Impact of Selective Withdrawal in a Large Reservoir on Downstream Fish Habitats

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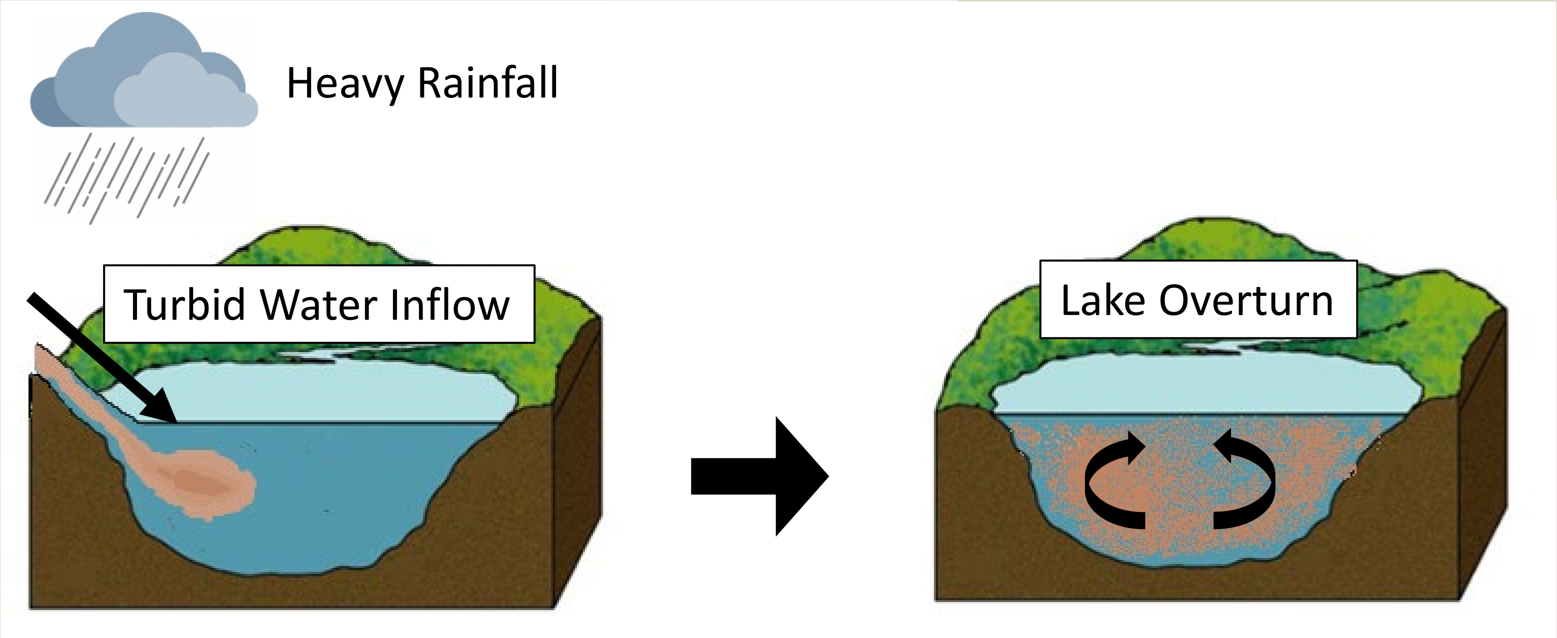
Turbid Water in Imha Reservoir

Republic of Korea

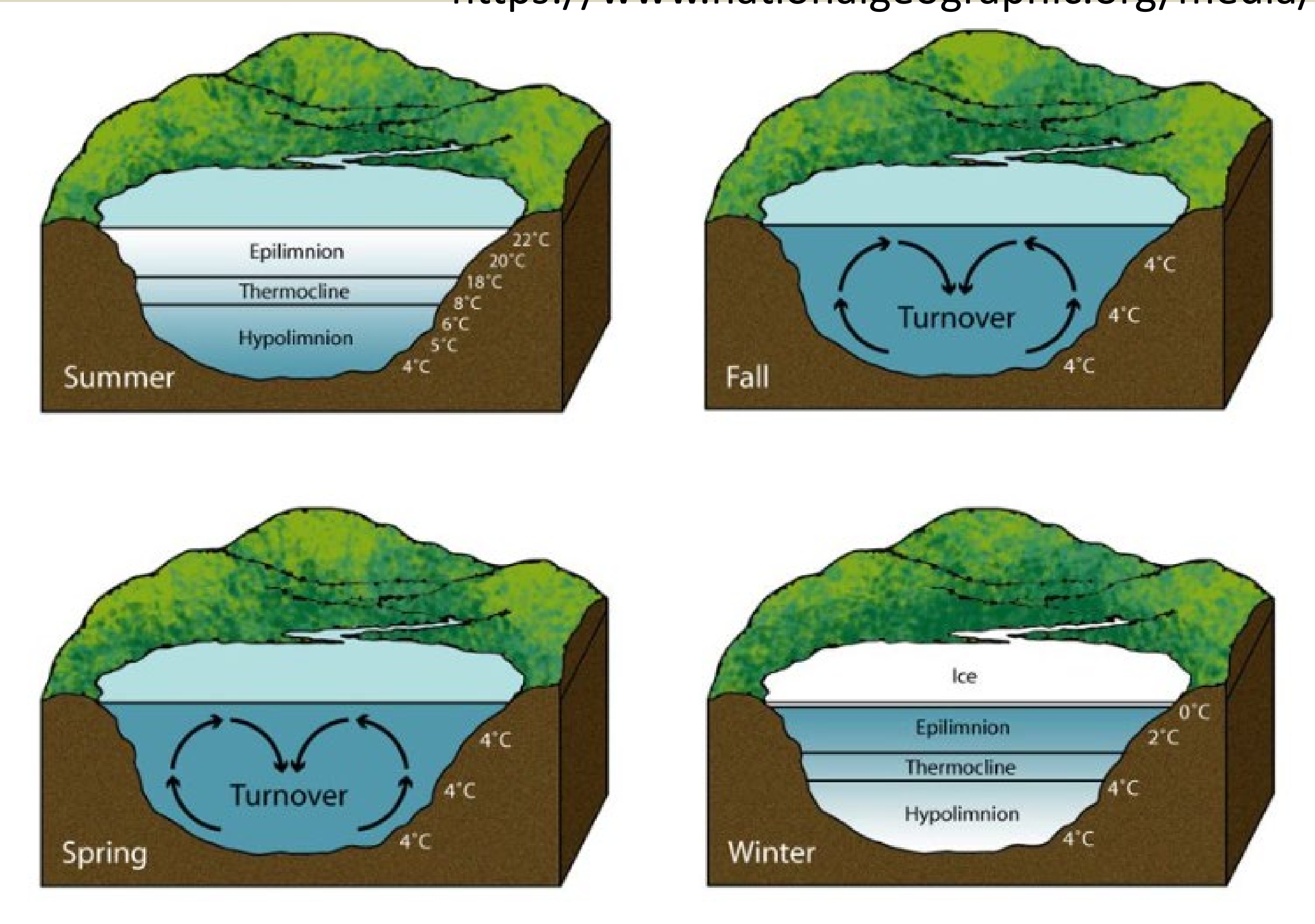
- Highly turbid water (max NTU=1,200) occurred after the typhoon Maemi hit Korea in Sep. 2003.
- Turbid water in the reservoir lasted for 340 days.

Long Lasting Turbid Water



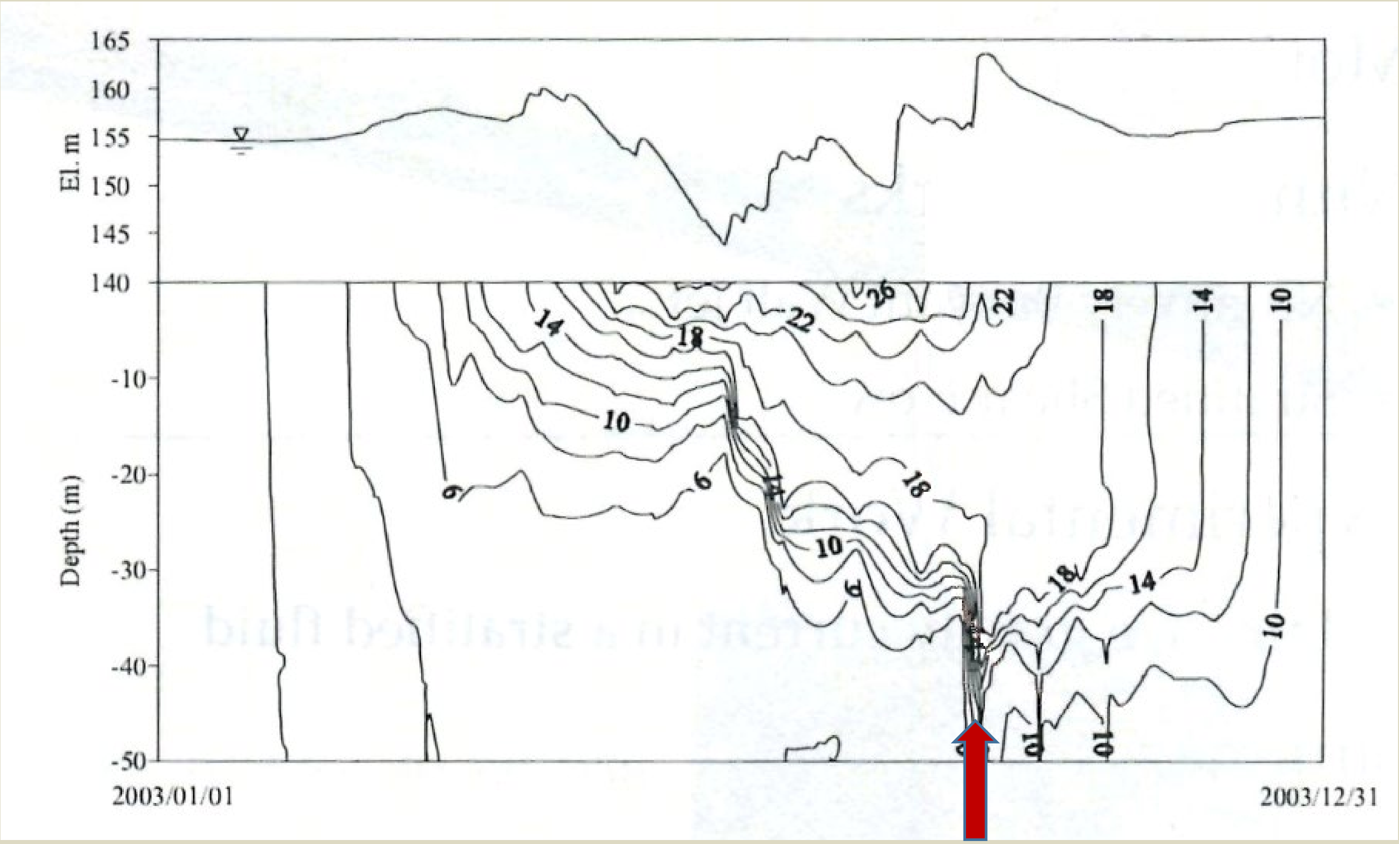
Lake Overturn

https://www.nationalgeographic.org/media/lake-turnover/



- Overturn is the process by which currents circulate the water in a the lake, resulting a movement of oxygen, nutrients, and sediment.

Annual Water Temperature Variation



- In 2003, overturn was thought to take place immediately after the typhoon hit Korea.

Turbid Water in Soyang Reservoir

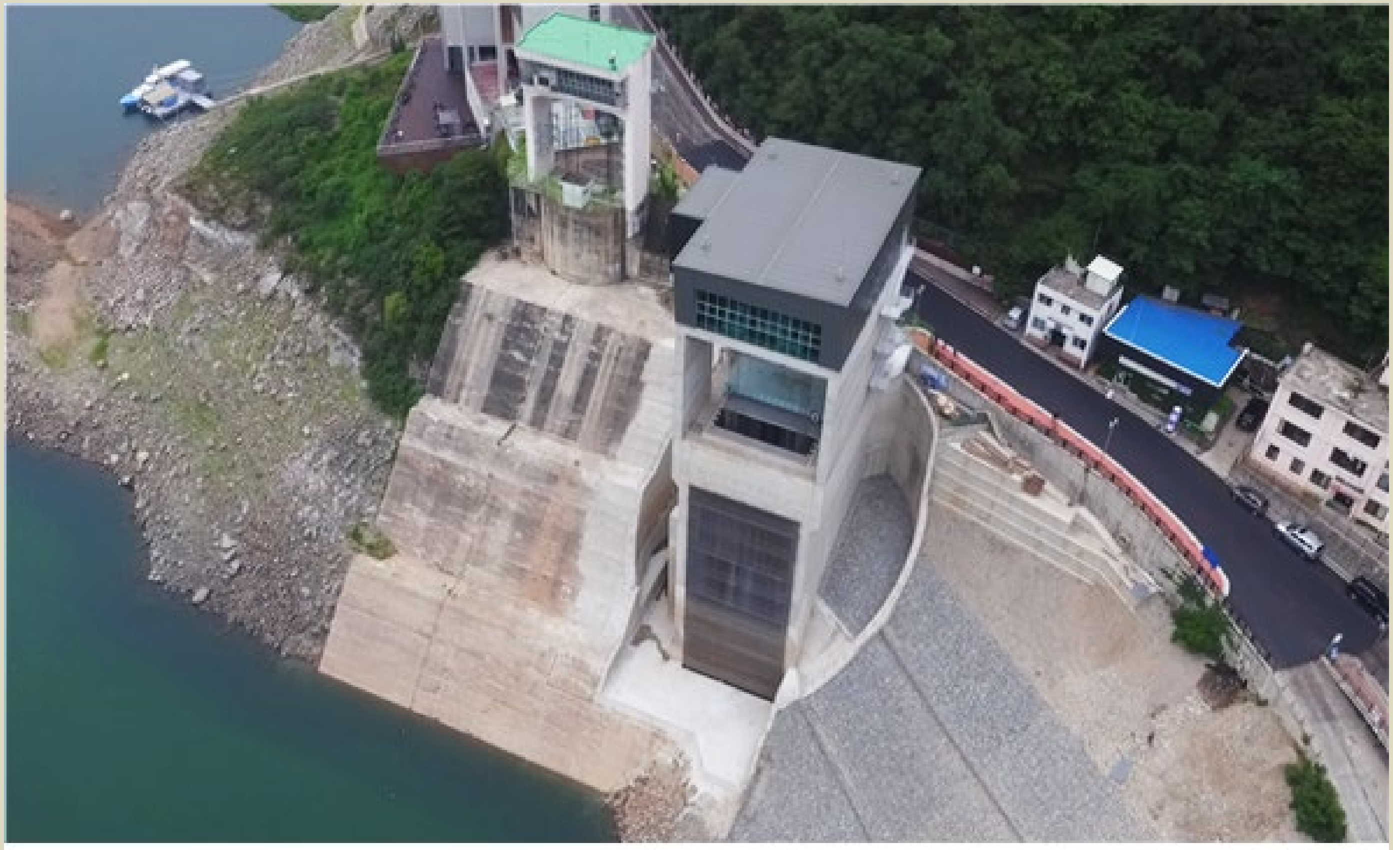
Republic of Korea

- In July 2006, highly turbid water occurred in the Soyang Reservoir with the typhoon Ewiniar in Korea.

Features

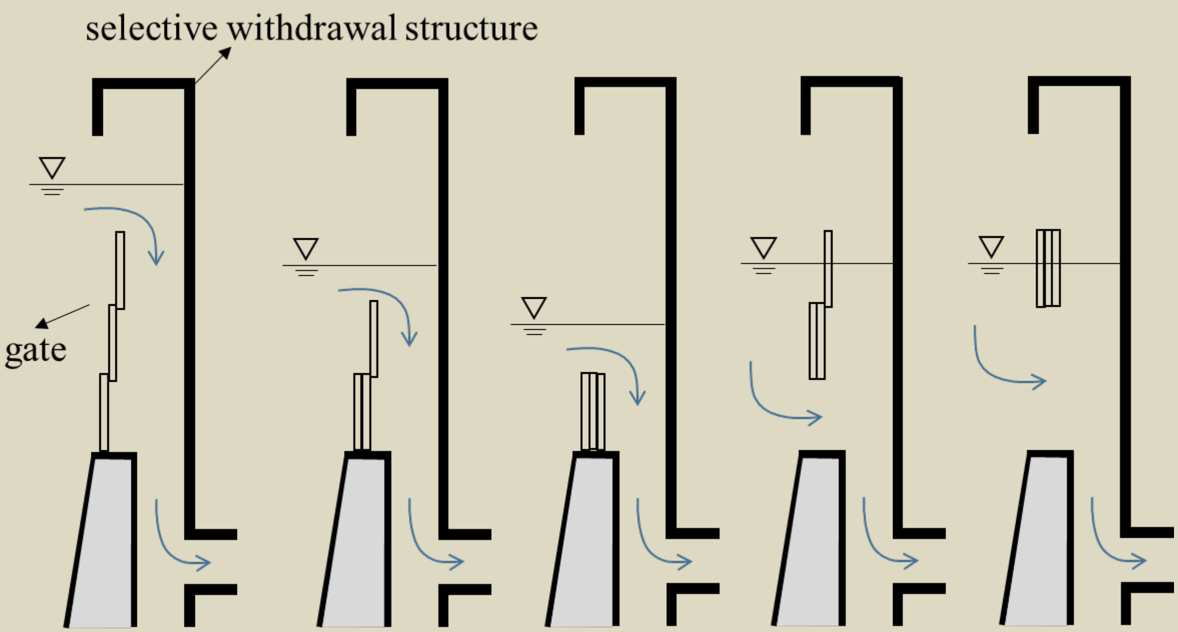
- Typhoon Ewiniar: July 10, 2006 – July 18, 2006
- Rainfall: 592.7 mm
- Particle size: Clay and Silt (2 – 24 μm)
- Maximum Turbidity in the Reservoir: 1,256 NTU
- Maximum Turbidity of the discharge from the dam: 328 NTU
- The turbid water was sustained for over 8 months, which interrupted water supply to nearby cities.
- The Government established so called “Turbidity Reduction Plan in the Reservoir”, and one of the action plans was to construct the selective withdrawal structure in the reservoir.

Selective Withdrawal Structure in the Soyang Reservoir



- To control turbidity of water released from the Soyang Reservoir, a selective withdrawal structure was constructed in 2017.

Selective Withdrawal Structure in the Soyang R.



(a) schematic diagram of operations of selective withdrawal using three gates

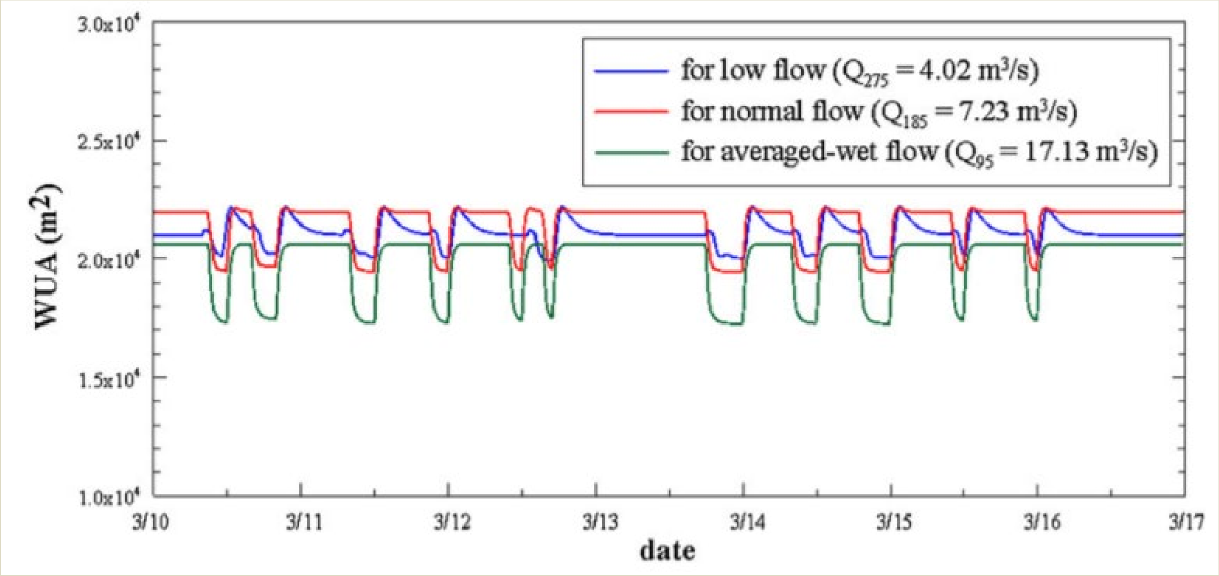
- The primary purpose of the selective withdrawal operation was to release clear water during the occurrence of turbid water.

Impacts of Upstream Dam

- Hydropeaking
- Thermopeaking
- Cold-water release
  - Water quality
  - Habitat

Impact of Upstream Dam (1): Hydropeaking

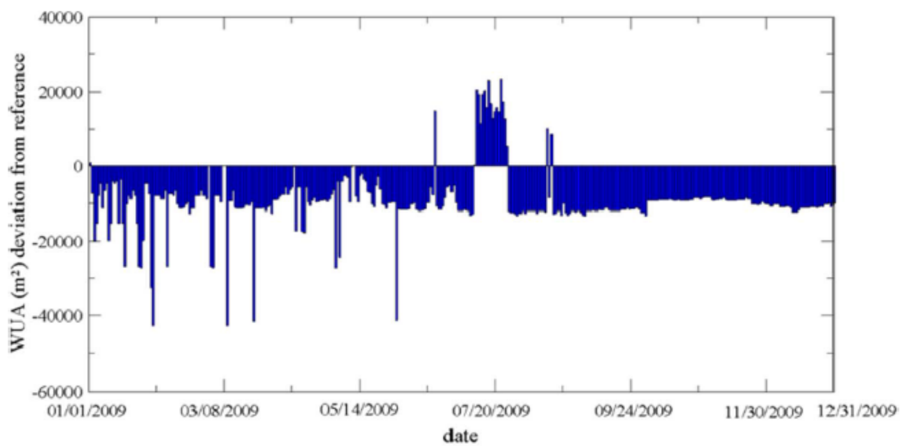
- **Hydropeaking: the rise and fall in the discharge caused by the hydropower plant operations (Choi et al., 2017).**
- **Hydropeaking causes changes in physical habitat variables such as flow depth, velocity, and substrate, which, in turn, directly affect the habitat abundance or availability of aquatic organisms.**



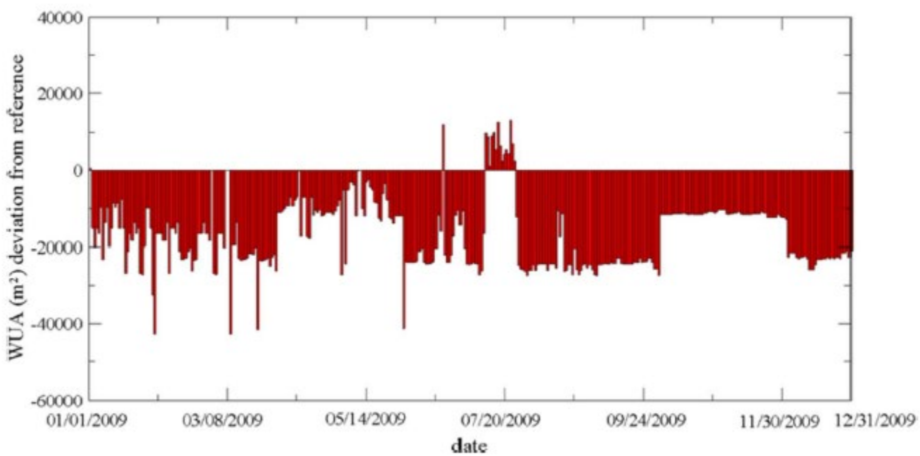
Decrease of available habitat (WUA) during hydropower generation (Choi et al., 2017)

Impact of Upstream Dam (2): Thermopeaking

- **Thermopeaking: fluctuations of water temperature in the reach downstream of a dam due to the release of water with different temperature during the hydropower generations.**
- **In general, water released from the dam is warmer and cooler than water flowing in the winter and summer, respectively.**



(a) hydropeaking

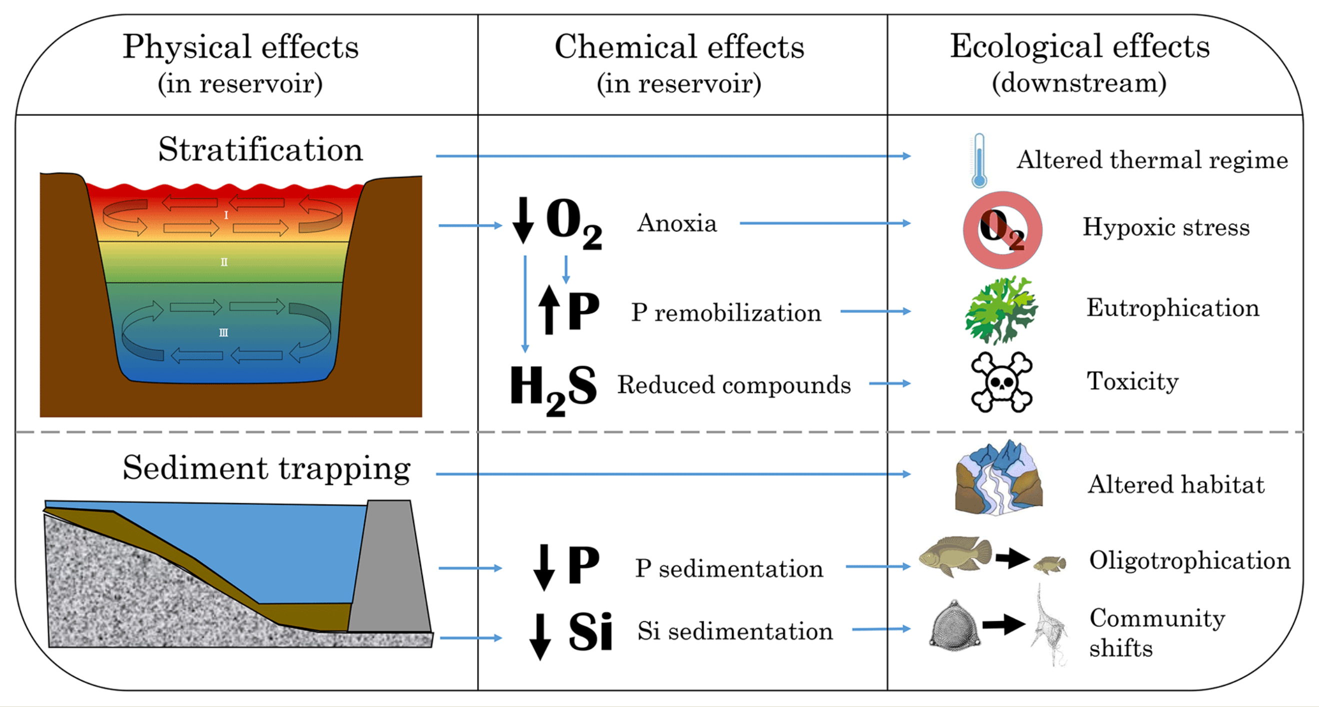


(b) hydropeaking and thermopeaking

WUA deviation from the natural flow regime (Choi and Choi, 2018)

Impact of Upstream Dam (3):
Degraded water quality by cold-water release

- **Dam tail waters with low oxygen or reduced compounds, such as hydrogen sulfide, are likely to stem from discharged deep water of a stratified reservoir.**



Conceptual summary of the physical and chemical water quality effects of dams and how they affect aquatic ecology (Winton et al., 2019)

Impact of Upstream Dam (3): Ecological damage by cold-water release

- Cold water release from the hypolimnectic layer in the reservoir degrades the quality of fish habitats in the downstream reach of the dam (Edwards, 1978).
- For example, serious degradation of fish abundance was observed (reduced to 10% of original population) in the downstream of the Gunnam Dam, Korea, due to the cold water release whose temperature was lower by 7℃ than water in the stream.

Gunnam Dam

Takifugu obscurus

Republic of Korea

Motivations

- The selective withdrawal structure was constructed in 2017 in the Soyang Reservoir not to release water with high SS concentration when high turbid water occurred in the reservoir.

- Our idea was to use the same structure with a purpose of reducing the damage from the cold-water release on downstream fish habitat.

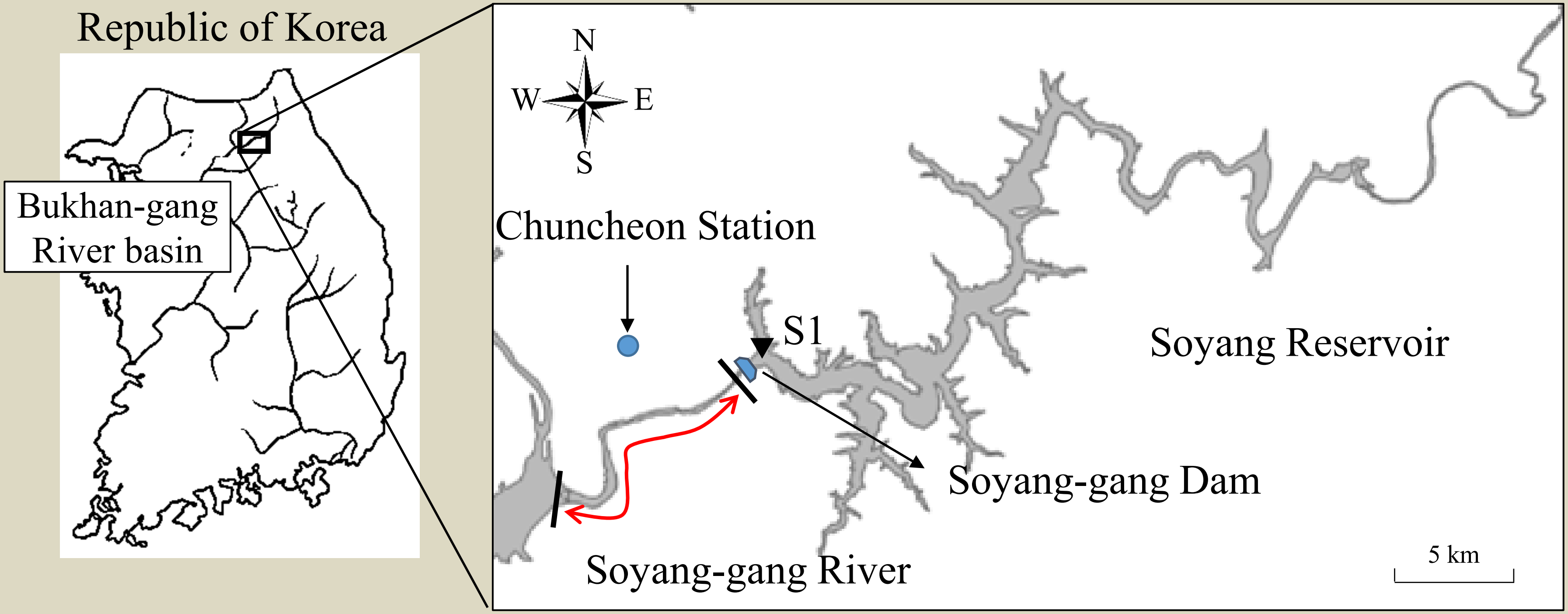
Research Objective

- The objective of the present study was to investigate the impact of the selective withdrawal in a large dam on the downstream fish habitat using physical habitat simulations (PHSs).

For this,

- A 11 km long reach in the Soyang-gang River was selected as a study area.
- First, water temperature and hydraulic simulations were carried out in the upstream and downstream reaches of the dam using numerical models.
- Then, changes of the physical habitat for the target fish species were simulated using the PHS.

Study Area



- A 11 km long reach located downstream of the Soyang-gang Dam was selected as the study area.

Methods

Three stages of numerical simulations were carried out to investigate the impact of the selective withdrawal on downstream fish habitat

(1) Distribution of water temperature in the reservoir
- CE-QUAL-W2 Model

(2) Hydrodynamic and water temperature simulations in the reach downstream of the dam
- HEC-RAS Model

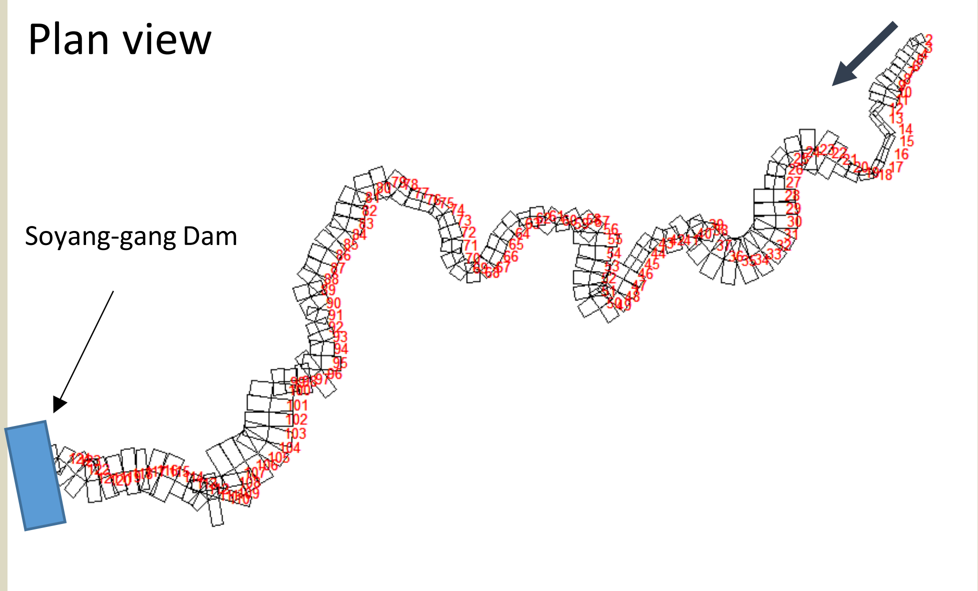
(3) Habitat Simulation for the target fish species in the reach downstream of the dam
- Habitat Simulation Model

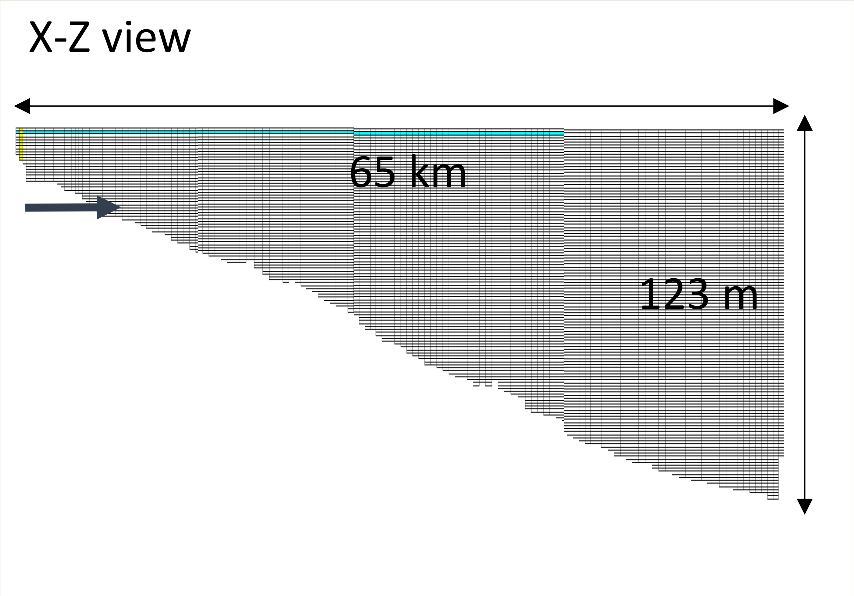
(1) CE-QUAL-W2 Model

- A two-dimensional hydrodynamic and water quality model, which is capable of calculating water surface elevation, velocity, water temperatures, and water quality components such as ammonium, nitrate-nitrate, phosphorus and so on (Cole and Wells, 2018).

- The CE-QUAL-W2 model assumes that lateral variations in velocity, temperature, and constituents are negligible. This assumption is valid for large reservoirs in mountainous area, the shape of which is long, narrow, and deep in the length, width, and depth, respectively.

(1) CE-QUAL-W2 Model: Soyang R.



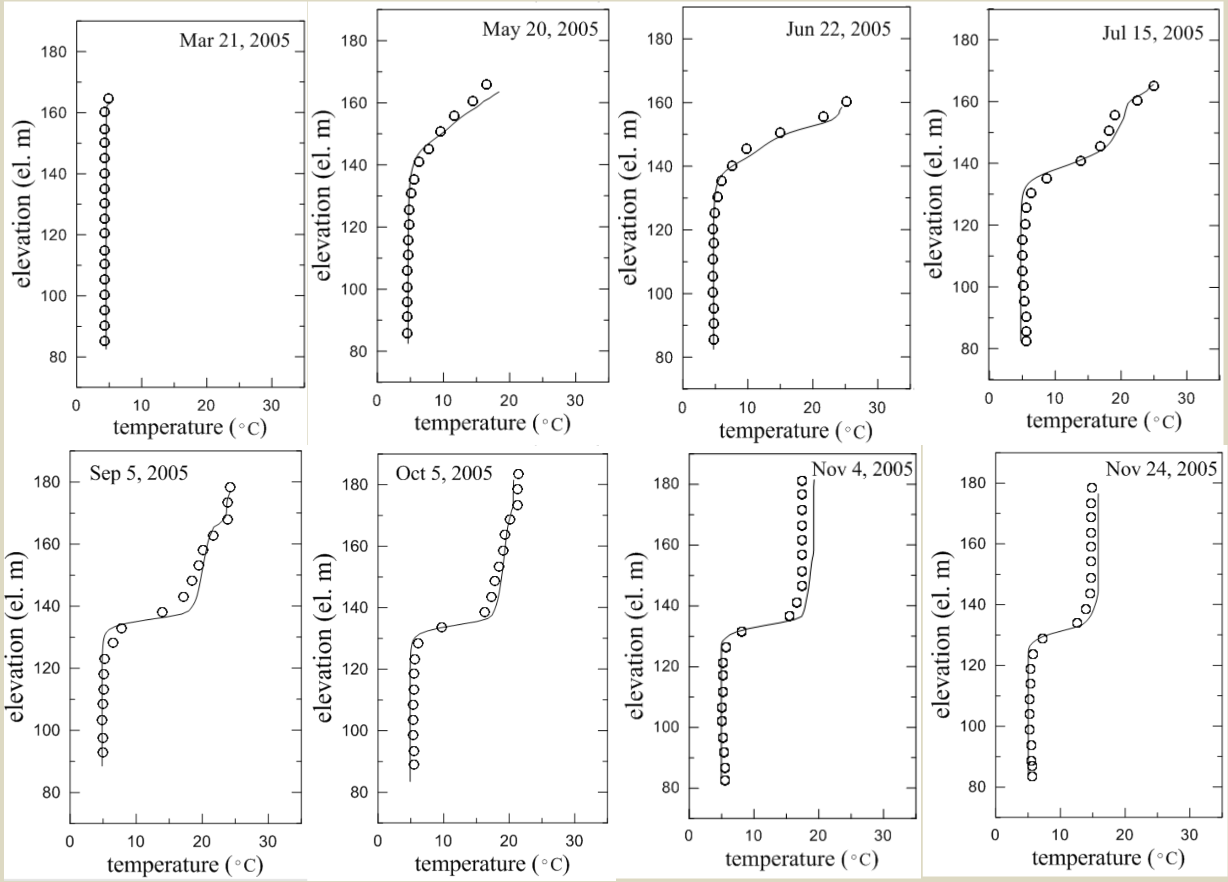


Model setup

- **Grid: 134 segments (longitudinal grid #), 123 layers (vertical grid #)**
- **Simulation Year: 2005, 2007**
- **Other input data (meteorological data, inflow & outflow, etc.) were obtained from Park et al. (2017), WAMIS (wamis.go.kr), KMA (kma.go.kr)**

(1) CE-QUAL-W2 Model Result (2005)

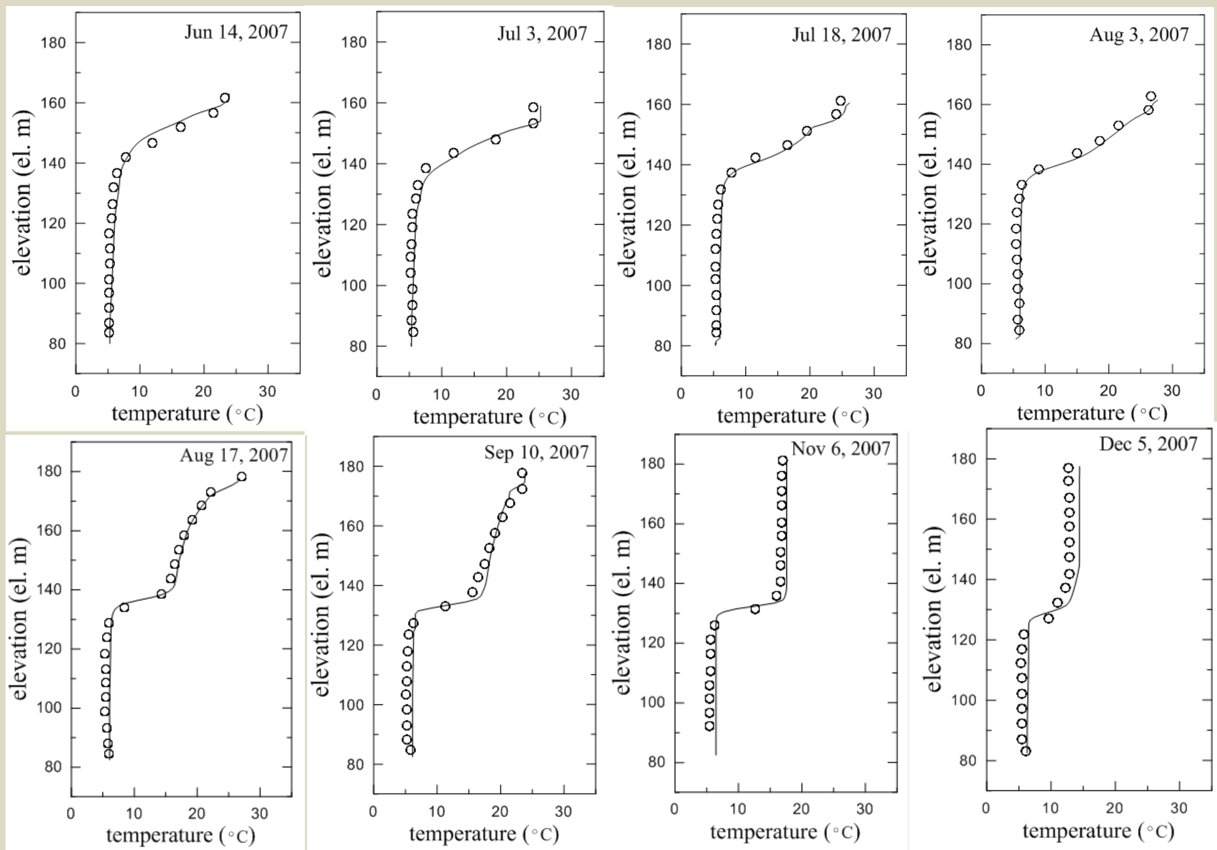
Comparison between simulated and measured water temperature



Mean absolute error: 0.15 – 0.93 ℃, Coefficient of determination: 0.92 – 0.99

(1) CE-QUAL-W2 Model Result (2007)

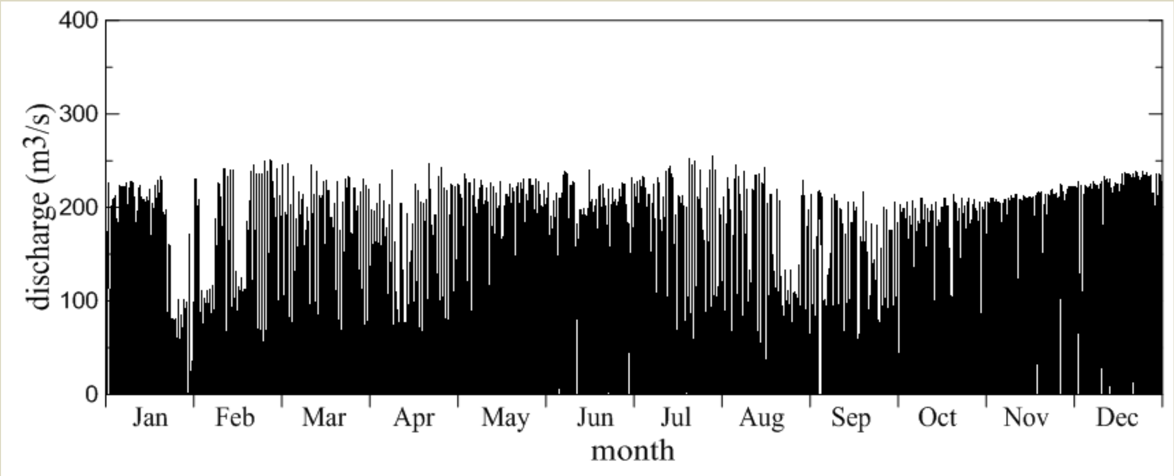
Comparison between simulated and measured water temperature



Mean absolute error: 0.53 – 1.31 ℃, Coefficient of determination: 0.95 – 0.99

(2) HEC-RAS Model

- **HEC-RAS Model was used to simulate the changes of flow depth, velocity, and water temperature by hydropeaking flows from the dam.**



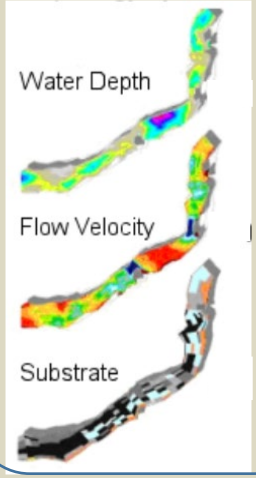
Qpeak = 230 cms
Qrec = 0.5 cms

Hydropeaking flows of the Soyang-gang Dam in 2007

(3) Physical Habitat Simulation

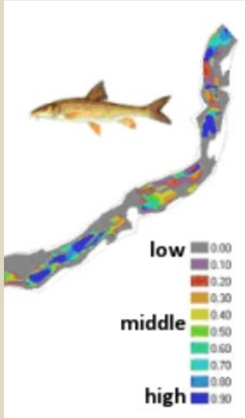
Physical habitat simulation

Hydraulic simulation

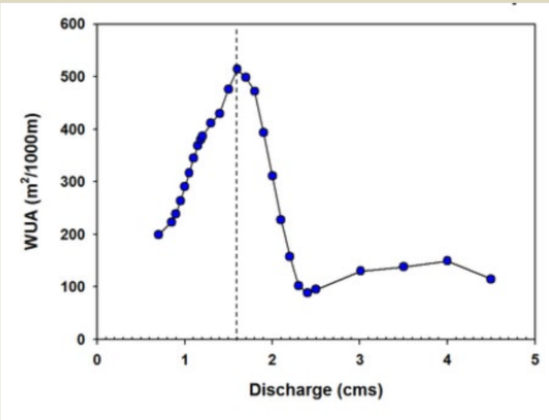


Habitat simulation

CSI distribution



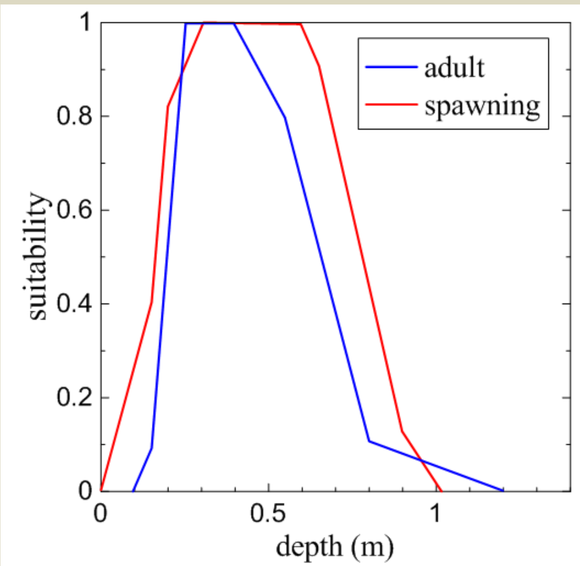
WUA – discharge curve



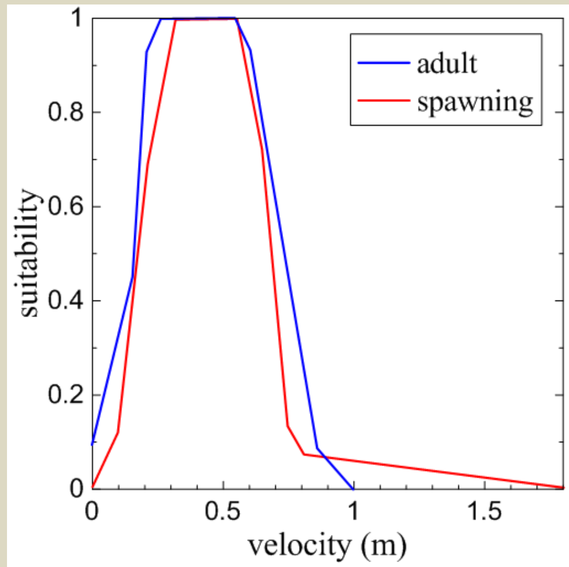
- **CSI (Composite Suitability Index): a value of habitat suitability, ranging between 0 (worst) ~ 1 (optimal).**
- **WUA (Weighted Usable Area): available habitat area**

(3) Habitat Suitability Curves for *Z. Platypus*

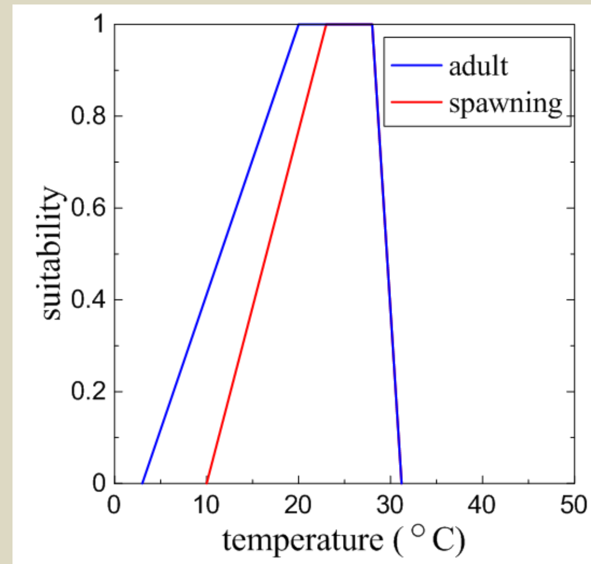
Flow depth



Velocity



Water temperature

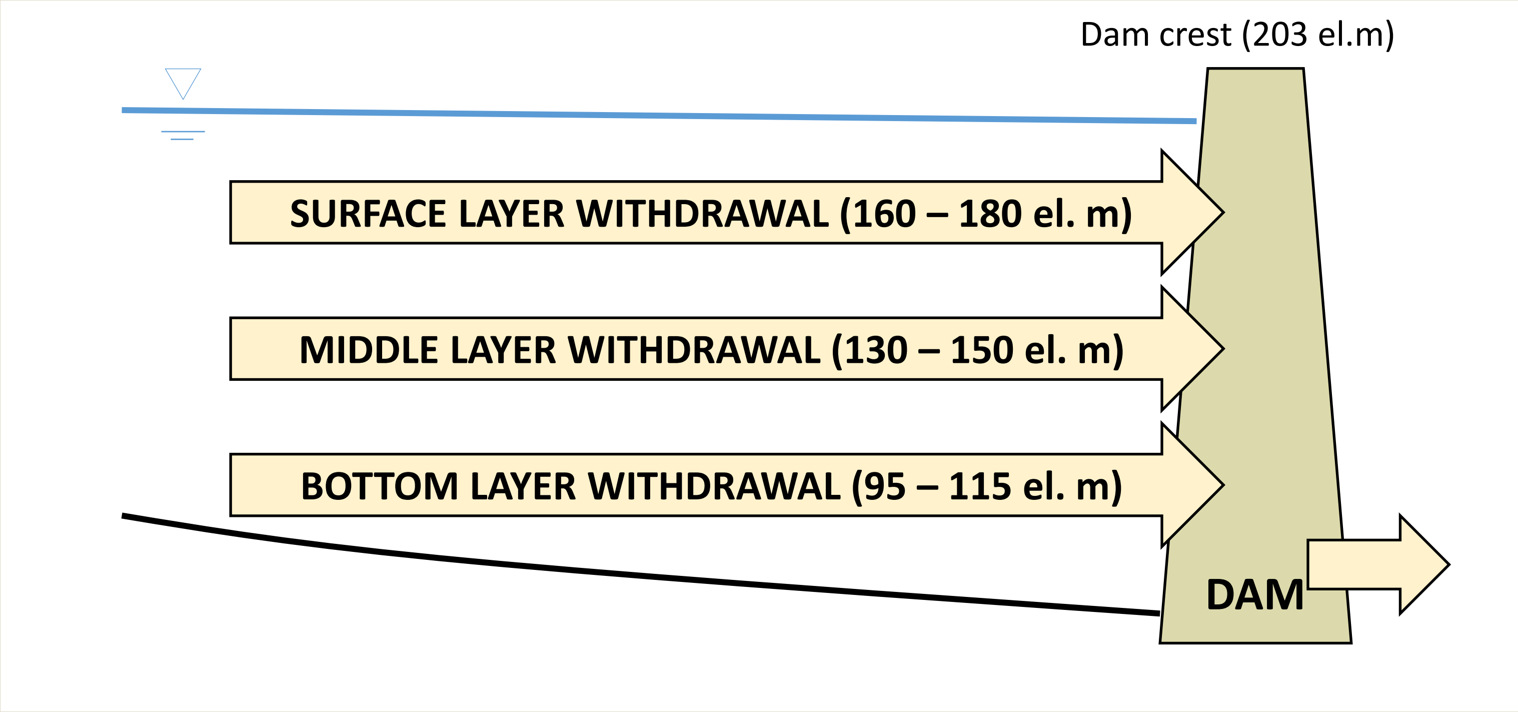


- In this study, *Zacco platypus*, which is a dominant fish species in the Soyang-gang River basin, was selected as the target fish for PHSs.
- Adult and spawning stages of *Z. platypus* were considered.

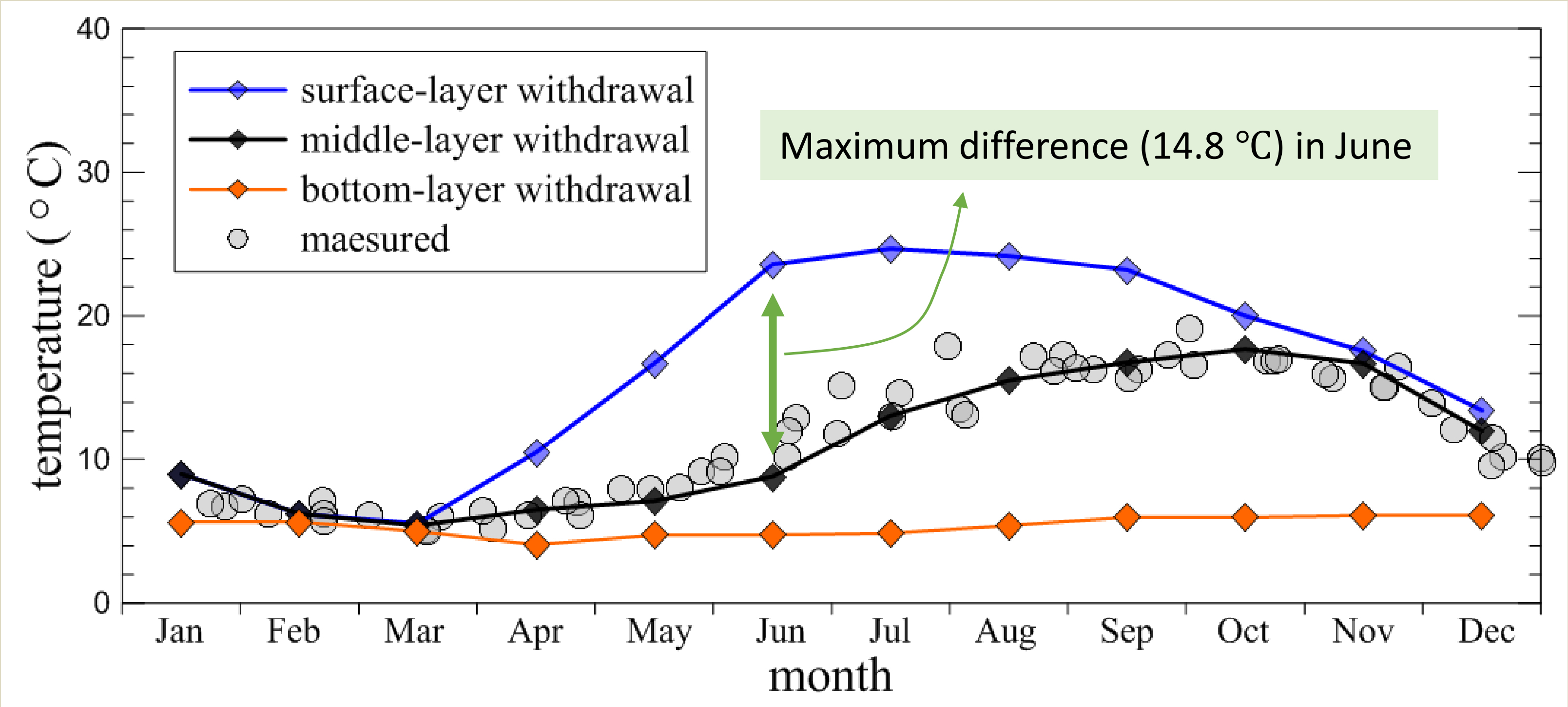
Results

Selective withdrawal Options

- **Three withdrawal options were considered based on the elevation of the water intake.**



Annual Change of Water Temperature

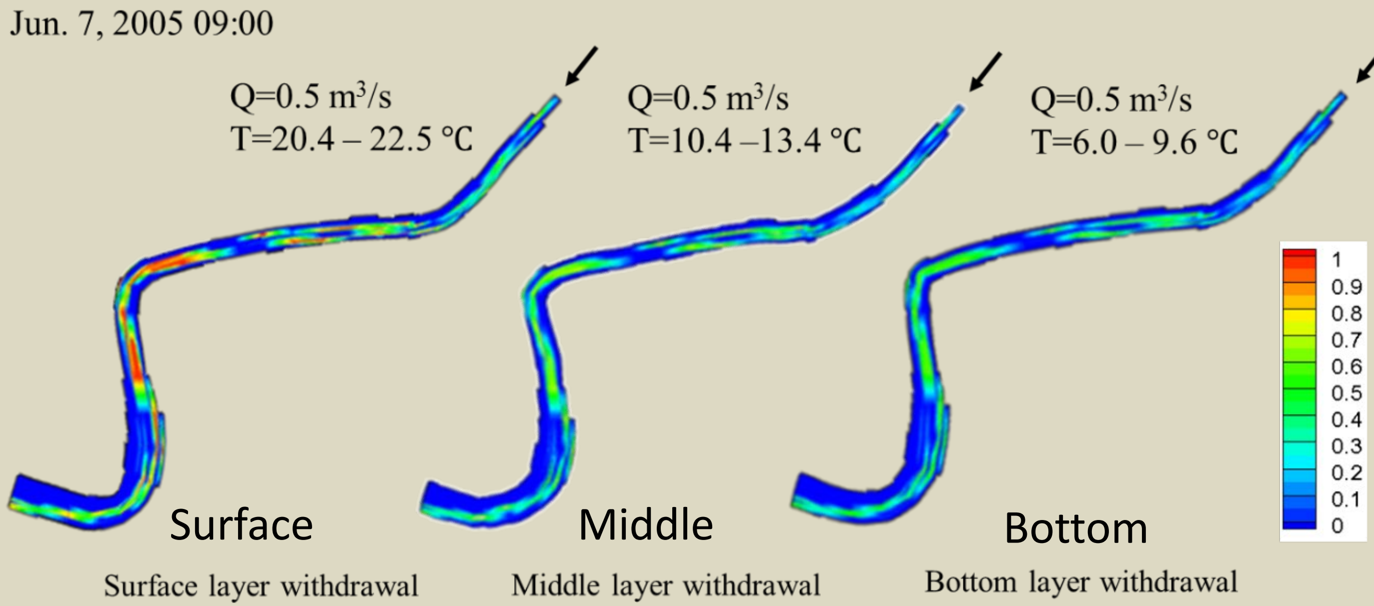


- Water temperature was highest for the surface-layer withdrawal, followed by middle-layer withdrawal and bottom-layer withdrawal.
- The release of water from the bottom layer affects badly downstream fish habitat due to too low water temperature all around the year.

CSI Distribution for the base flow (Adult *Z. Platypus*)

Jun 7, 2005

Base flow
Q=0.5 m^3/s

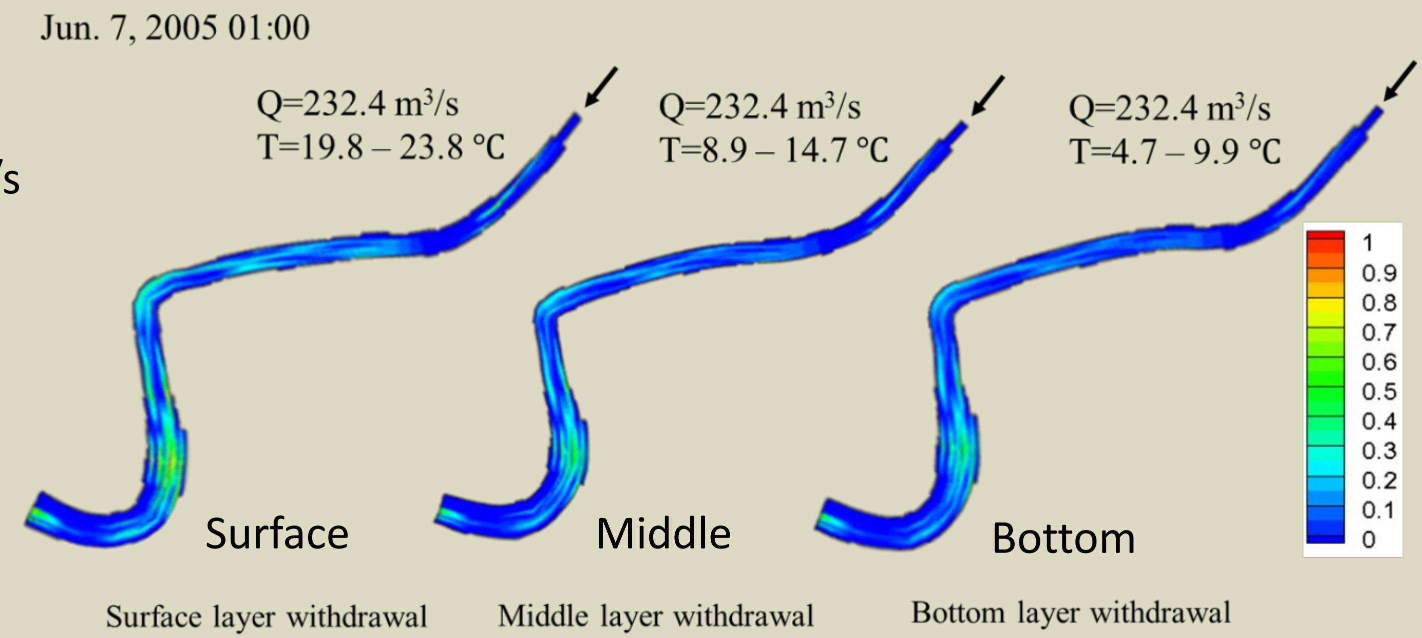


- **Overall CSI for the surface-layer withdrawal appears to be relatively high, followed by CSI for the middle-layer withdrawal and CSI for the bottom-layer withdrawal.**
- **This is mainly due to that water temperature by the surface-layer withdrawal is most suitable for adult *Z. platypus*.**

CSI Distribution for the peak flow (Adult *Z. Platypus*)

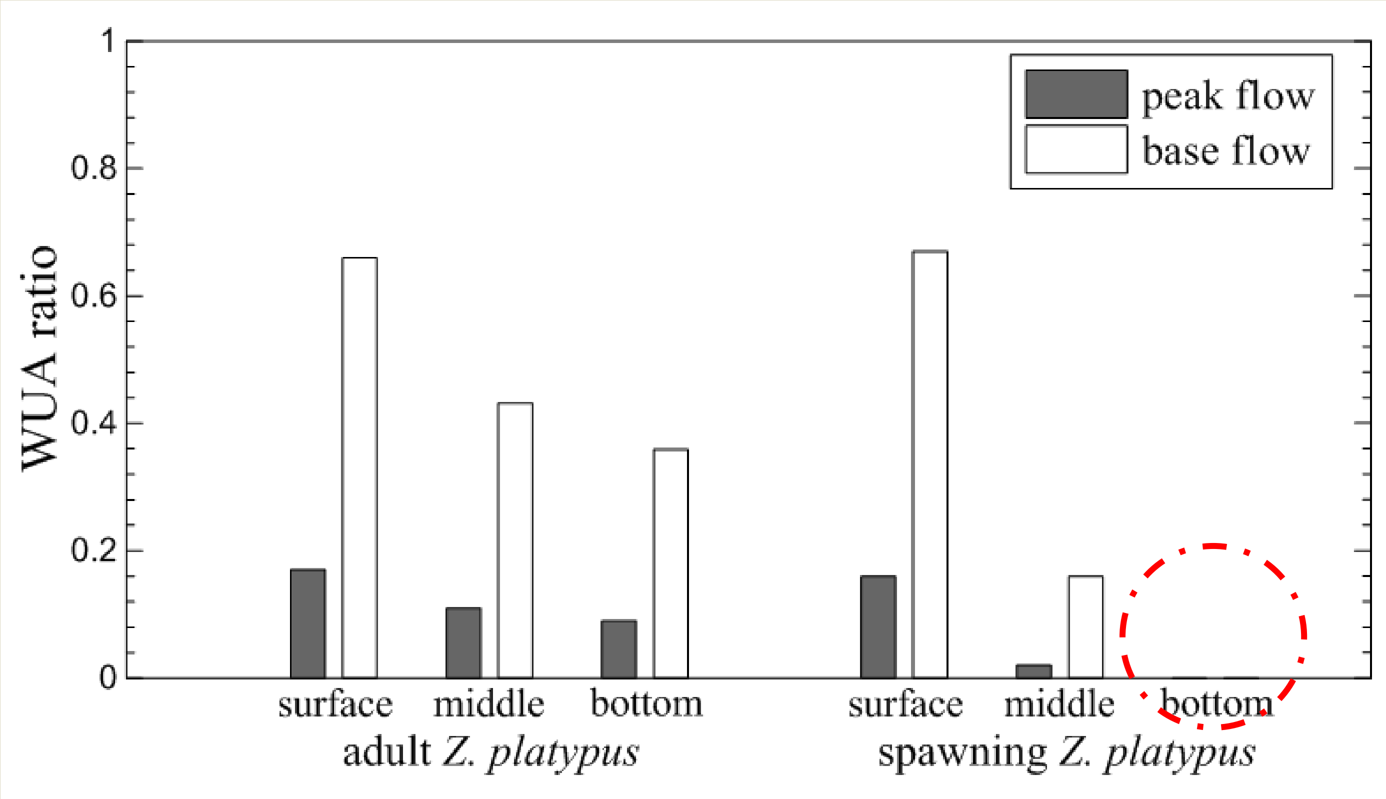
Jun 7, 2005

Peak flow
Q=232.4 m^3/s



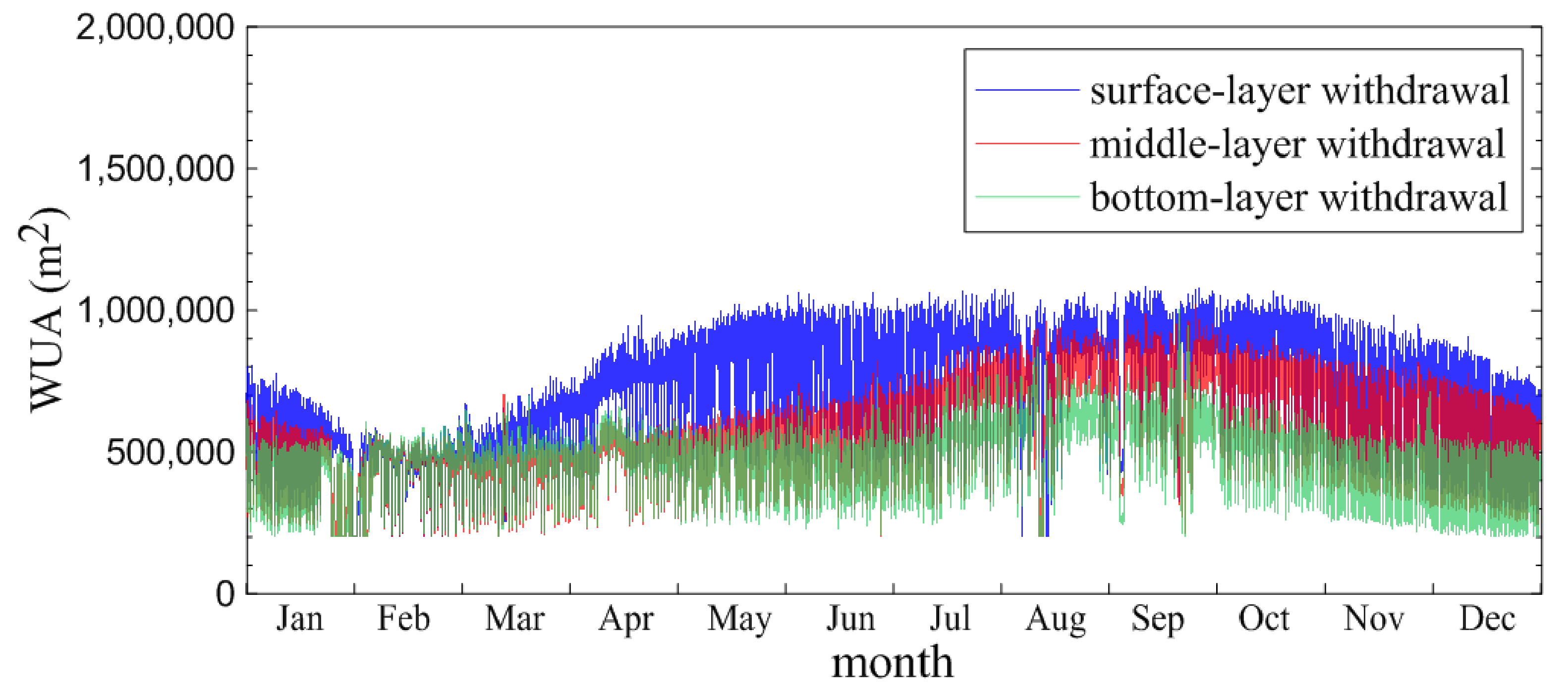
- **Similarly, CSI values for the surface-layer withdrawal are relatively high for the peak flow, followed by CSI for the middle-layer withdrawal and CSI for the bottom-layer withdrawal.**

Comparison of WUA Ratios



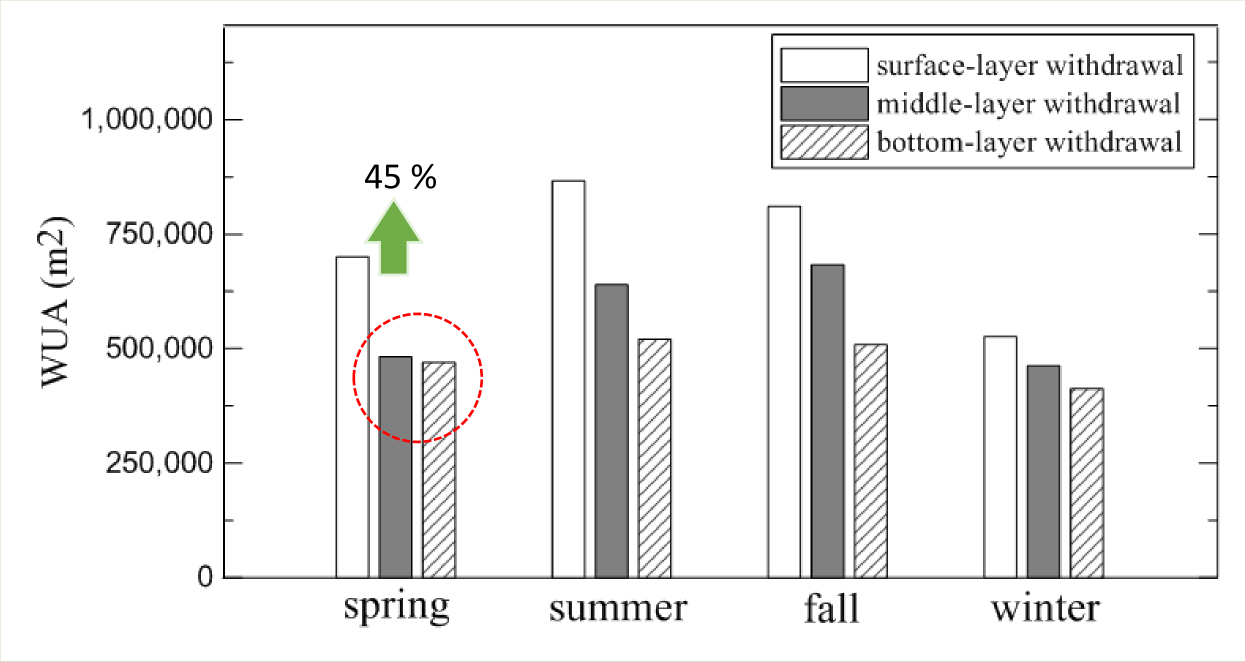
- **WUA ratio = % of available habitat area over the whole study area**
- **Spawning *Z. platypus* is more affected by the type of withdrawals.**
- **For the spawning *Z. platypus*, the available habitat is zero by the bottom layer withdrawal for both peak and base flows.**

Annual Change of WUA for Adult *Z. platypus*



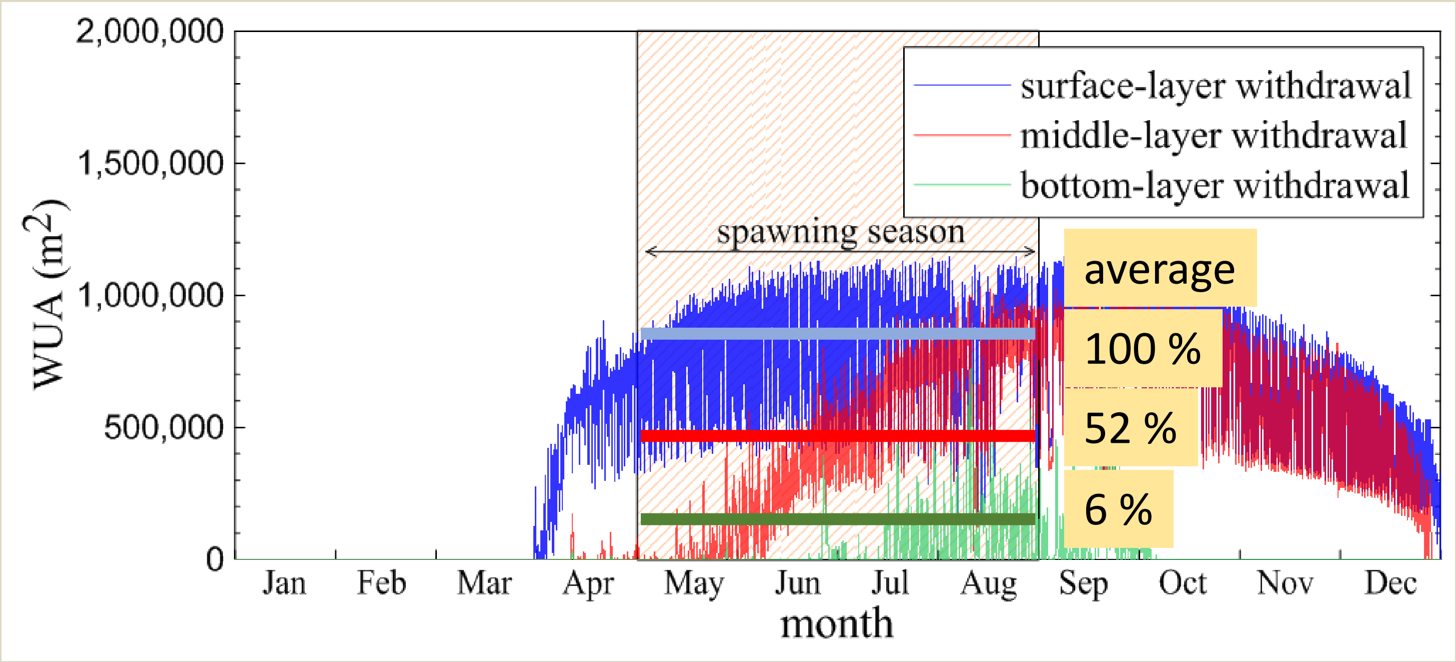
- **The WUA fluctuates daily.**
- **Over a year, the WUA by the surface-layer withdrawal is largest, followed by the middle-layer withdrawal and the bottom-layer withdrawal.**

Seasonal Change of WUAs for Adult *Z. Platypus*



- **The averaged WUA by the surface-layer withdrawal is largest, followed by the averaged WUAs by the middle-layer withdrawal and by the bottom-layer withdrawal.**
- **The only exception was in the spring. This is due to that water temperature in the middle and bottom layers are almost same.**

Annual Change of the WUA for Spawning *Z. platypus*



- The WUA by the surface-layer withdrawal, starting to increase from April, were high from May to October. This period of high WUA includes the spawning season.
- WUAs by all withdrawal operations were zero from January to March, indicating that the study area did not provide suitable habitats to spawning *Z. platypus*.

Conclusion 1

- An upstream dam affects downstream fish habitat via hydropeaking, thermopeaking, and cold-water release.
- Highly turbid water occurred ocasionally in large reservoirs in Korea, which necessitates the building the selective withdrawal structures.
- Our idea was to use the selective withdrawal structure to reduce the ecological impact of cold-water release from the upstream dam.

Conclusion 2

- **We performed PHS for adult and spawning Zacco platypus.**

- **Results indicated that habitat for both adult and spawning *Z. platypus* was most suitable for the surface-layer withdrawal, followed by the middle- and bottom-layer withdrawals.**

- **The surface layer withdrawal increased WUA by 45% in the spring compared with the middle- and bottom-layer withdrawals.**

- **The present study indicated that fish habitat in the regulated streams can be degraded seriously due to cold water release, but its impact can be reduced to some extent by the use of the selective withdrawal.**

Thank you.