Dynamics of water quality and algal blooms in the regulated Geum River, Korea

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- Research background
  - Harmful algal blooms (HABs) in regulated water body by hydraulic structures
  - The decision of the committee about weir operation and removal

Baekje weir

Weir gate operation (2017 ~ 2021)

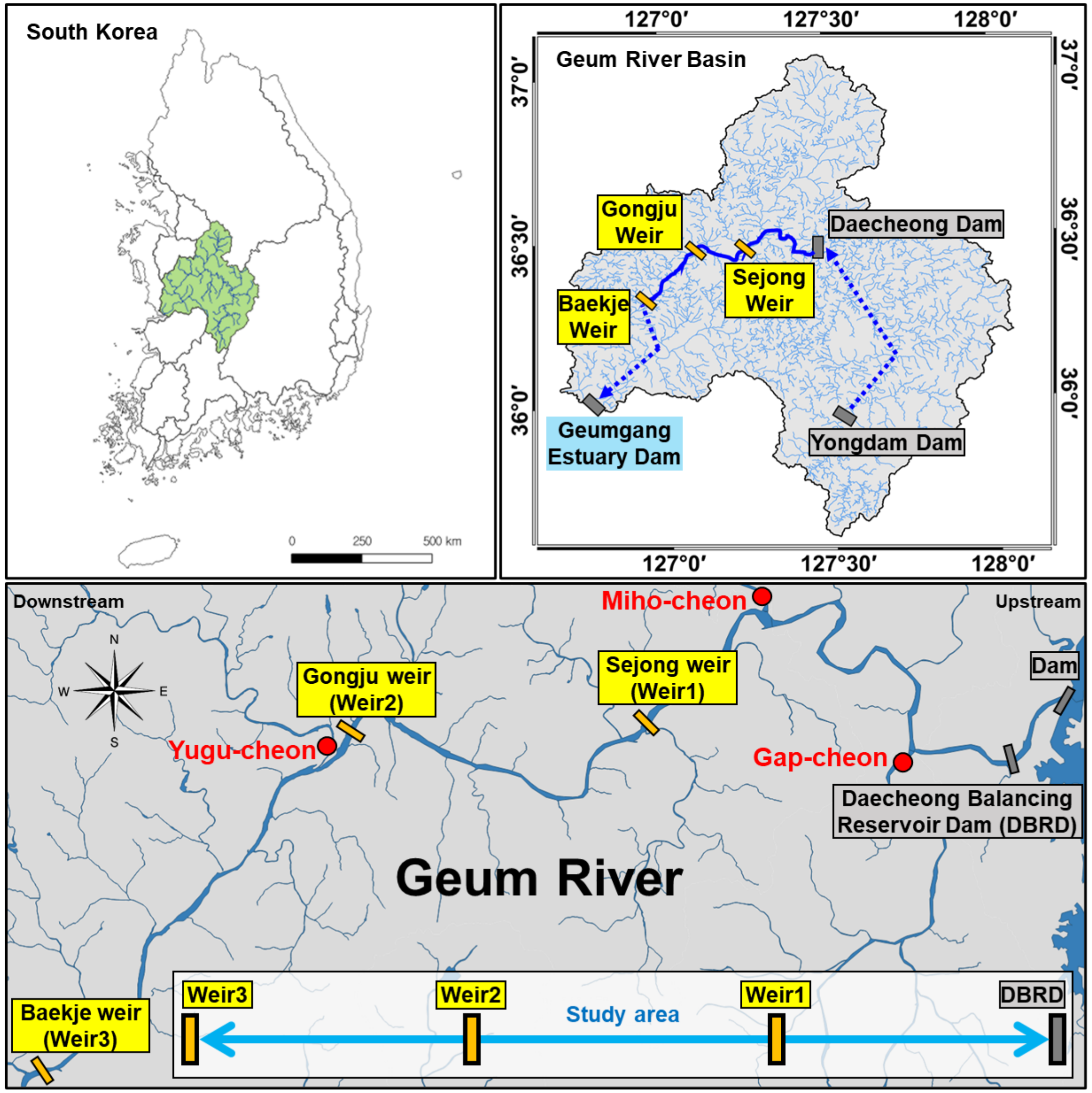
1. Introduction

- Research purpose
  - Analysis of dynamics of water quality and harmful algal blooms with hydraulic changes due to weir gate operations in the Geum River
    - To provide expanded insights about water quality interactions and HAB dynamics in the regulated river using modeling approaches

  - Factors affecting harmful algal bloom occurrence in a river with regulated hydrology
    - Kim et al. (Journal of Hydrology: Regional Studies, 2021)

2. Material and methods

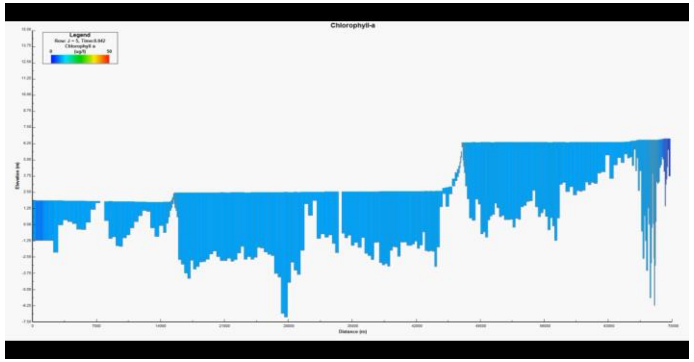
- Study area: Geum River
  - The third largest river
  - Total length: 69.5 km
    - DBRD to Baekje weir
  - Three in-stream weirs
    - Sejong weir (Weir1)
    - Gongju weir (Weir2)
    - Baekje weir (Weir3)

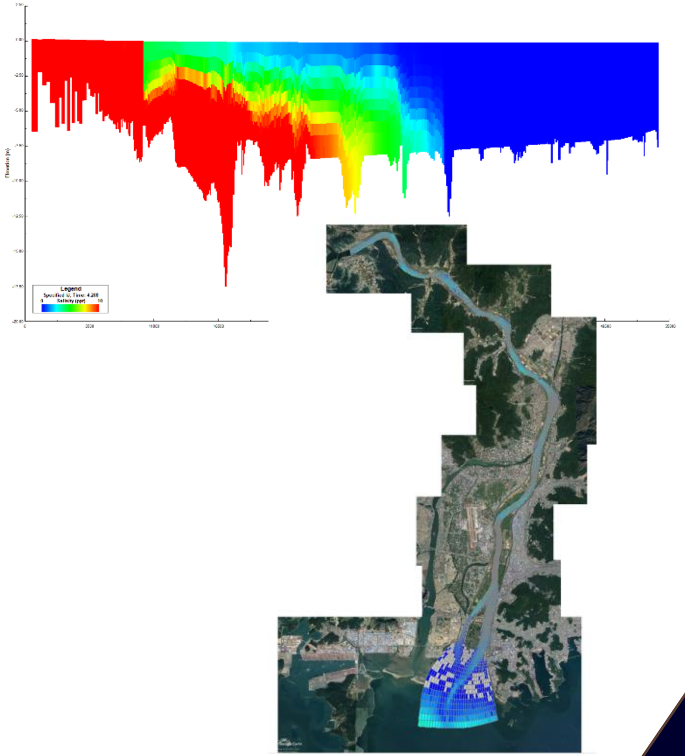


2. Material and methods

- Environmental Fluid Dynamics Code (EFDC)
  - Multifunctional surface water model
    - Based on the Hydrodynamics module
    - Successful applications to various environments

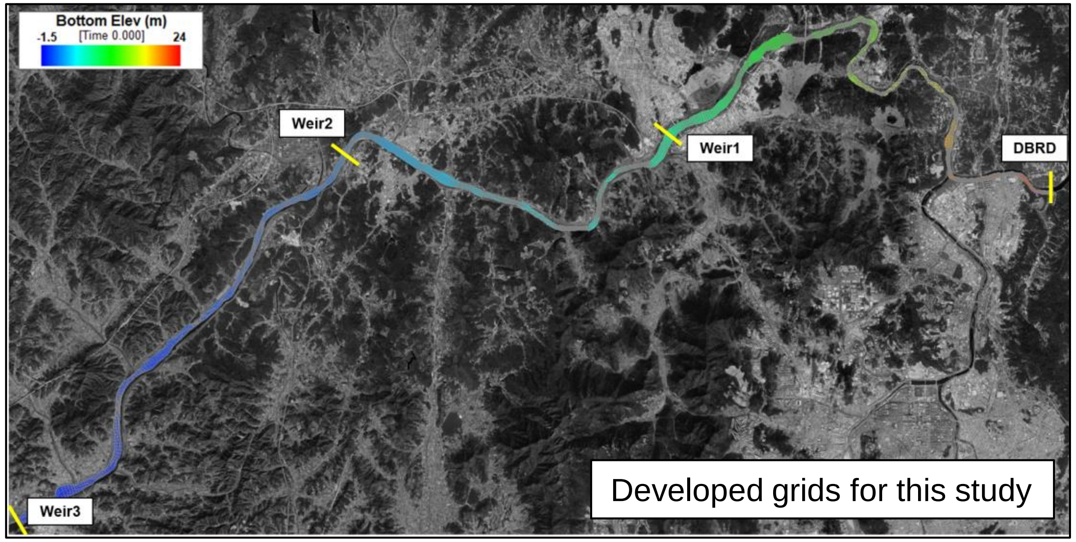
EFDC main modules
• Hydrodynamics
• Water column constituent transport
• Water quality kinetics
• Sediment erosion and deposition
• Toxic
• Lagrangian Particle Tracking



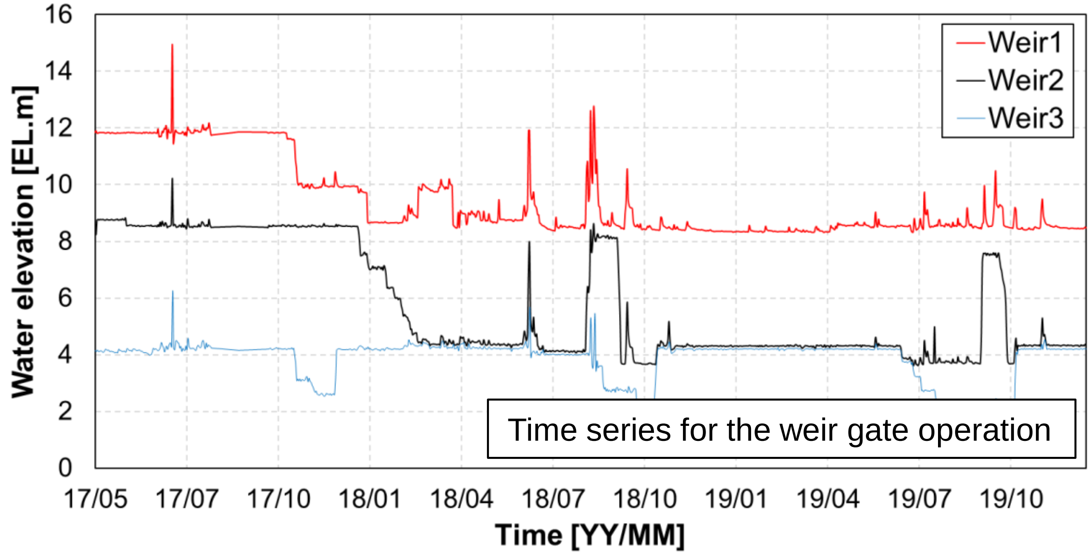


2. Material and methods

- Model development
  - Grid generation
    - 34,900 grids
  - Initial condition
  - Boundary condition
  - Time series
    - 2017-05-01 to 2019-12-31
  - Parameter estimation
  - Model calibration



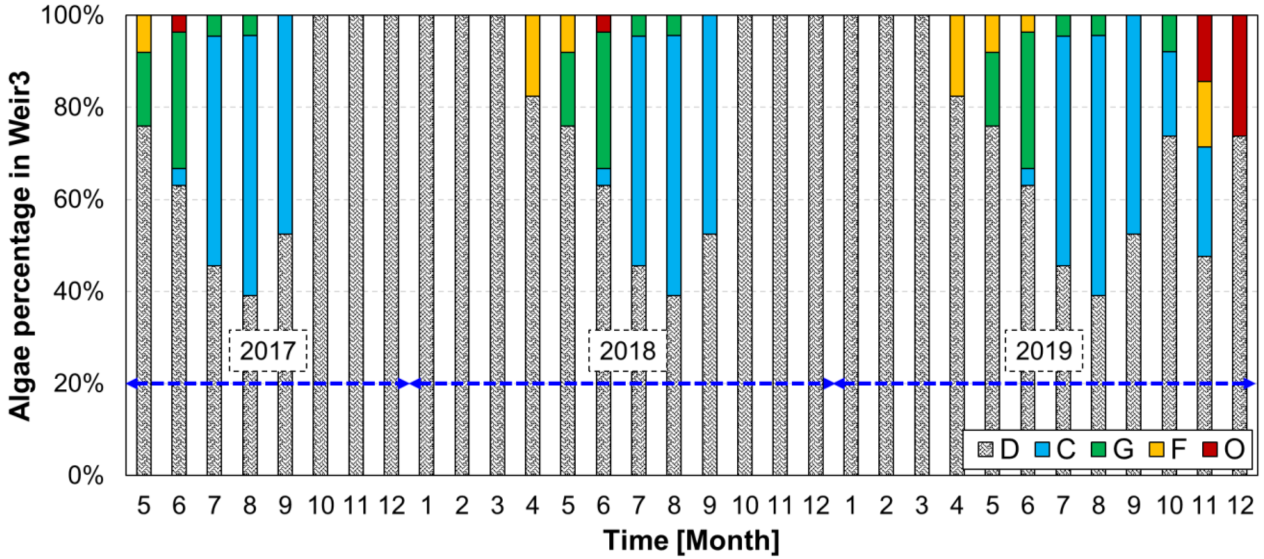
Developed grids for this study



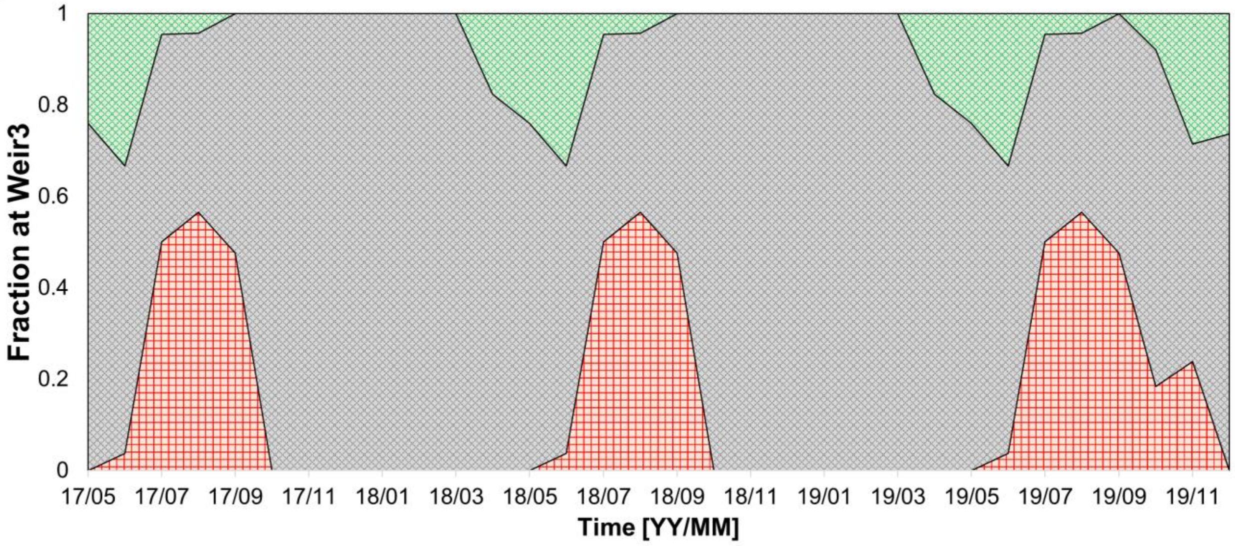
Time series for the weir gate operation

2. Material and methods

- Algae fraction
  - Diatoms
  - Cyanobacteria
  - Green algae
  - Flagellate
  - Other algae

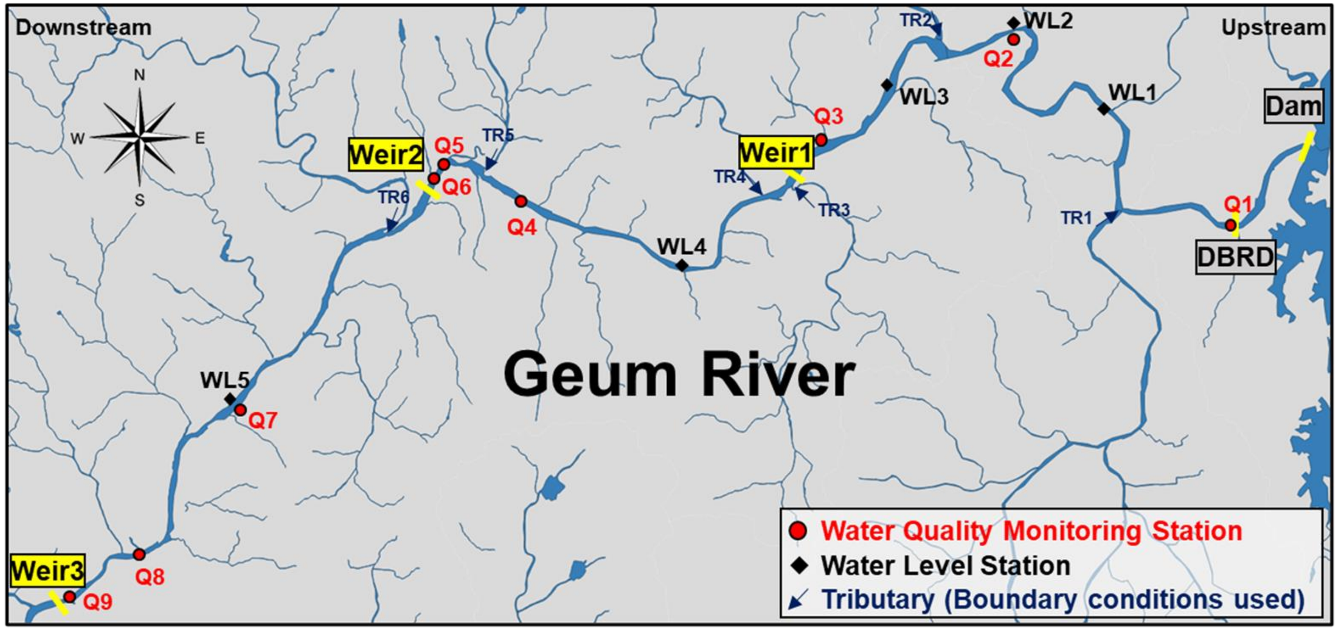


- Model application
  - Group1: Cyanobacteria
  - Group2: Diatoms
  - Group3: Others



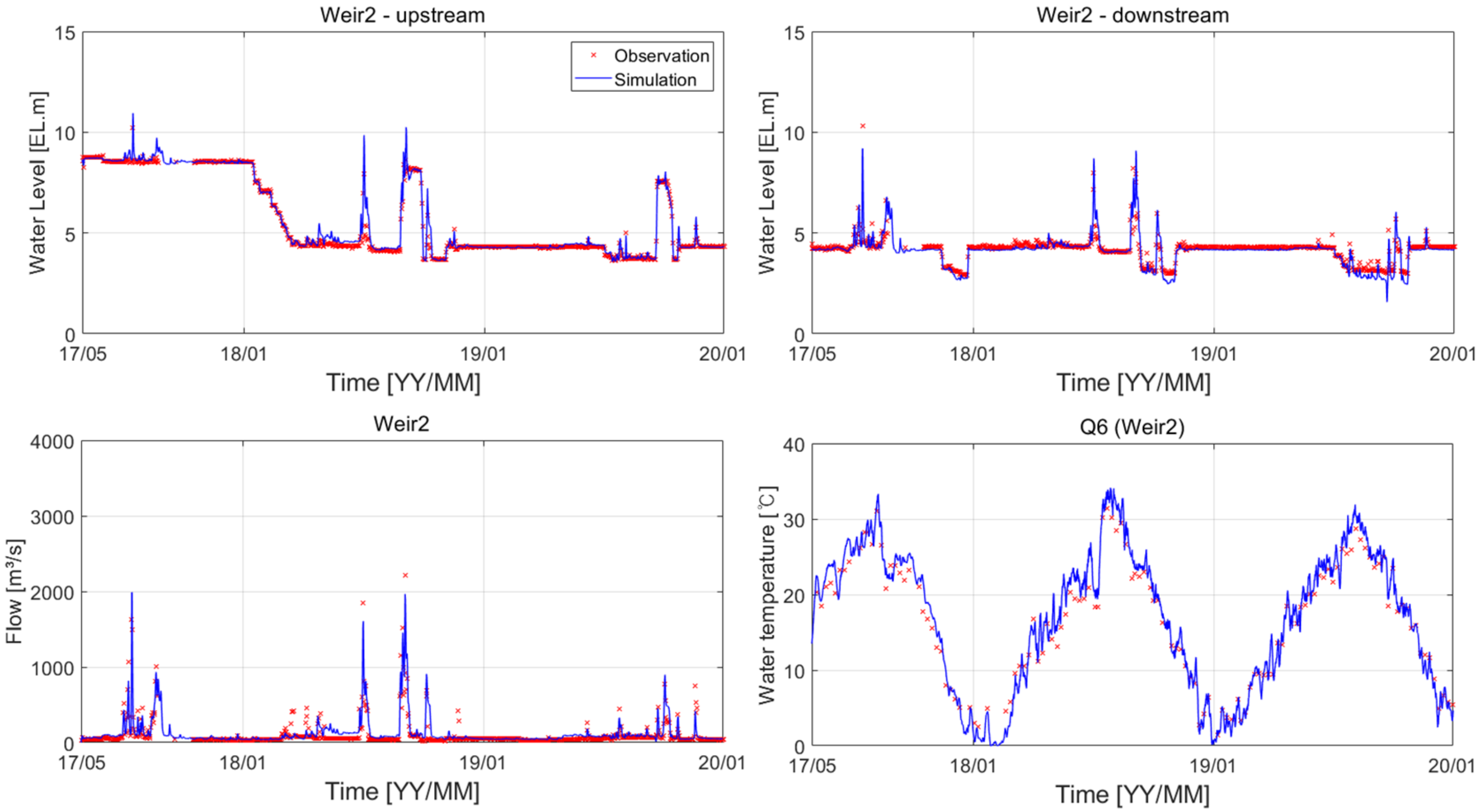
2. Material and methods

- Model calibration
  - Water level (8 sites)
    - WL (1-5) and Weir (1-3)
  - Flow (3 sites)
    - Weir (1-3)
  - Water temperature (8 sites)
    - Q (2-9)
  - Water quality (8 sites)
    - Q (2-9)



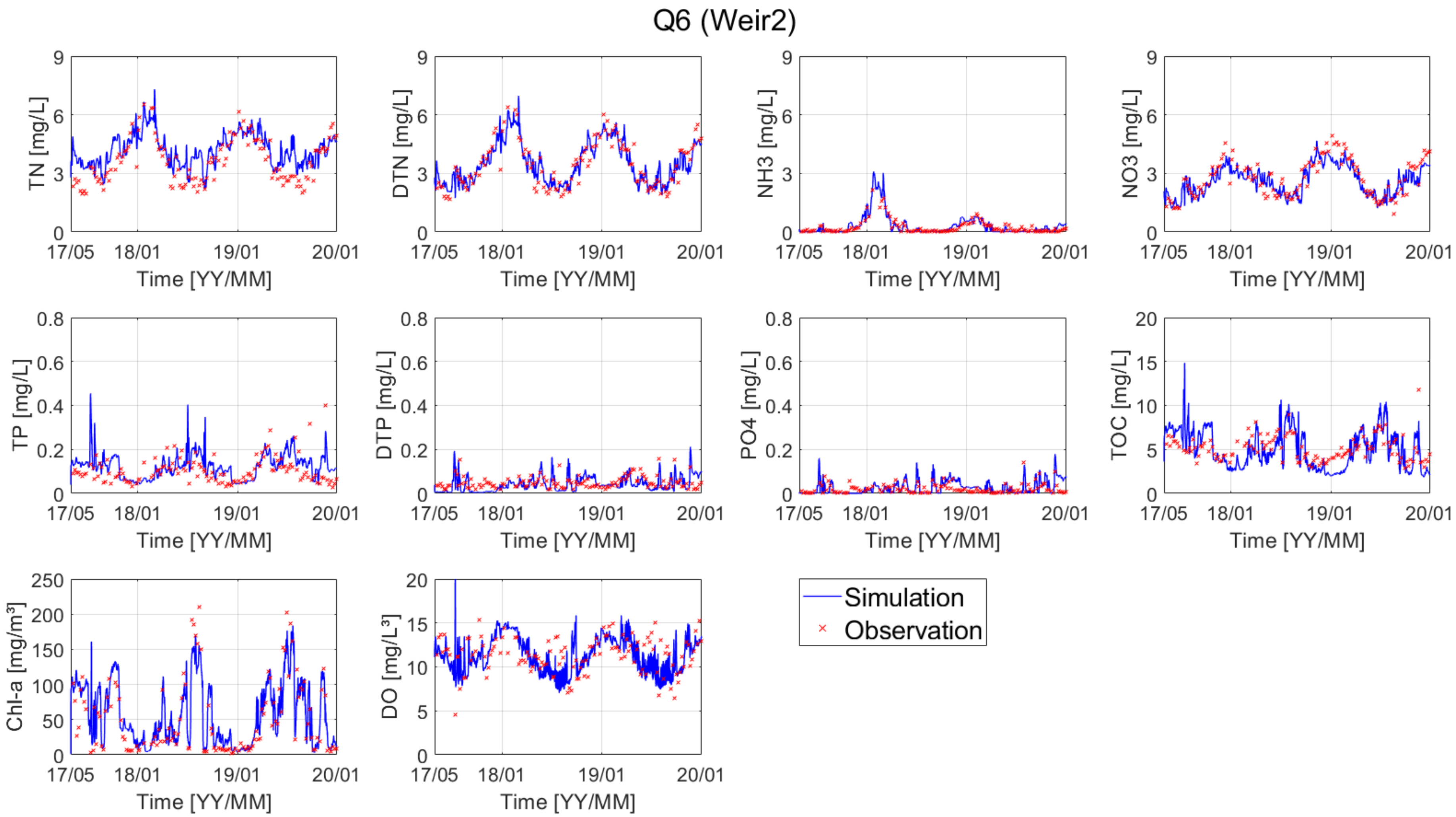
2. Material and methods

- Calibration results at Gongju weir (Weir2)



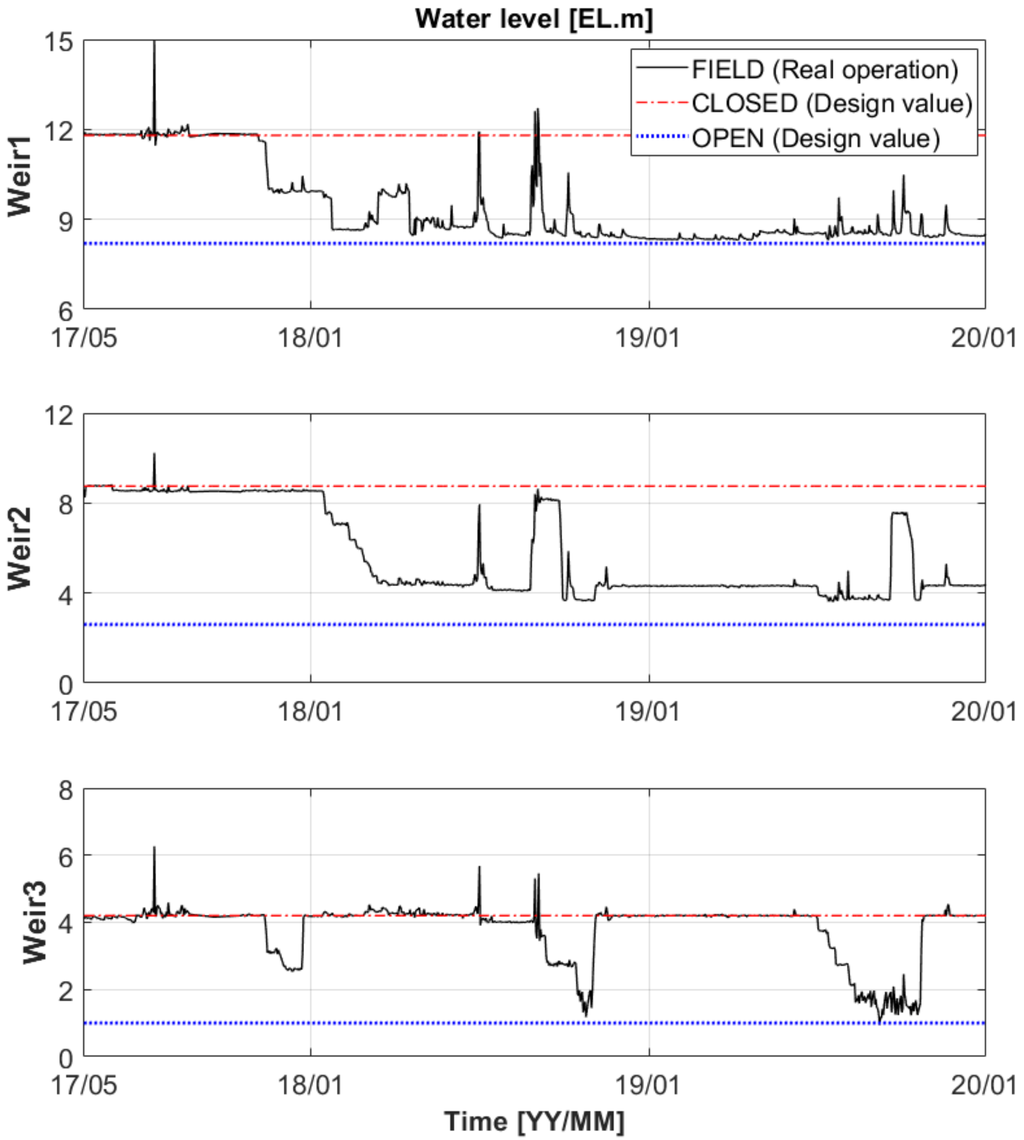
2. Material and methods

- Calibration results at Gongju weir (Weir2)



2. Material and methods

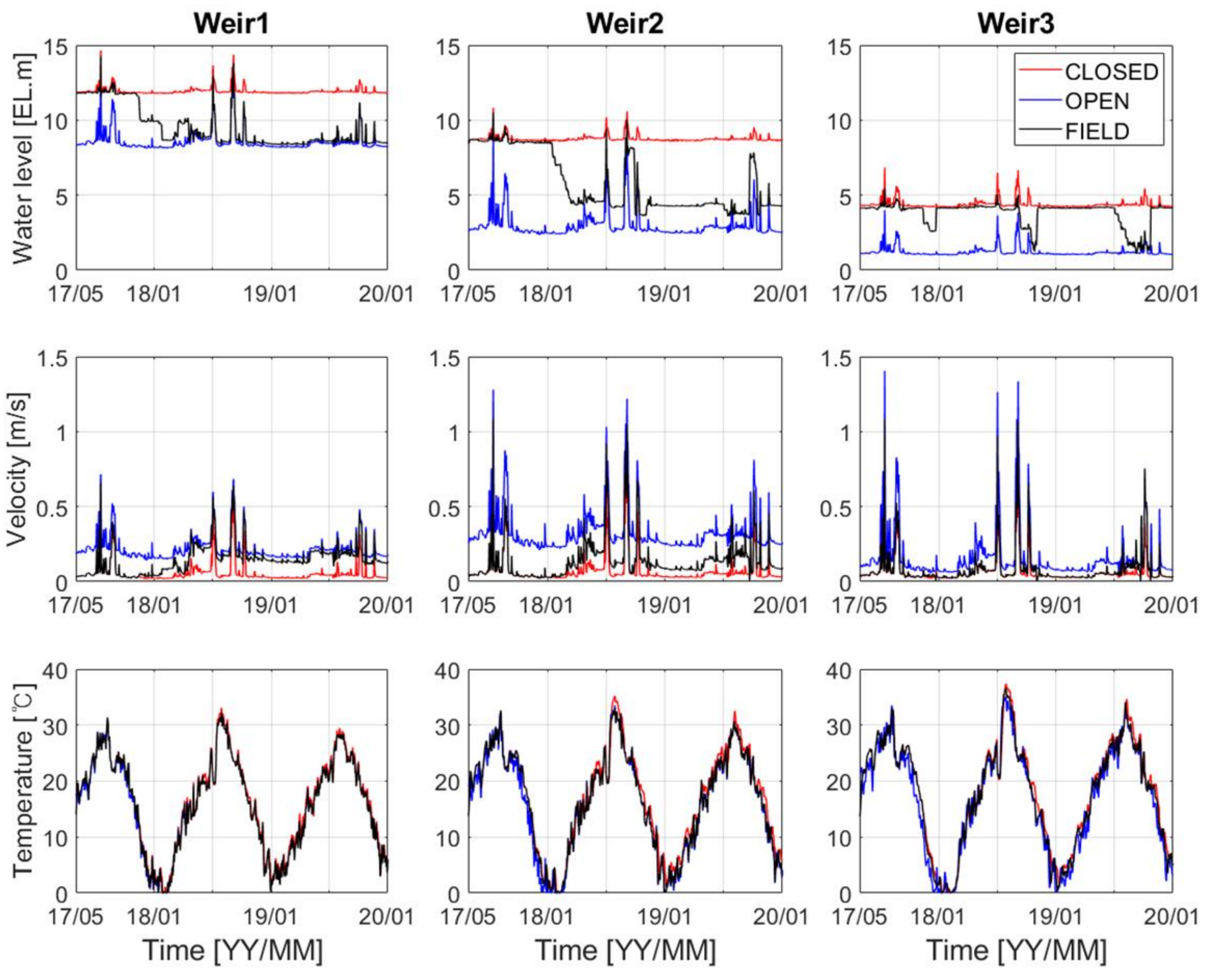
- Scenario development
  - Weir gate operation scenarios
    - FIELD: Calibrated condition
    - CLOSED: Maintaining water levels
    - OPEN: Weir gate opening



Scenario	Weir1 (Sejong)	Weir2 (Gongju)	Weir3 (Baekje)
CLOSED (Design value)	11.80 EL.m	8.75 EL.m	4.20 EL.m
OPEN (Design value)	8.20 EL.m	2.60 EL.m	1.00 EL.m
FIELD	Field operation condition		

3. Results and discussion

- Physical changes due to gate controls

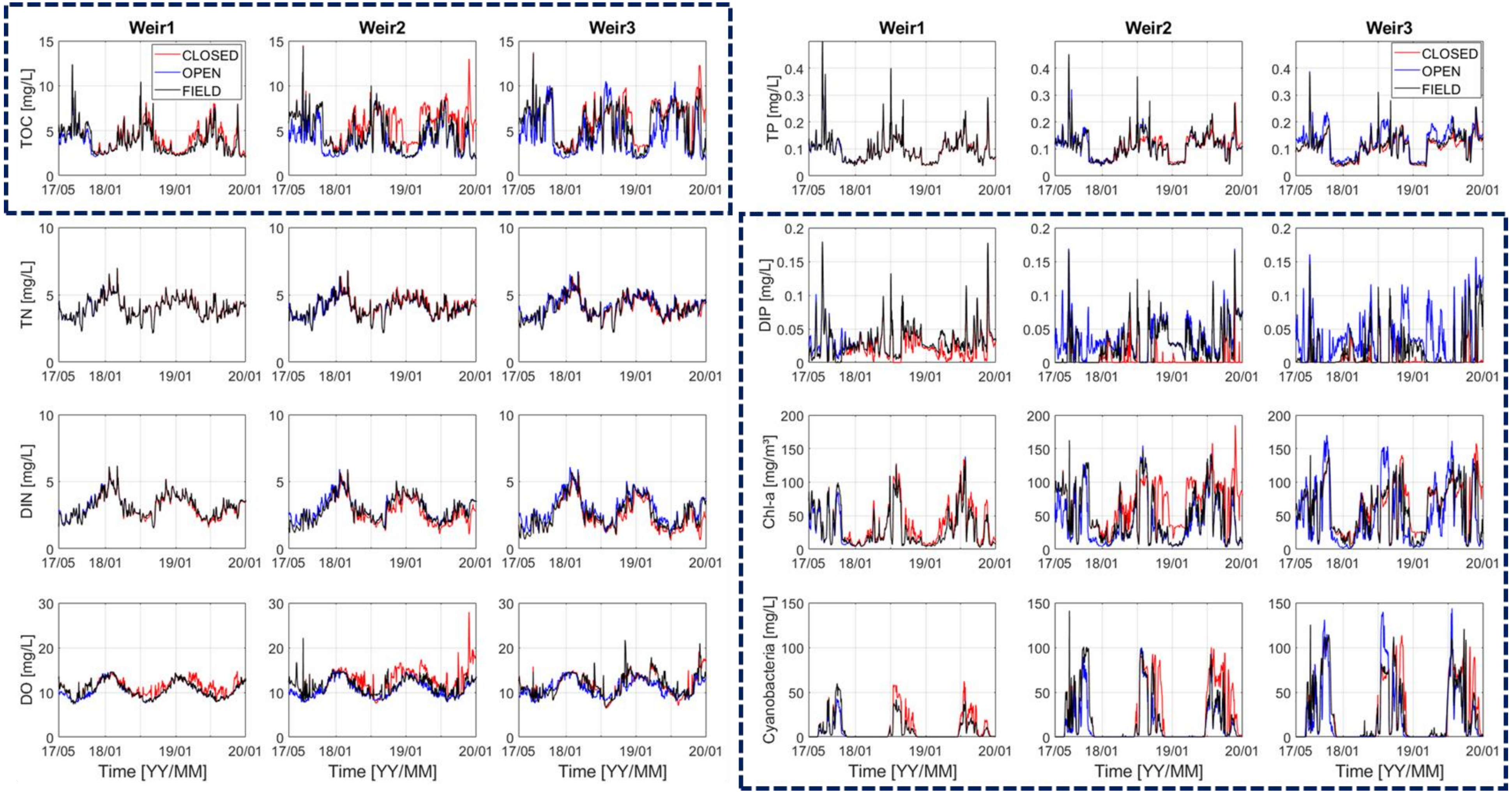


C: CLOSED, O: OPEN, F: FIELD

Variable	Unit	Weir1 (Sejong)			Weir2 (Gongju)			Weir3 (Baekje)		
		C	O	F	C	O	F	C	O	F
Water level	EL.m	11.9	8.6	9.5	8.8	3.0	5.8	4.4	1.2	3.8
	%	100.0	71.9	79.9	100.0	34.0	66.3	100.0	27.8	86.3
Velocity	m/s	0.059	0.219	0.148	0.075	0.328	0.137	0.067	0.157	0.083
	%	100.0	372.7	252.1	100.0	437.3	182.4	100.0	234.3	124.1
Temp	ºC	16.4	15.8	15.9	17.3	16.0	16.4	18.2	16.7	17.6
	%	100.0	96.7	97.2	100.0	92.5	95.0	100.0	92.1	97.0

3. Results and discussion

- Water quality changes due to gate controls



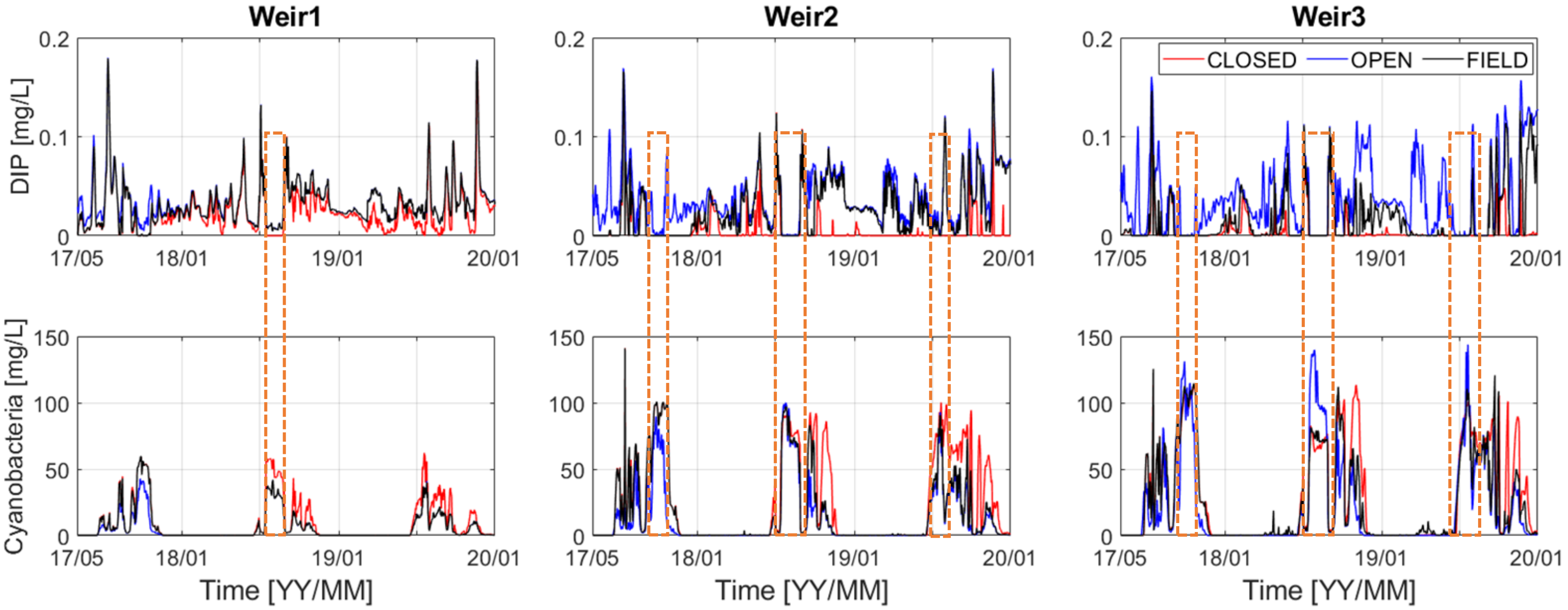
3. Results and discussion

Variable	Unit	Weir1			Weir2			Weir3		
		CLOSED	OPEN	FIELD	CLOSED	OPEN	FIELD	CLOSED	OPEN	FIELD
TOC	mg/L	4.18	3.70	3.81	5.80	3.95	4.58	6.22	4.61	5.59
	%	100.0	88.5	91.1	100.0	68.2	79.1	100.0	74.0	89.7
TN	mg/L	4.04	4.03	4.02	4.09	4.03	4.05	3.99	4.12	4.06
	%	100.0	99.6	99.5	100.0	98.6	98.9	100.0	103.1	101.7
DIN	mg/L	3.08	3.18	3.15	2.68	3.07	2.93	2.38	2.96	2.64
	%	100.0	103.1	102.1	100.0	114.9	109.6	100.0	124.5	110.8
DO	mg/L	11.2	10.4	10.6	12.6	10.7	11.5	11.6	11.0	11.8
	%	100.0	92.6	94.7	100.0	84.9	91.3	100.0	94.4	101.3
TP	mg/L	0.099	0.099	0.099	0.112	0.110	0.111	0.105	0.125	0.110
	%	100.0	99.9	99.8	100.0	98.8	99.2	100.0	118.7	104.8
DIP	mg/L	0.025	0.034	0.032	0.007	0.038	0.027	0.006	0.038	0.016
	%	100.0	137.0	128.6	100.0	547.0	383.9	100.0	688.5	279.7
Chl-a	mg/m^3	36.9	28.4	30.4	69.1	38.5	49.2	65.3	48.7	58.9
	%	100.0	77.0	82.3	100.0	55.6	71.1	100.0	74.6	90.1
Cyano*	mg/m^3	20.4	12.0	14.5	51.6	26.0	36.9	58.1	43.1	50.2
	%	100.0	58.9	71.0	100.0	50.4	71.5	100.0	74.1	86.4

Cyano*: Average Chl-a concentration over certain periods: (1) 2017-06-22 to 2017-11-17, (2) 2018-06-24 to 2018-11-18, and (3) 2019-06-24 to 2019-12-02 (Cyanobacteria >15 mg/m^3)

3. Results and discussion

- After weir gate opening
  - DIP depletion
  - At Weir3, maximum cyanobacteria increased up to 2.2 times



3. Results and discussion

- Algal growth

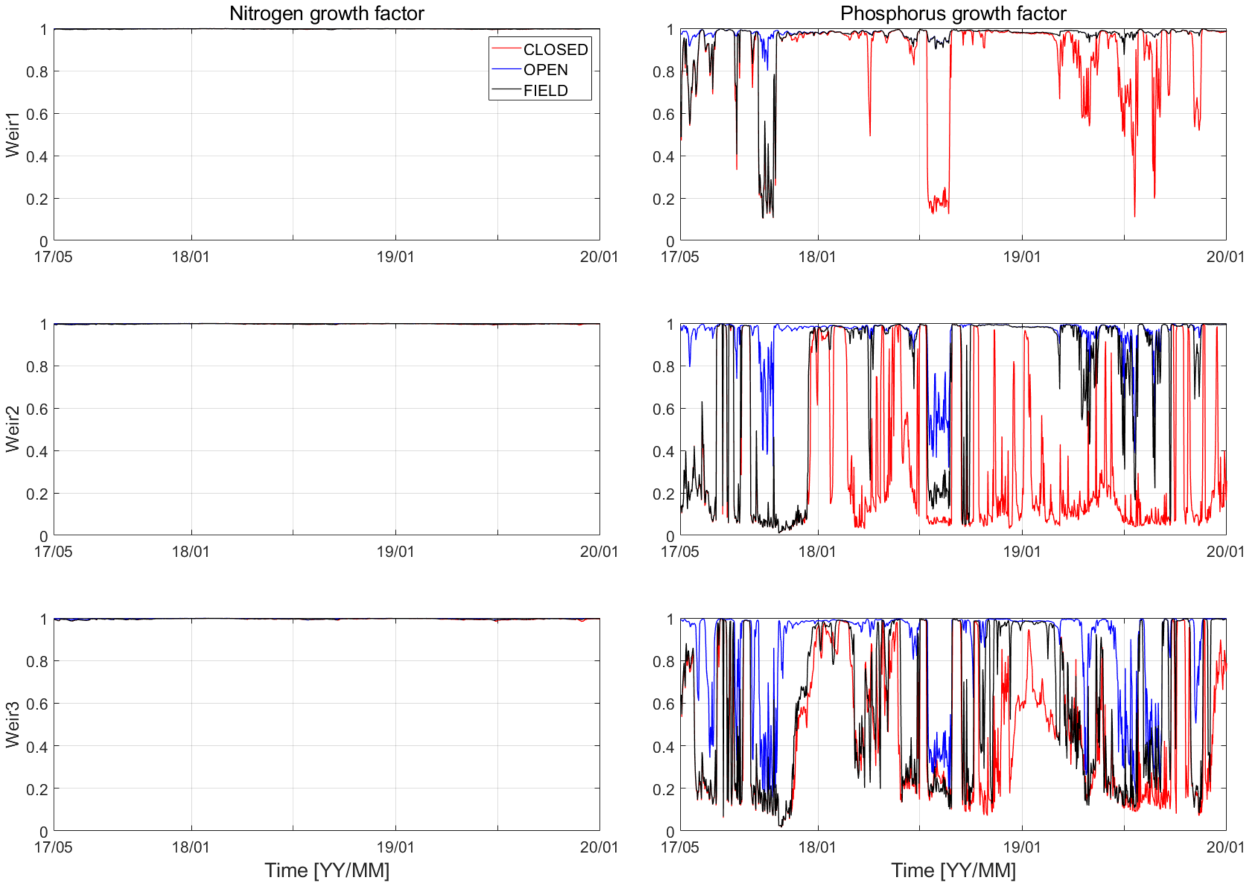
  - $P = PM \cdot F(N) \cdot F(L) \cdot F(T)$

    - P: The growth rate (1/day)
    - PM: The maximum growth rate under optimal conditions (1/day)
    - $f(N)$: The effect of suboptimal nutrient concentration (0 ~ 1)
      Based on Liebig's **"Law of the minimum"**
    - $f(I)$: The effect of suboptimal light intensity (0 ~ 1)
      Based on **"Steele's function"**
    - $f(T)$: The effect of suboptimal temperature (0 ~ 1)
      Based on **"Gaussian probability curve"**

3. Results and discussion

- Nutrient growth factor
  - Regardless of the scenarios
    - At Weir1: Highest
    - At Weir3: Lowest
  - Regardless of the locations
    - In OPEN: Highest
    - In CLOSED: Lowest
    - 111 ~ 402 % (1.7 times)
  - Weir gate opening can increase the algal growth potential
    - In terms of nutrients

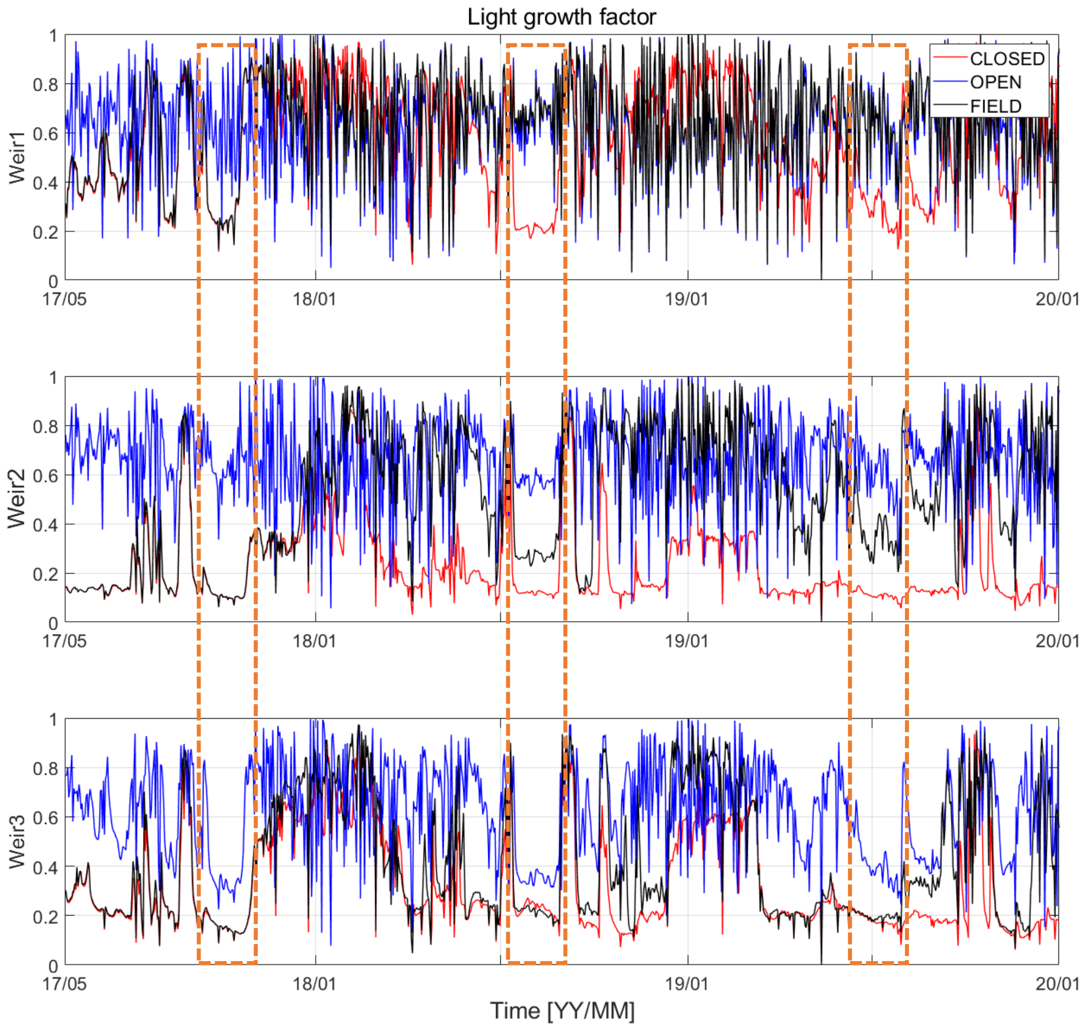
$$F(N) = \min\left(\frac{NH_3 + NO_3}{KHN + NH_3 + NO_3}, \frac{PO_4d}{KHP + PO_4d}\right)$$



3. Results and discussion

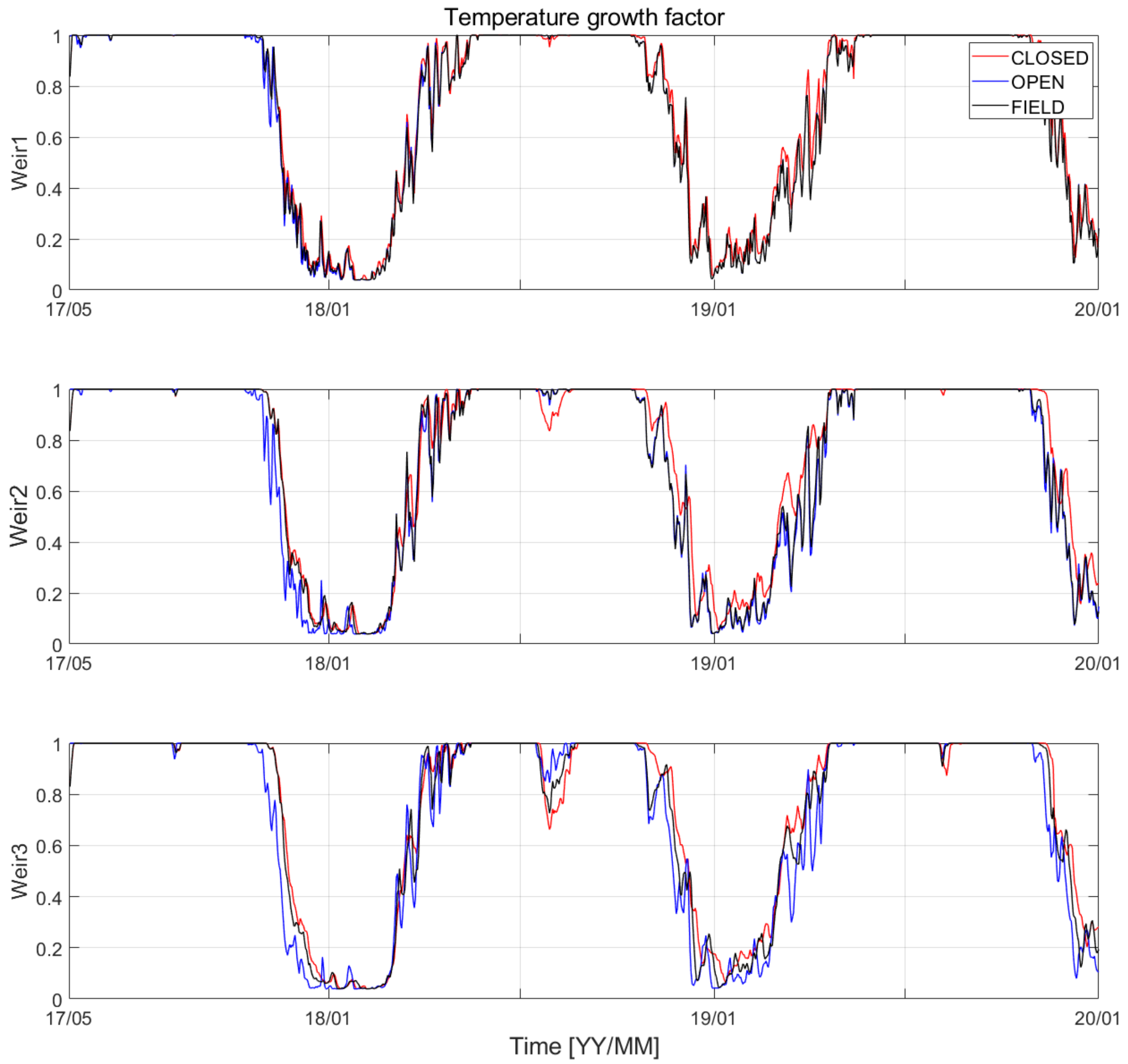
- Light growth factor
  - After weir gate opening
    - 103 ~ 339 % (1.7 times)
    - Due to reduced water depth
  - Excessive algal growth caused self-shading
  - Weir gate opening can increase the algal growth potential
    - In terms of light availability

$$F(L) \leftarrow \frac{1}{\boldsymbol{Chla} * (\Delta z)}$$



3. Results and discussion

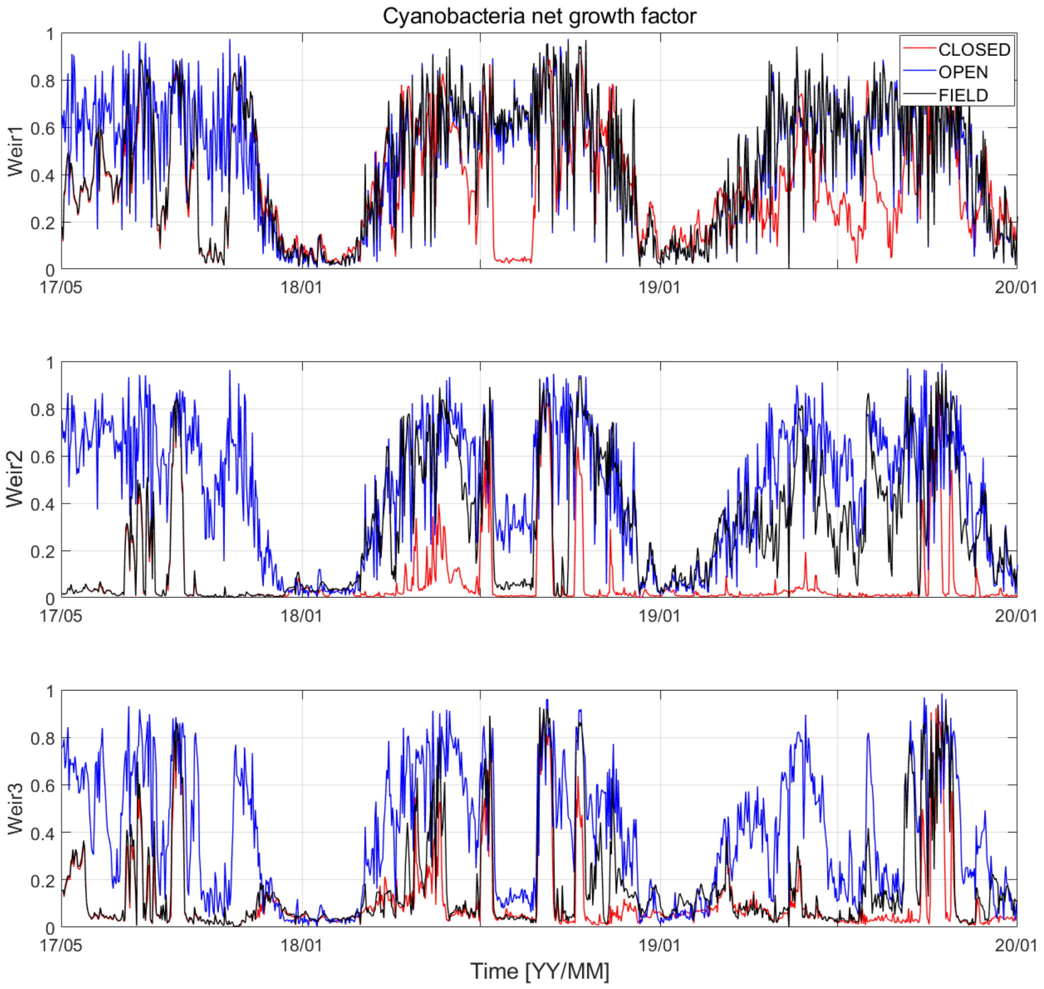
- Temperature growth factor
  - After weir gate opening
    - Average -3.2% or -0.031
  - Negligible temperature changes



3. Results and discussion

- Net growth factor
  - After weir gate opening
    - 134 ~ 696 % (2.4 times)
    - Increased nutrient growth factor
      - Increased DIP concentrations
    - Increased light growth factor
      - Decreased water depth
  - Physical changes increased the algal growth potential

$$P = PM \cdot \boldsymbol{f(N)} \cdot \boldsymbol{f(L)} \cdot \boldsymbol{f(T)}$$



3. Results and discussion

- Cyanobacteria proliferation in the summer season
  - Decreased hydraulic residence time (HRT)
  - Increased algal growth potential (AGP)
  - AGP > HRT

- To verify and quantify “AGP > HRT”
  - Track cyanobacterial particles
    - Lagrangian Particle Tracking module
  - Measure HRT of each cyanobacterial particle
  - Calculate AGP of each cyanobacterial particle

No.	Year	Input Day	# Particle
1	2017	140	100
2		145	100
3		150	100
4	2018	440	100
5		445	100
6		450	100
7		455	100
8		460	100
9		465	100
10		470	100
11		475	100
12		480	100
13	2019	805	100
14		810	100
15		815	100

3. Results and discussion

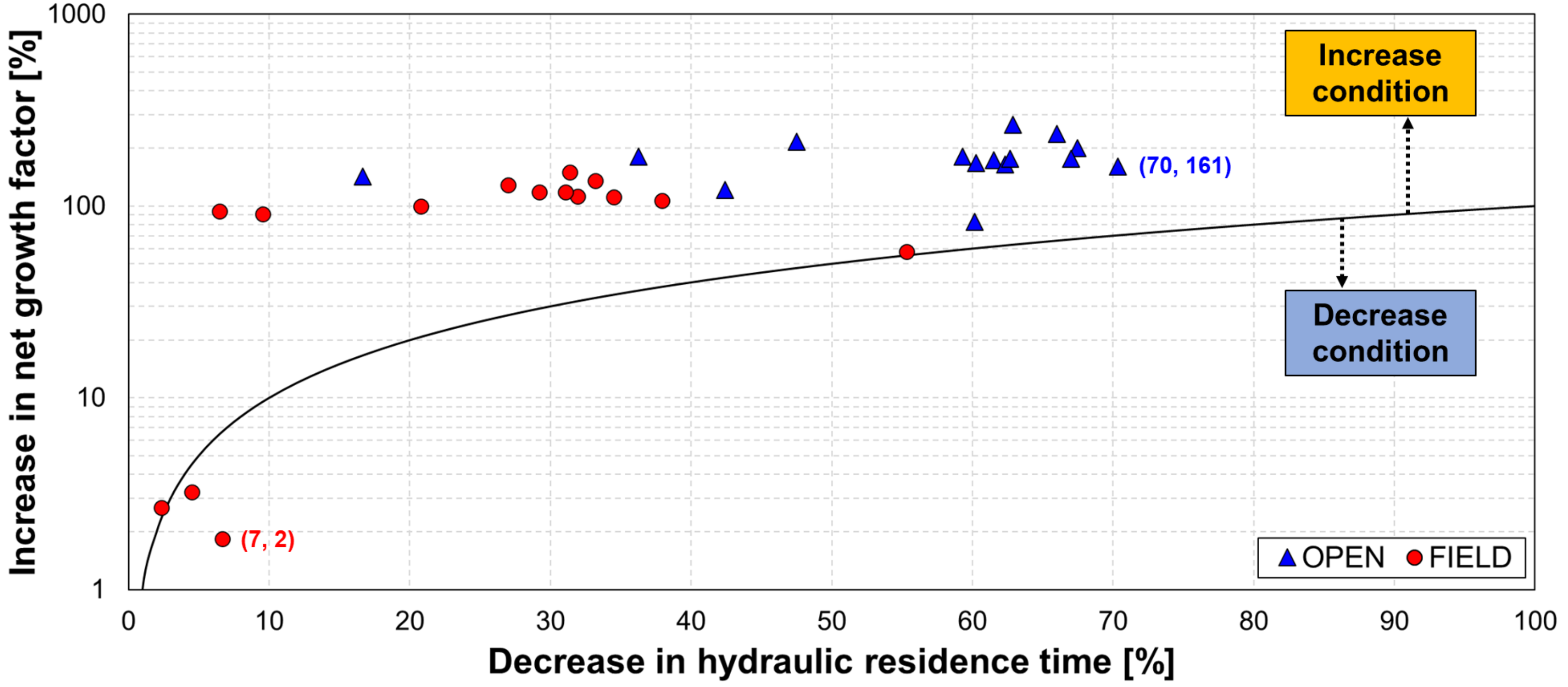
CLOSED

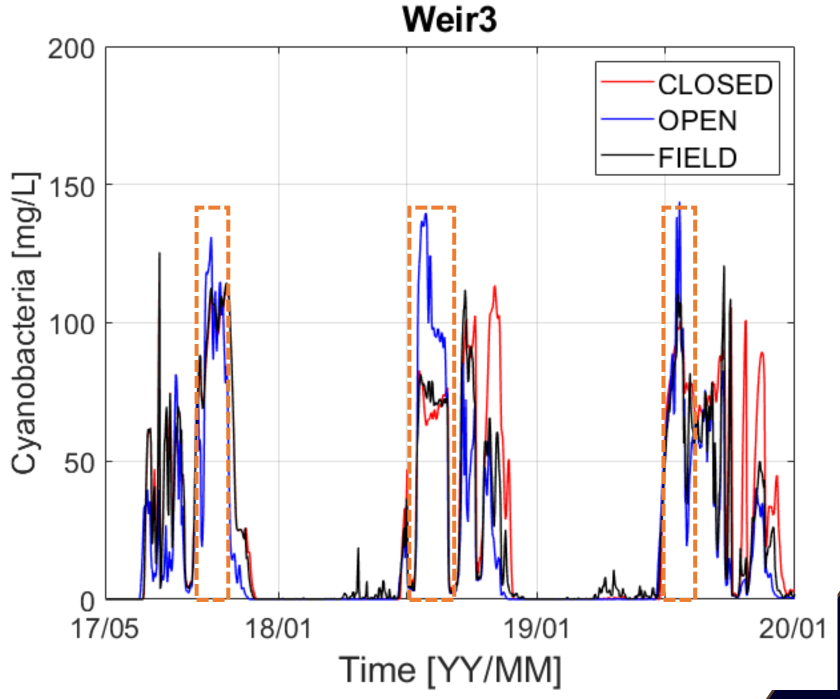
OPEN

No.	Year	Input Day	Residence time [day]			Net growth factor		
			CLOSED	OPEN	FIELD	CLOSED	OPEN	FIELD
1	2017	140	20.5	7.6	19.2	0.139	0.507	0.141
2		145	21.4	7.0	20.4	0.130	0.391	0.134
3		150	23.0	6.8	22.5	0.146	0.380	0.150
4	2018	440	20.6	7.0	13.8	0.141	0.477	0.332
5		445	18.8	7.7	13.3	0.138	0.389	0.301
6		450	17.8	6.8	12.1	0.144	0.394	0.305
7		455	18.1	6.8	11.3	0.154	0.407	0.318
8		460	16.9	5.6	11.1	0.159	0.438	0.335
9		465	16.1	6.0	11.1	0.156	0.430	0.340
10		470	14.0	5.6	11.1	0.164	0.440	0.329
11		475	9.6	5.5	9.0	0.177	0.392	0.344
12		480	5.3	4.4	4.8	0.203	0.493	0.389
13	2019	805	12.6	6.6	8.7	0.134	0.423	0.335
14		810	9.4	6.0	6.9	0.140	0.393	0.320
15		815	9.4	3.8	4.2	0.206	0.376	0.325
Mean			15.6	6.2	12.0	0.155	0.422	0.293

3. Results and discussion

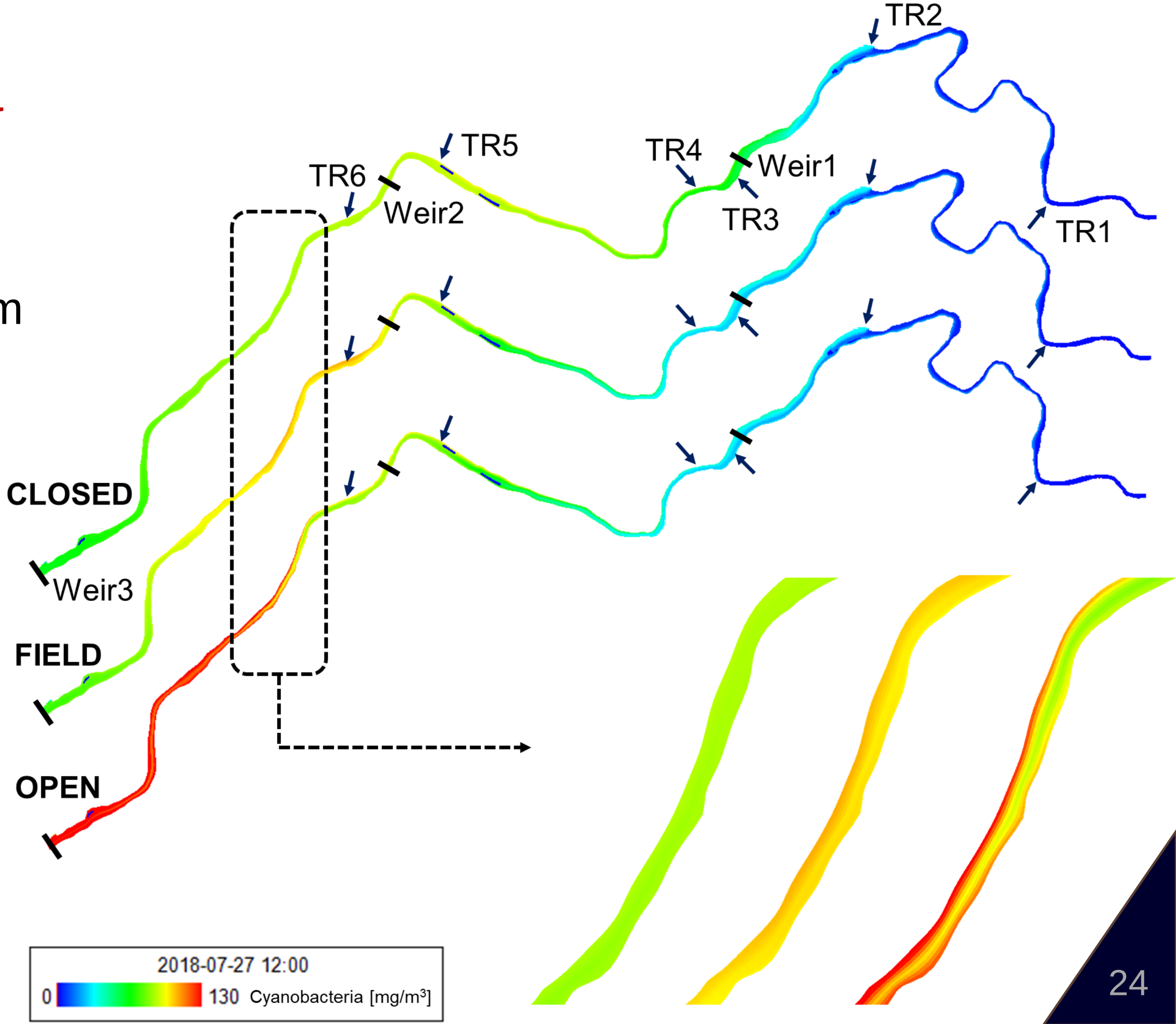
- Assessment of algal growth condition
  - Increase in net growth factor compared to CLOSED
  - Decrease in hydraulic residence time compared to CLOSED
  - Isocline: no net change





3. Results and discussion

- Distribution of cyanobacteria
  - After weir gate opening
    - Improvement of HABs upstream
    - Severe HABs occurred downstream
      - Due to increased water velocity
    - Strength of the lateral distribution
      - Due to enhanced central flow



4. Conclusion

- Control factors of Algal growth in the Geum River
  - DIP availability
  - Residence time and water depth

- Hydrologic regulations may not improve water quality and guarantee HAB improvement
  - Increased water velocity accelerates the migration of pollutants toward downstream
  - Reducing HABs will likely require a reduction in the pollution load

Thank you