±4.8	14.49±4.09	22.43±11.34
Bottom Velocity (10^{-2} m/s)						3		
	2013	W	3.42±1.50	2.71±1.68	1.66±0.95	2.62±1.24	1.67±0.83	1.40±1.41
	2017	W	3.75±1.11	3.62±1.40	2.50±1.21	3.11±1.14	1.66±0.93	1.65±0.78
	2013	S	2.13±0.51	6.18±2.62	2.46±1.65	3.15±1.77	5.62±1.34	5.81±2.59
Average velocity (10^{-2} m/s)	2017	S	2.51±0.87	6.21±3.02	0.73±0.53	1.43±1.11	3.90±1.58	4.92±2.29
	2013	W	0.75±0.49	0.82±1.73	0.80±0.53	1.75±0.90	1.19±0.91	0.50±1.64
	2017	W	0.97±0.63	0.98±0.68	1.05±0.71	2.11±0.81	2.19±1.49	0.53±0.23
	2013	S	1.00±0.36	2.41±1.41	1.90±0.82	2.11±1.16	2.59±1.47	0.74±0.52
Horizontal velocity (10^{-2} m/s)	2017	S	0.91±0.28	2.45±1.38	1.17±0.79	1.17±0.48	1.23±0.50	0.88±0.44
	2013	W	0.74±0.46	0.74±0.44	0.80±0.53	1.74±0.90	1.18±0.91	0.41±0.20
	2017	W	0.95±0.63	0.98±0.68	1.05±0.71	2.11±0.81	2.19±1.49	0.53±0.23
	2013	S	1.00±0.36	2.41±1.41	1.90±0.82	2.11±1.16	2.59±1.47	0.74±0.52
Vertical velocity (10^{-4} m/s)	2017	S	0.91±0.28	2.45±1.38	1.17±0.79	1.17±0.48	0.92±0.73	0.88±0.44
	2013	W	2.81±1.48	14.04±8.09	-0.071±1.15	-0.29±1.04	-2.8±1.72	2.5±1.31
	2017	W	2.67±2.78	12.96±9.02	-0.70±1.80	0.29±0.28	-1.83±1.38	2.90±1.67

Total bed shear (10^{-2} N/m ²)	2013	S	3.81±3.12	24.53±9.10	-1.74±2.52	-2.03±2.41	-9.08±3.21	2.48±3.91
	2017	S	3.53±1.73	27.99±5.37	0.89±2.88	-6.20±1.95	-8.81±2.54	2.73±1.96
	2013	W	3.68±2.69	2.31±1.53	1.34±1.39	3.33±2.76	1.69±1.13	0.70±0.61
	2017	W	3.92±2.10	3.88±2.48	3.19±2.89	4.56±3.29	1.68±1.50	0.86±0.59
	2013	S	1.45±0.63	11.65±7.94	3.39±3.42	5.08±4.39	13.17±5.25	11.67±9.11
	2017	S	1.74±1.87	11.53±7.73	3.62±7.12	1.46±2.15	4.23±2.32	8.13±5.54

Note: - refereed to negative direction in sigma three-dimensional coordinate.

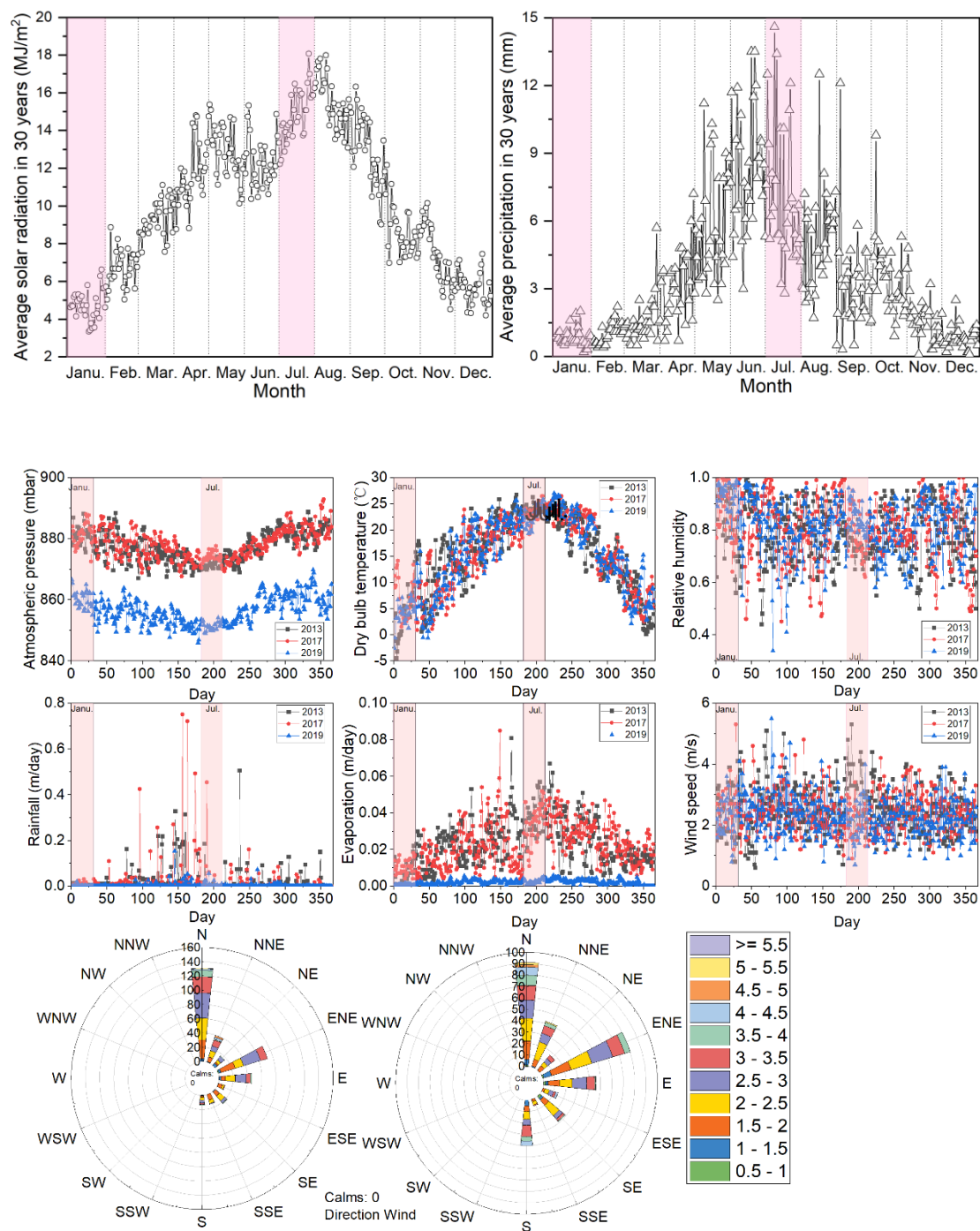


Figure S1. Average solar radiation and precipitation in 30 years. Data was obtained from Greenhouse Data (<http://data.sheshiyuanyi.com/WeatherData/>). Atmospheric pressure, dry bulb temperature, relative humidity, rainfall, evaporation, wind speed and wind direction in 2013, 2017 and 2019. Data was obtained from National Meteorological Science Data Center (<https://data.cma.cn/>). There were also the interannual difference.

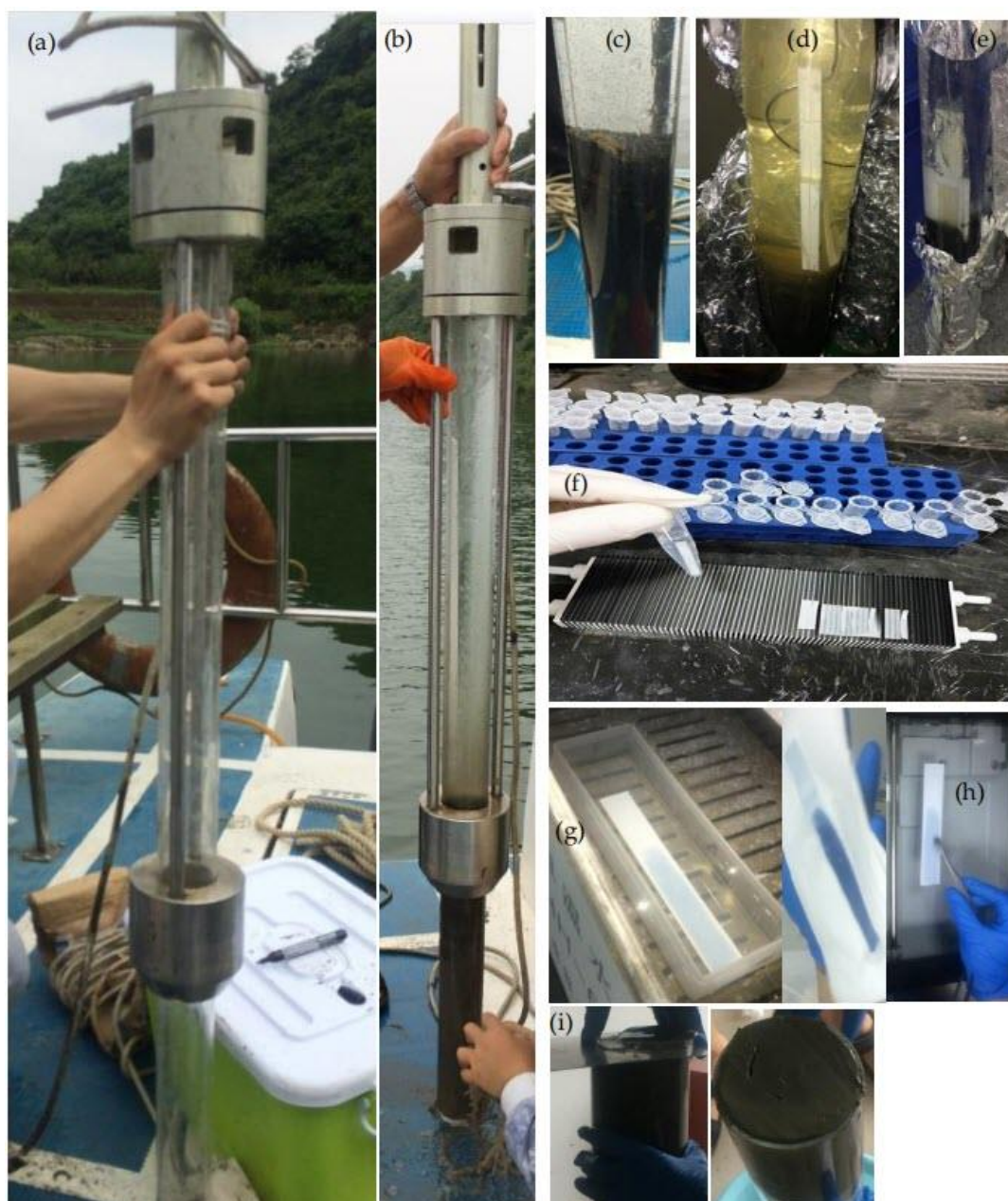


Figure S2. Sediment core sampling, storage, and treatment. (a) portable sediment sampler, (b) Sediment cores collected with a portable sediment sampler, (c) clear sediment-water interface, (d, e) DGT technology devices added at sediment-water interface, (f) films of ZrO-AT devices cut with 2-mm interval by the ceramic knife, (g) color film of ZrO device by molybdenum antimony color reagent in winter, (h) the thin film of ZrO scanned in a scanner, (i) sediment cut with 1-cm interval.

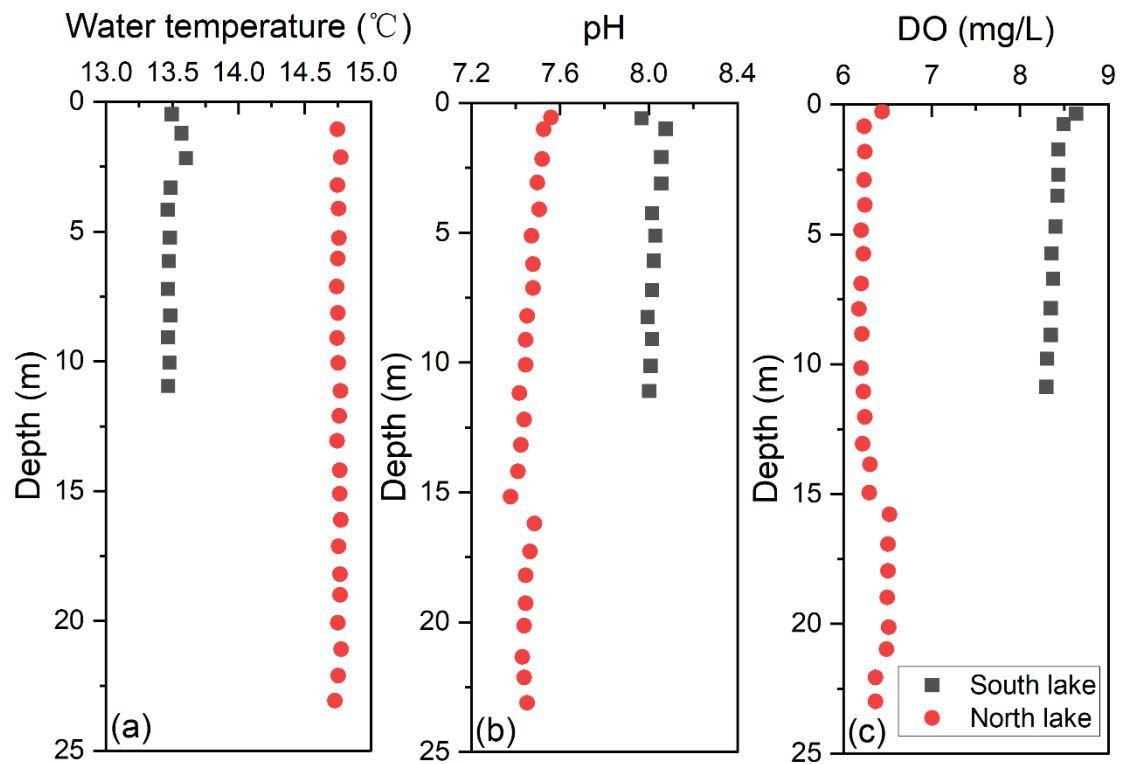


Figure S3. Water temperature(a), pH (b), and DO (c) of water profiles in Hongfeng Lake in winter.

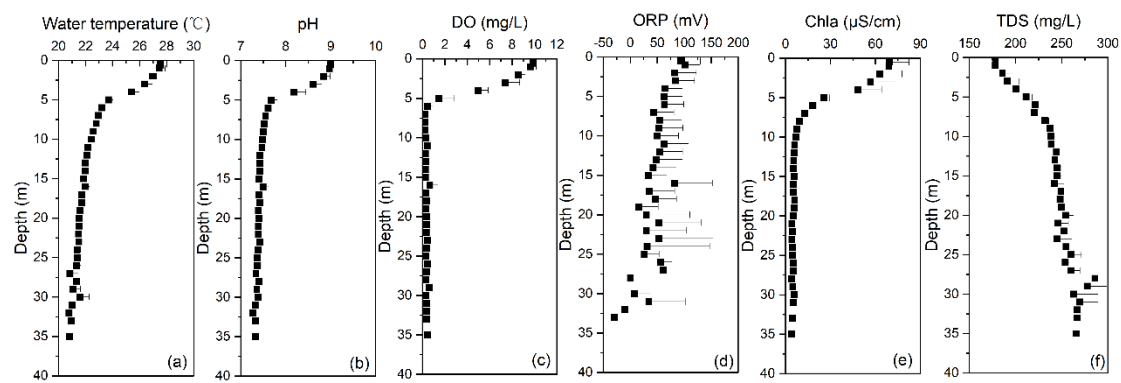


Figure S4. Water temperature(a), pH (b), DO (c), ORP (d), Chlorophyll (e), and TDS (f) of water profiles in Hongfeng Lake in summer.

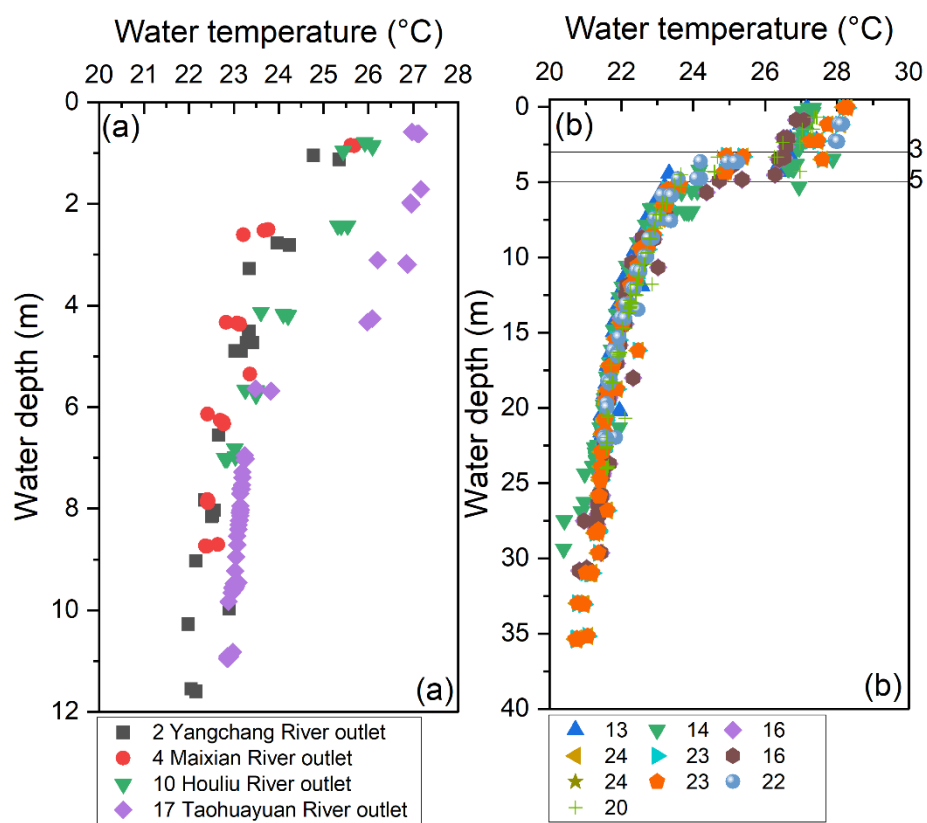


Figure S5. Water temperature of river outlets(a) and still water zone (b) of water profiles in Hongfeng Lake in summer.

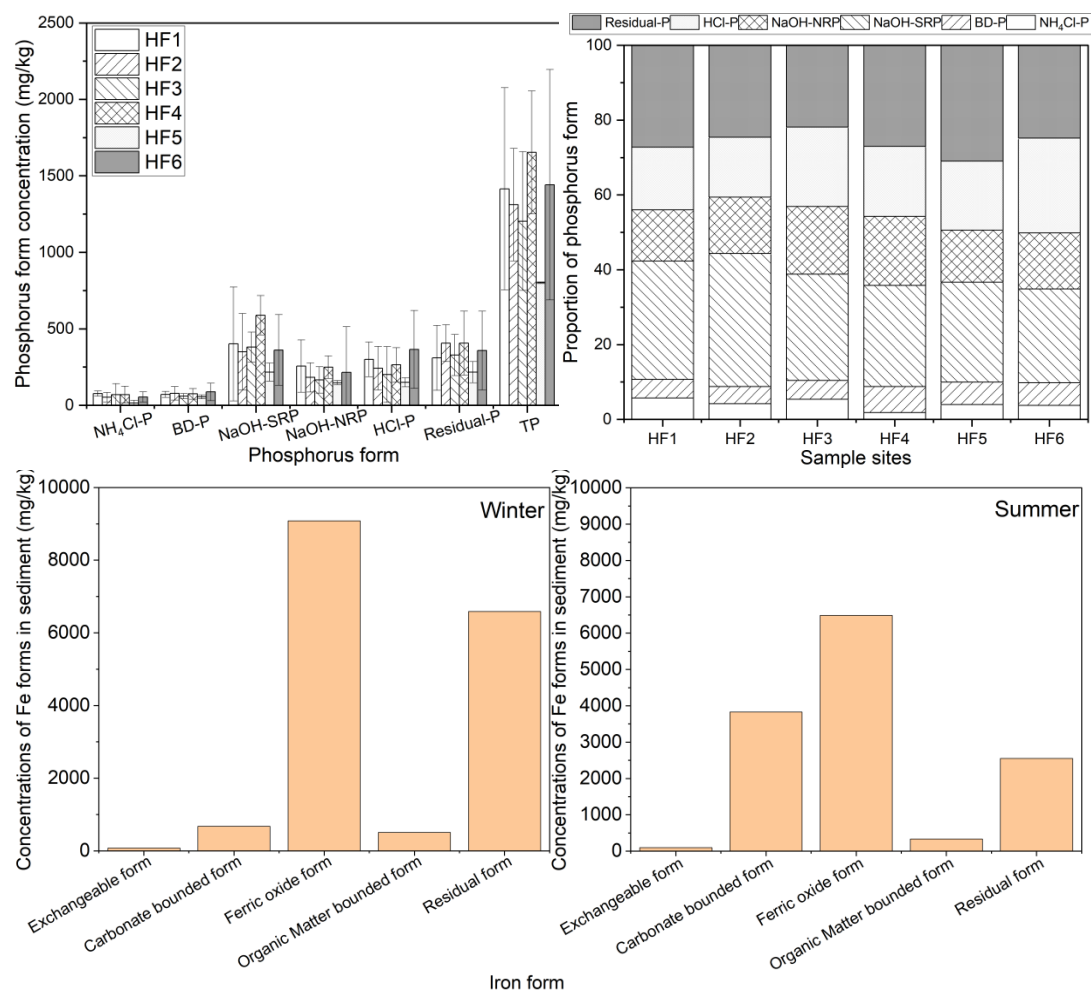


Figure S6. P and Fe concentration and proportion of surface sediment of Hongfeng Lake.

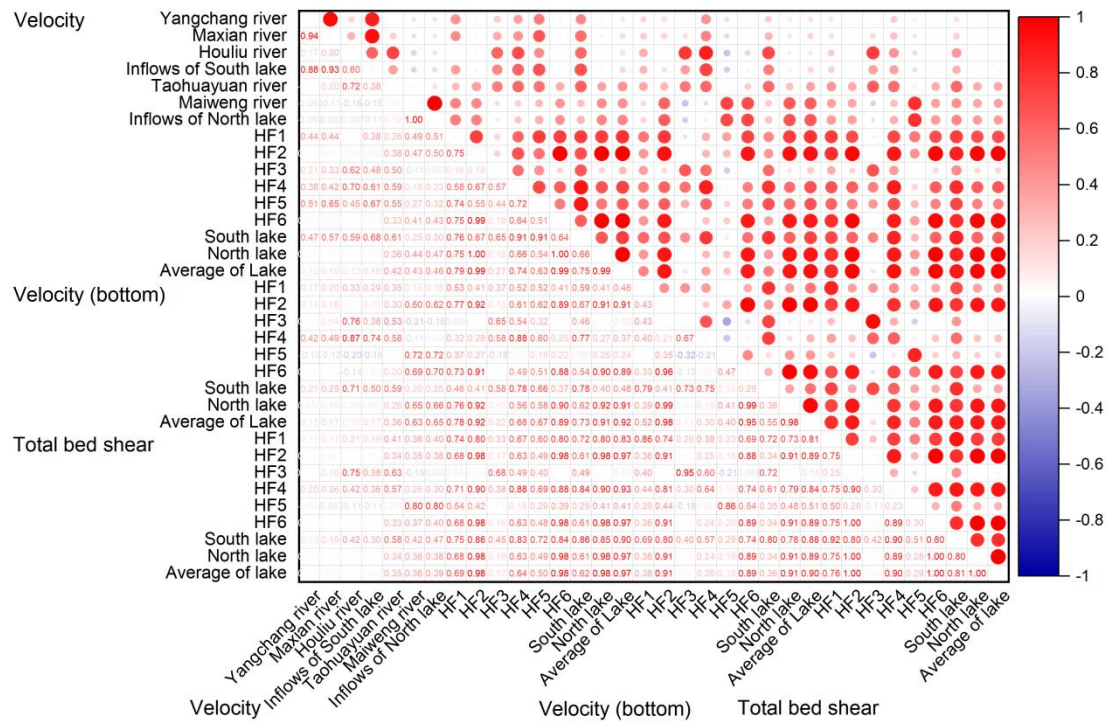


Figure S7. Correlation analysis among inflow, lake water velocity and total bed shear. Yangchang river, Maxian river, Houliu river, HF1, HF3, HF4, and HF5 were in South lake, Taohuayuan river, Maiweng river, HF2, and HF6 were in North lake.

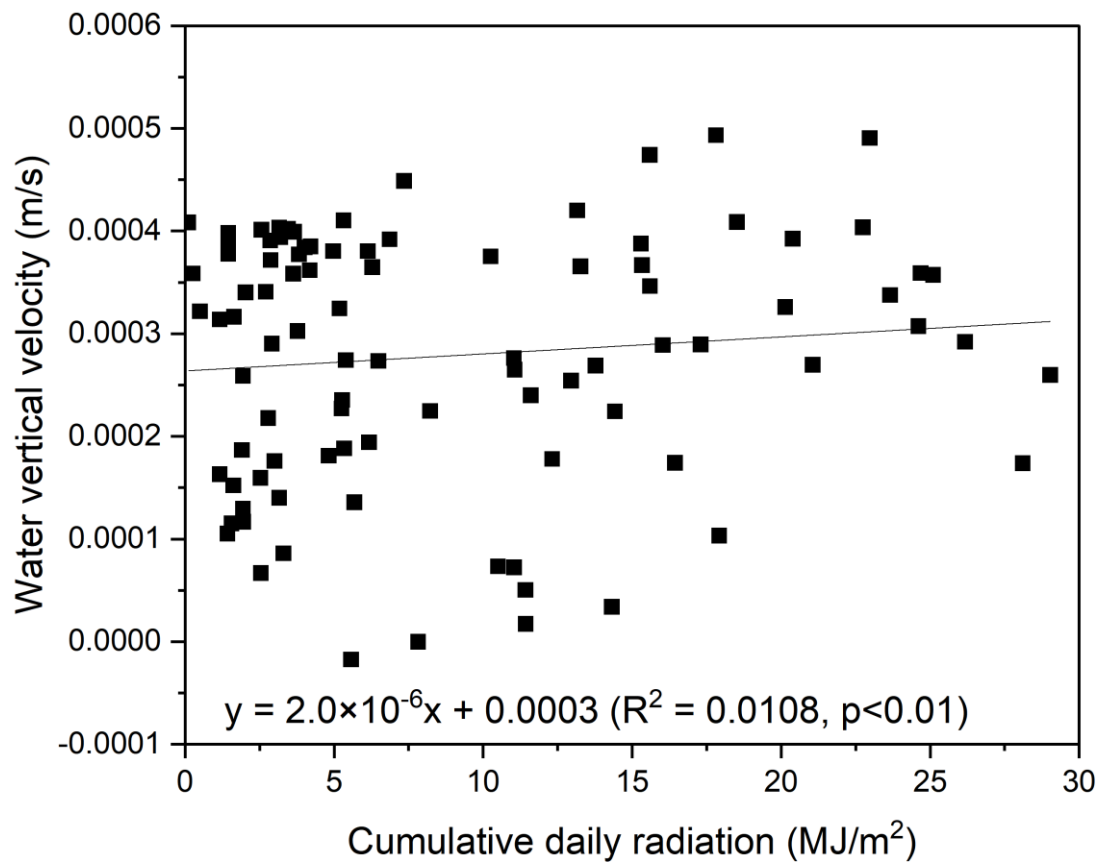


Figure S8. Linear relationship between water vertical velocity and cumulative daily radiation.

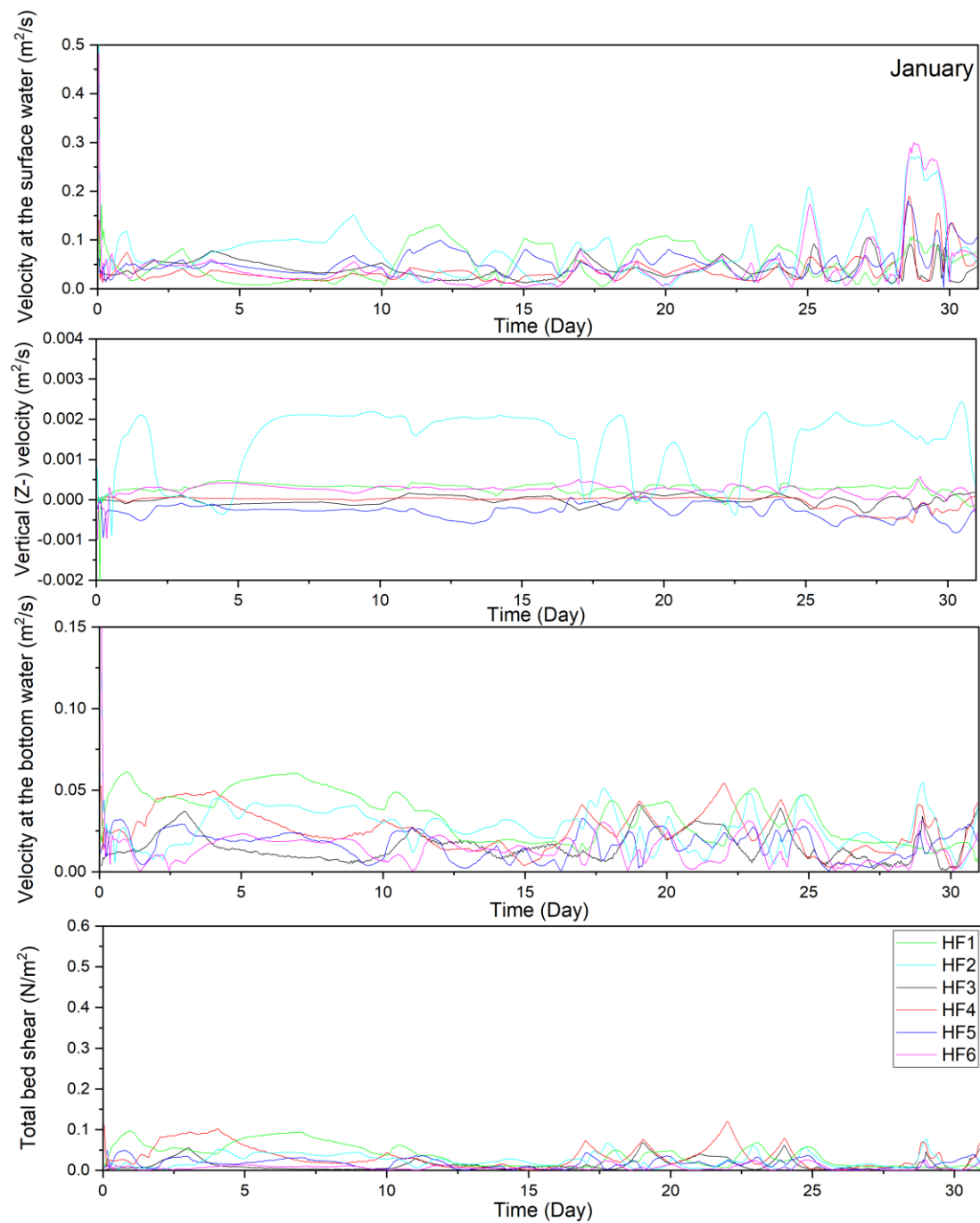


Figure S9. The simulated velocity magnitude of surface water, the vertical velocity, bottom water, and total bed shear in sample sites in January of LFY. The legend from top to bottom showed HF1~ 6 in turn.

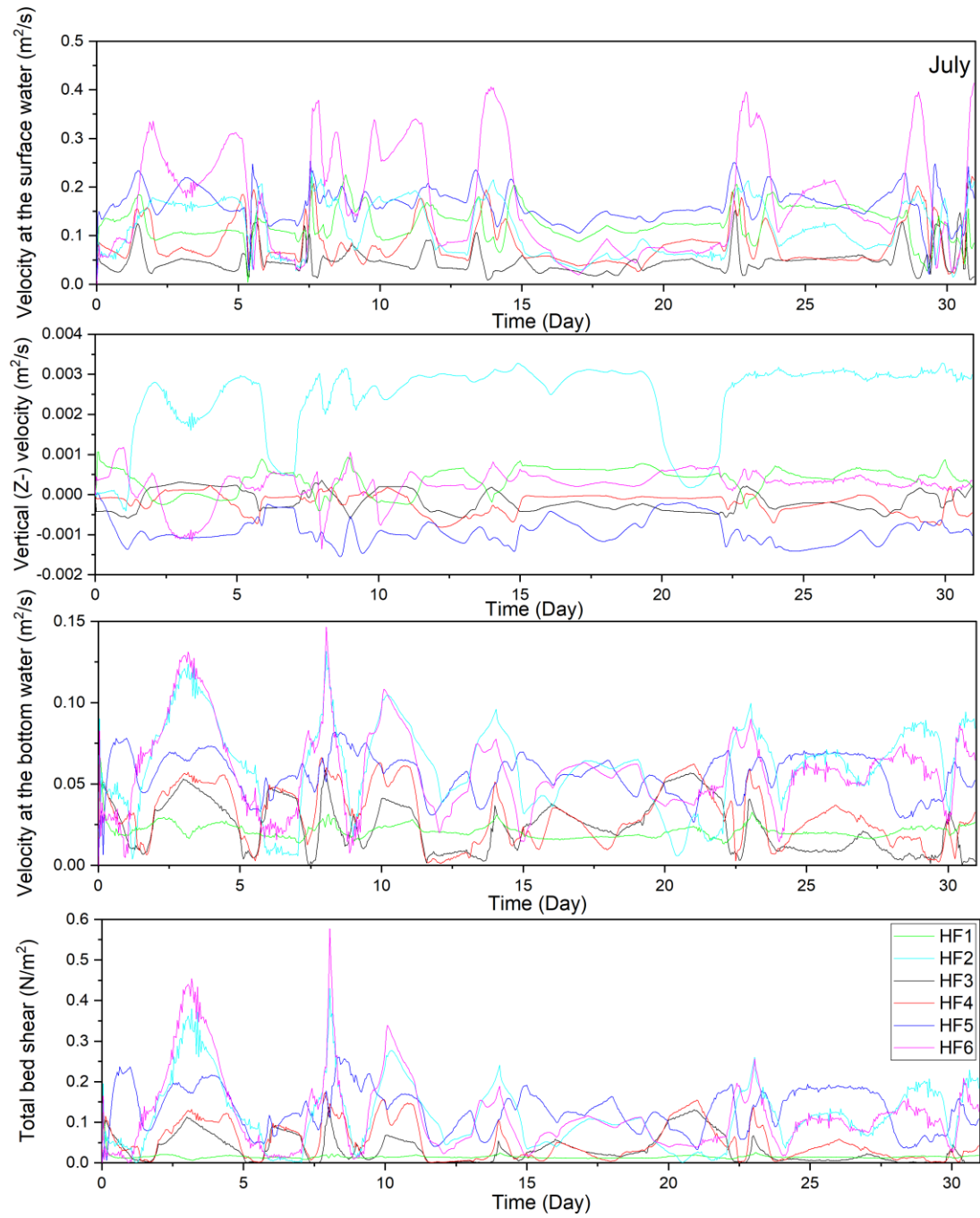


Figure S10. The simulated velocity magnitude of surface water, the vertical velocity, bottom water, and total bed shear in sample sites in July of LFY. The legend from top to bottom showed HF1~ 6 in turn.

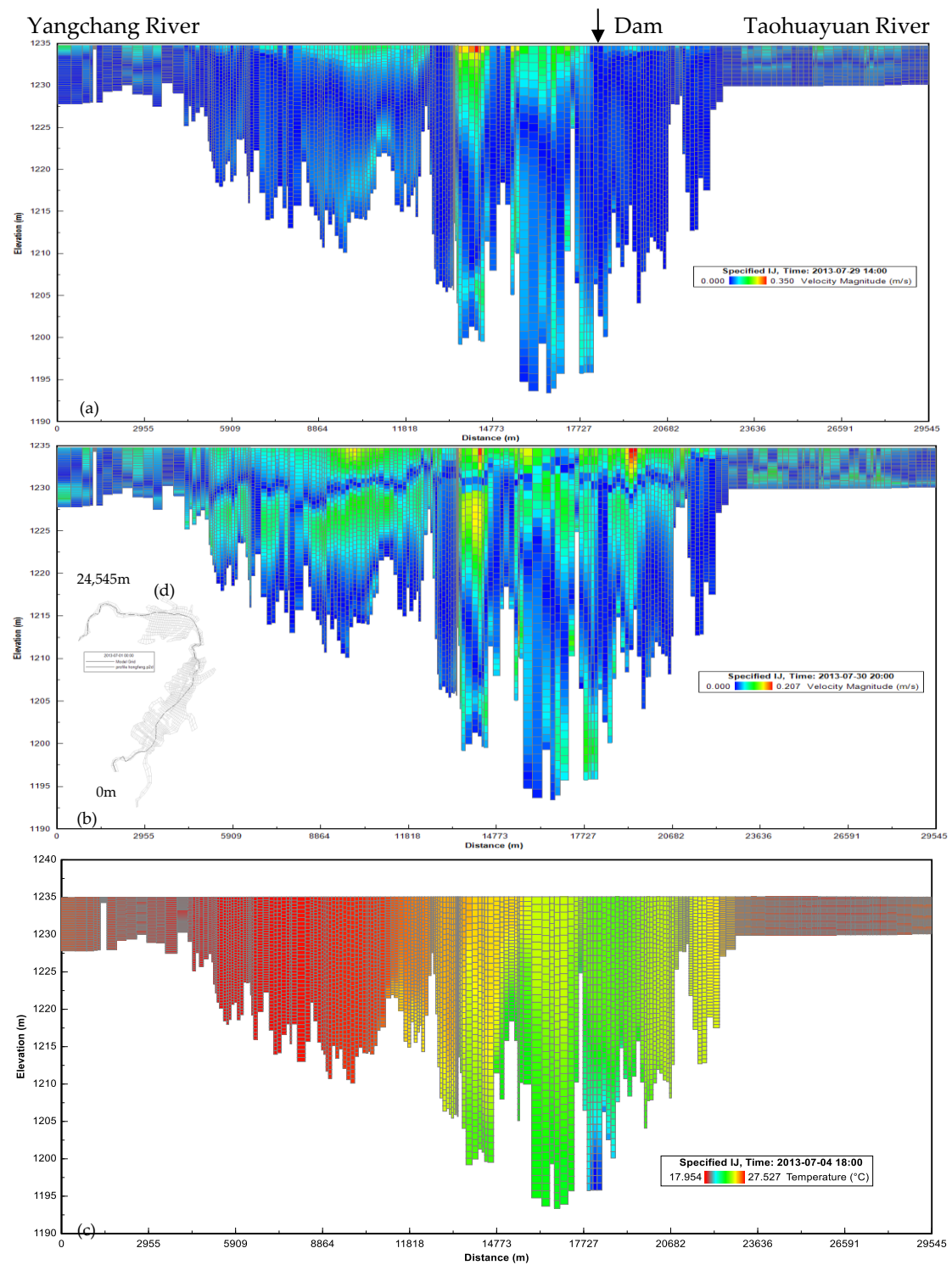


Figure S11. The water velocity (a) Day 14:00 29/07/ 2013; (b) Light 20:00 30/07/2013; (c) Temperature in the profiles of Hongfeng Lake; (d) The black line in Hongfeng Lake is the section.

References

1. Hupfer, M.; Gächter, R.; Giovanoli, R. Transformation of phosphorus species in settling seston and during early sediment diagenesis. *Aquat. Sci.* **1995**, 57(4), 305-324, doi:10.1007/BF00878395.
2. Tessier, A.; Campbell, P.; Bisson, M. Sequential extraction procedure for the speciation of particulate trace metals. *Appl. Geochem.* **1979**, 51(7), 844-851, doi:10.1021/ac50043a017.
3. Murphy, J.; Riley, J. P. A modified single solution method for the determination of phosphate in natural waters. *Anal. Chim. Acta* **1962**, 27, 31-36, doi.org/10.1016/S0003-2670(00)88444-5.
4. SEPA, State Environmental Protection Administration. Water and Wastewater Monitoring. China Environmental Science Press, Beijing, China, **2002**, 246-284 (In Chinese).
5. Ding, S.; Sun, Q.; Xu, D.; Jia, F.; He, X.; Zhang, C. High-resolution simultaneous measurements of dissolved reactive phosphorus and dissolved sulfide: the first observation of their simultaneous release in sediments. *Environ. Sci. Technol.* **2002**, 46(15), 8297-8304, doi: 10.1021/es301134h.
6. Crank, J. Diffusion and chemical reaction. Mathematics of Diffusion, United States, Oxford university press, **1956**, 347.
7. Li, Y. H. and Gregory, S. Diffusion of ions in sea water and in deep-sea sediments. *Geochim. Cosmochim. Acta* **1974**, 38(5), 703-714, doi.org/10.1016/0016-7037(74)90145-8.
8. Fan, C.; Zhang, L.; Yang, L.; Huang, W. Simulation of internal loadings of nitrogen and phosphorus in a lake. *Oceanol. Limnol. Sin.* **2002**, 33(4), 370-378 (In Chinese).

9. Wang, Y. Biogeochemistry of nutrient elements (Carbon, Nitrogen and phosphorus) at sediment-water interface in Hongfeng Lake and Baihua Lake, Guizhou Province. Institute of Geochemistry, Chinese Academy of Sciences, PhD dissertation, **2001** (In Chinese).
10. Li, B.; Feng, X.; Chen, X.; Wang, Y.; Shen, Y.; Wu, Q. L. Abundant sediment organic matter potentially facilitates chemical iron reduction and surface water blackness in a Chinese deep lake. *Environ. Pollut.* **2021**, 272, 116002, doi: 10.1016/j.envpol.2020.116002.
11. Berner, R. A. Early diagenesis: a theoretical approach. Princeton University, Press, New Jersey, USA. **1980**.
12. Henrichs, S. M. and Reeburgh, W. S. Anaerobic mineralization of marine sediment organic matter: rates and the role of anaerobic processes in the oceanic economy. *Geomicrobiol. J.* **1987**, 5,191-237, doi.org/10.1080/01490458709385971.
13. Yu, S. Modeling Phosphorus Cycling in a summerally Stratified Reservoir (Fanshawe Reservoir, Ontario, Canada). University of Waterloo, Master's thesis, **2020**.
14. DSI LLC. User's Manual for EFDC_Explorer 10: pre/post processor for the environmental fluid dynamics code. Guide. Available online: <https://eemodelingsystem.atlassian.net/wiki/spaces/EK/overview?homepageId=3407890> (accessed on 1 October 2021).
15. Zhang, P. An analysis of the influence of different flood volumes on the water temperature and layered structure of hongjiadu reservoir. *China Rural Water Hydropower* **2019**, 12,75-79,85 (In Chinese).
16. Yu, N. Carbon Burial Mechanism and Carbon Budget of Cascade Reservoirs in the Wujiang River. Shanghai University, Master's thesis, **2019** (In Chinese).

17. DHMWR, Department of Hydrology, Ministry of Water Resources. the People's Republic of China (P. R. China) Hydrological data of Changjiang river basin, Annual hydrological report P. R. China 2013 Volume 6, **2014** (In Chinese).
18. Li, Y.; Gong, R.; Craig, P. Numerical simulation and prediction of surface water environment- EFDC modeling technology and case training. Science press, Beijing, China, **2019** (In Chinese).
19. He, S.; Li C.; Pan, Z.; Luo, M.; Meng, W.; Mo, C.; Wang, F. Geochemistry and environmental quality assessment of Hongfeng Lake sediments, Guiyang City. *Geophy. Geochem. Explor.* **2012**, (2), 26 (In Chinese).