RECONSTRUCTING REALITY IN WATERSHED MODELING: TOWARD PHYSICAL REALISM AND PROCESS-REFLECTIVE SWAT APPLICATIONS

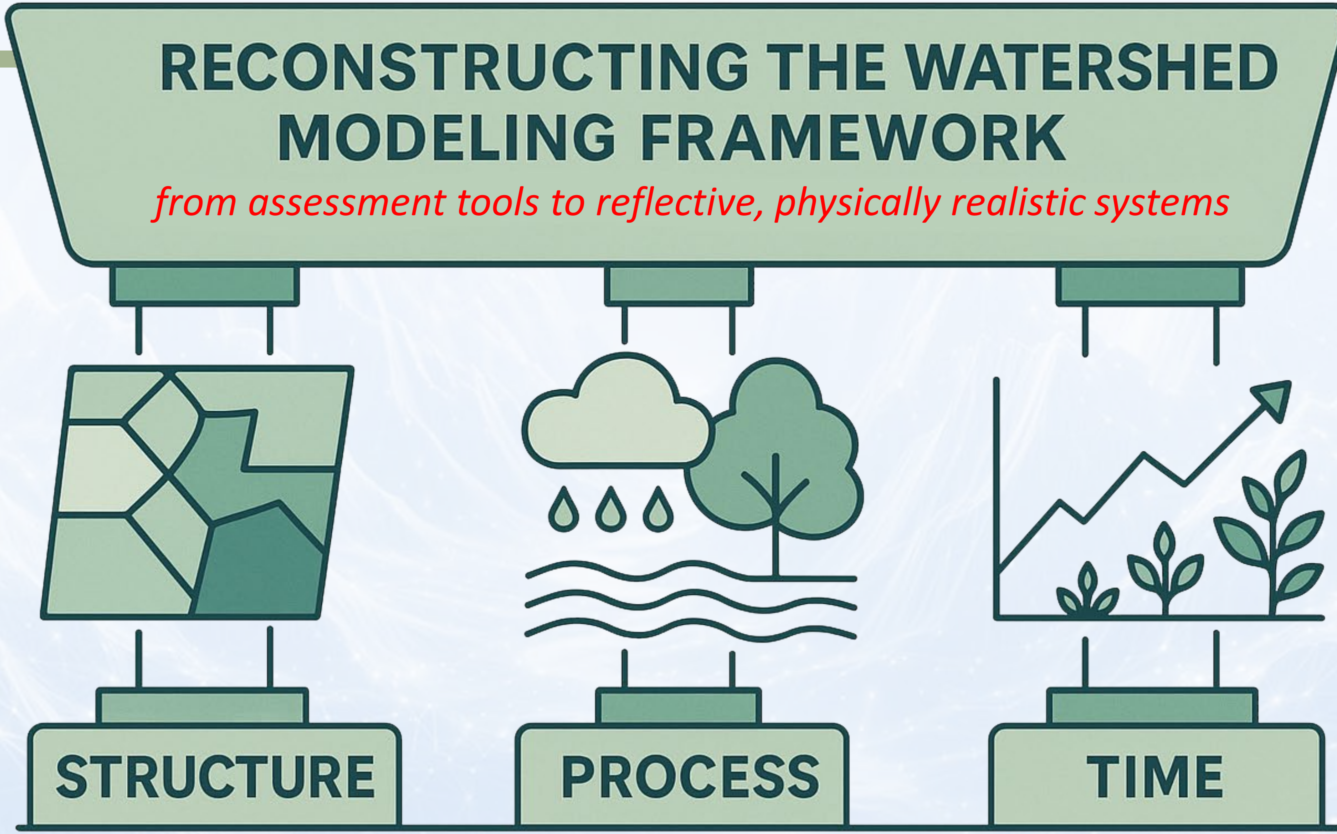
Kunyang Wang

Graduate School of Advanced Science and Engineering, Hiroshima University, 1-7-1 Kagamiyama, Higashi-Hiroshima, Hiroshima 739-8521, Japan

MODELING IN A COMPLEXIFYING WORLD

- Our *understanding* of watershed systems has deepened: Increasingly complex, coupled watershed systems.
- Our *necessary* of watershed study have become more complicated： Driven by climate extremes and increasingly comprehensive human activities.
- Our *management* goals have expanded: from prediction to resilience, equity, sustainability.
- Our *modeling framework* must evolve to match this rising complexity.

🤔→ We must move beyond static, simplified representations.



🔷 *Structural Reconfiguration*

Represent real-world spatial heterogeneity

E.g., dynamic imperviousness, lakeshore boundaries

🔴 *Process Decomposition*

Unpack hydrological fluxes into interpretable components

E.g., canopy evaporation vs. transpiration vs. soil evaporation

⏳ *Temporal Dynamism*

Integrate long-term changes in vegetation, land use, and groundwater

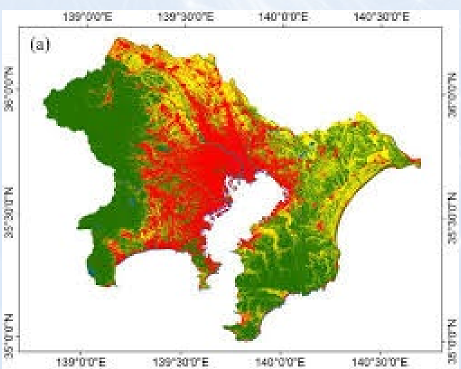
E.g., LAI time series, interdecadal recharge response

RECONFIGURING URBAN WATERSHEDS

the role of dynamic imperviousness

- Urbanization alters hydrological structure beyond land cover categories
- Static LULC maps miss internal heterogeneity of urban space
- Introduced **time-varying Percent Imperviousness of Urban surface (PIU)** to represent evolving urban surface

Residential area in Nara city

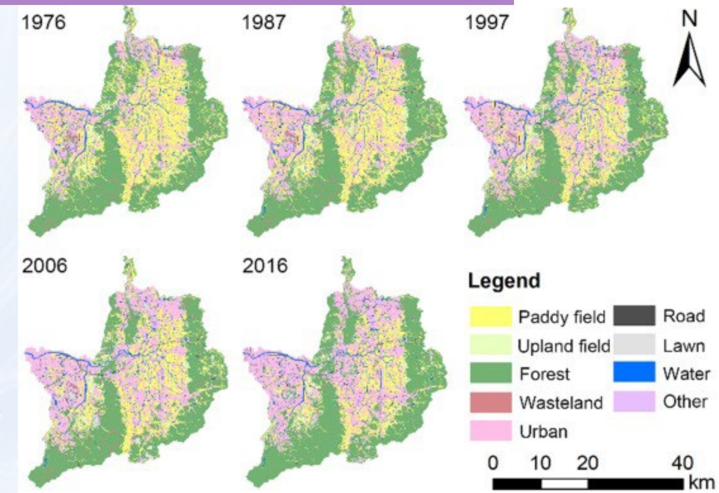


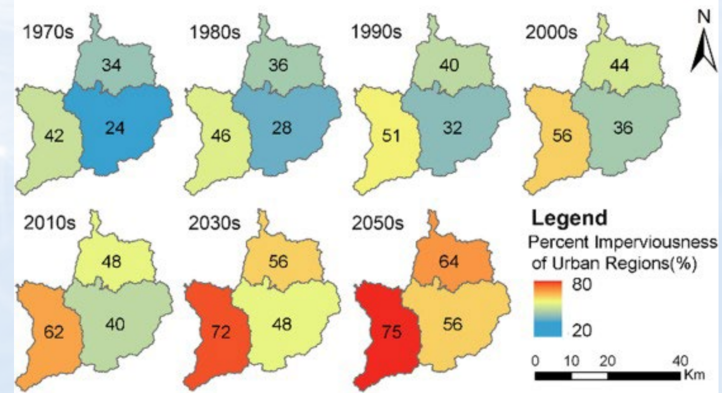
Low PIU → High PIU

Residential area in Osaka city

MODELING DYNAMIC URBAN IMPERVIOUSNESS

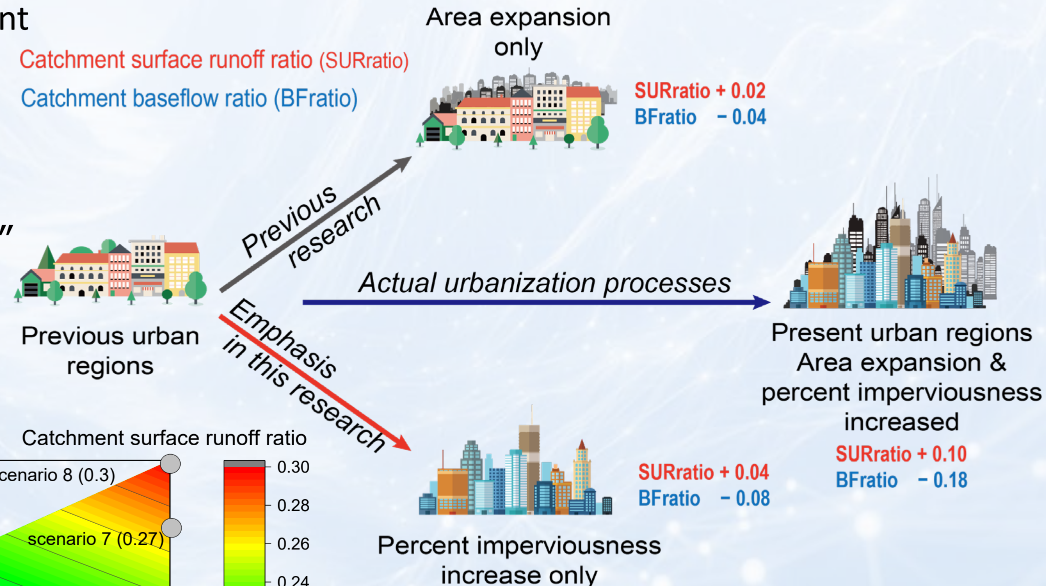
- **Remote Sensing Mapping**
  - Landsat images (1976–2016)
  - Visual interpretation of imperviousness
- **PIU & PIC Parameterization**
  - PIU = total impervious surface / urban area
  - PIC = directly connected impervious area / urban area
- **SWAT Integration**
  - Assigned PIU/PIC by sub-catchment
  - Modified CN2 to reflect composite urban runoff behavior

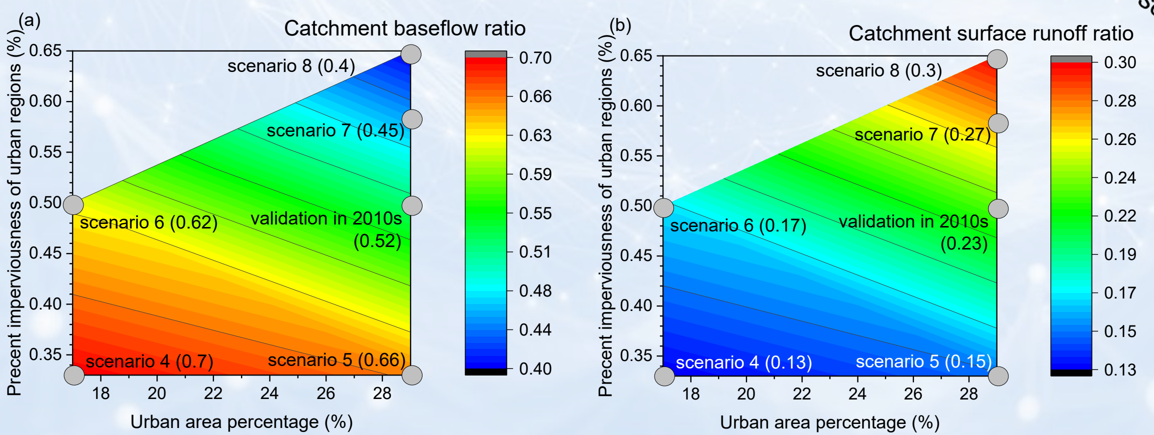




RESULTS: SURFACE–BASEFLOW PARTITIONING SHIFT WITH URBAN DENSITY

- PIU increase from 0.33 → 0.50 led to catchment SFR ratio +0.04 and BF ratio −0.08
- Baseflow decreased in high-PIU zones despite same land use class
- Spatial contrasts between "low-density urban" and "high-density urban" clearly reflected in hydrographs

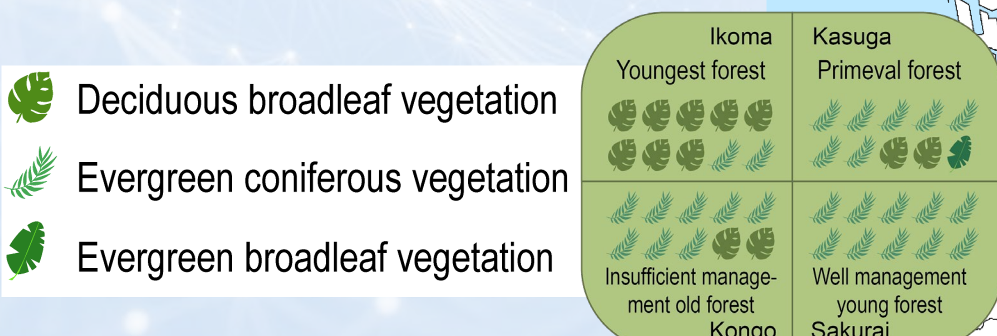


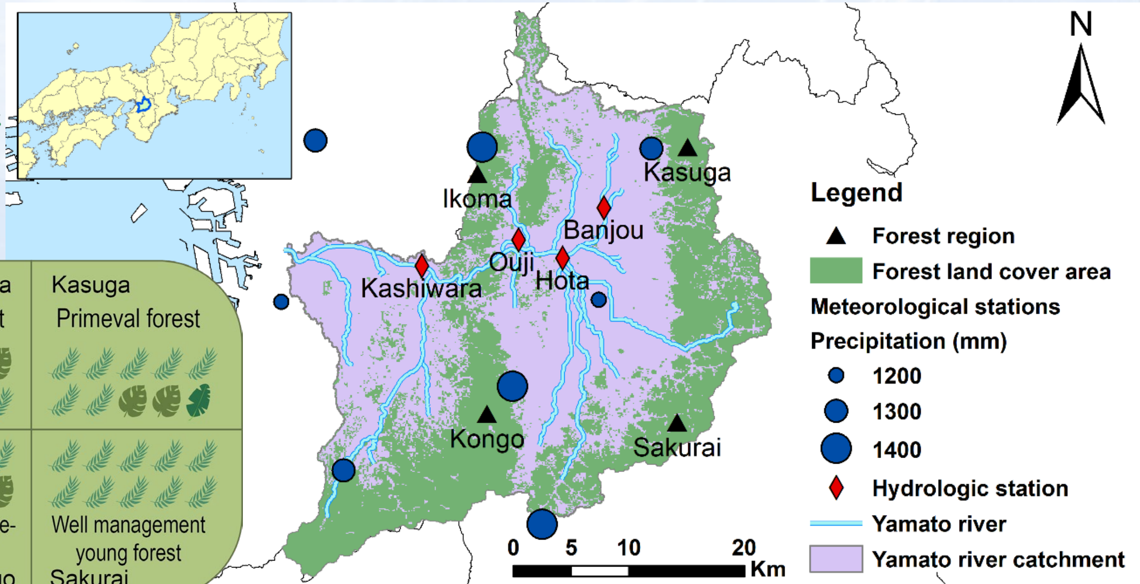


FOREST GROWTH ALTERS CANOPY DENSITY

beyond urban, ecosystems densify too

- Forest systems undergo density changes over time (e.g., aging, succession, management)
- Vegetation type itself matters—different forest types have inherently distinct canopy structures
- We used remote sensing LAI to quantify both temporal growth and spatial heterogeneity





SEPARATING EVAPOTRANSPIRATION

canopy evaporation, transpiration, and soil evaporation

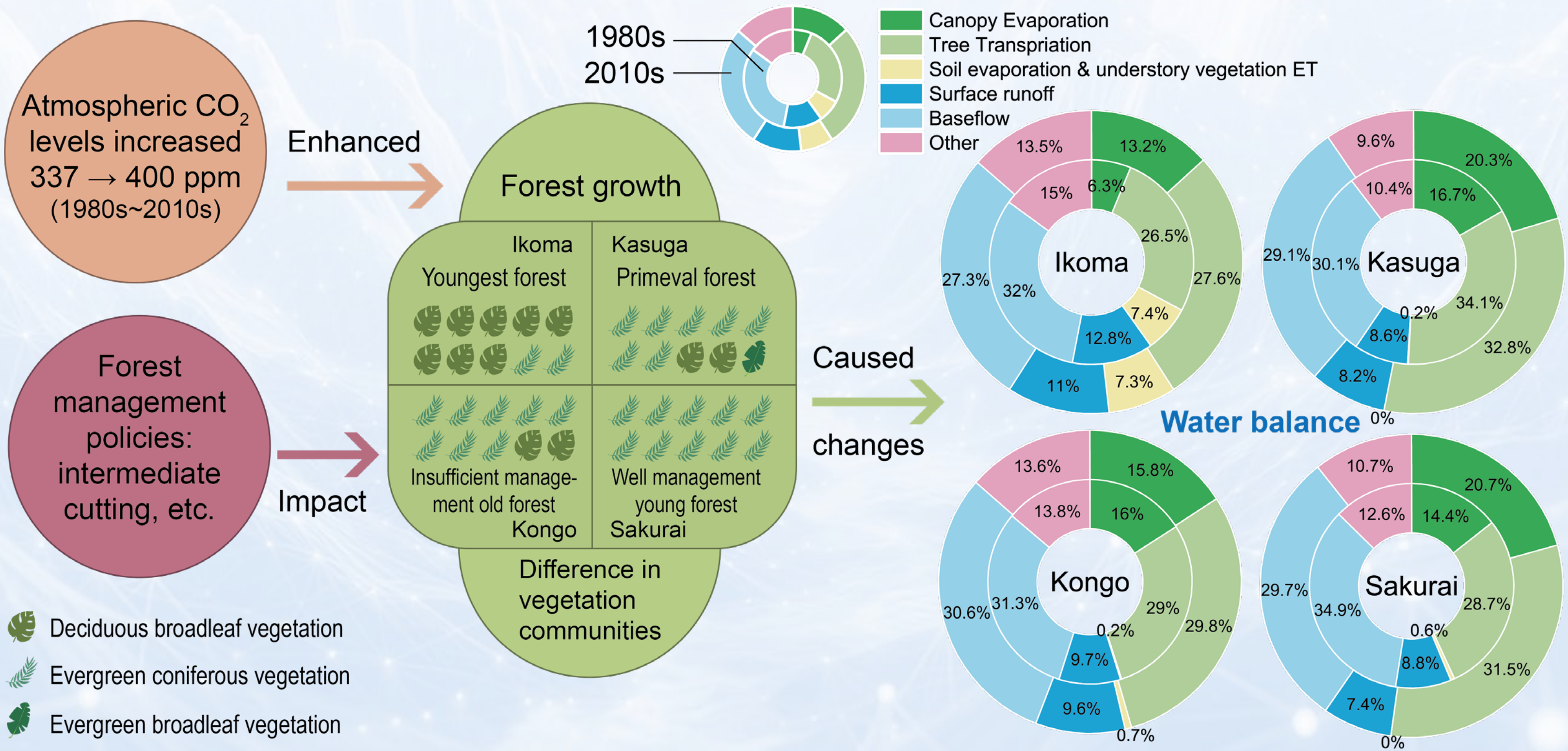
- We modified SWAT to **explicitly separate**:
  - ✓ **Canopy evaporation (E_{can})**
  - ✓ **Transpiration (T)**
  - ✓ **Soil evaporation (E_s)**

- 1) Calculate the actual free water held in the canopy.
  - if $R_{day} + can_0 \geq can_{day}$: $can_t = can_{day}$
  - if $R_{day} + can_0 < can_{day}$: $can_t = R_{day} + can_0$

- 2) Calculate the canopy evaporation E_{can}.
  - if $can_t \geq ET_{day}$: $E_{can} = ET_{day}$, $can_0' = can_t - ET_{day}$, $ET' = 0$
  - if $can_t < ET_{day}$: $E_{can} = can_t$, $can_0' = 0$, $ET' = ET_{day} - E_{can}$

- 3) Estimate tree transpiration T, soil evaporation and understory vegetation evapotranspiration E_s ($ET' > 0$).
  - if $LAI \geq 3$: $T = ET'$, $E_s = 0$
  - if $LAI < 3$: $T = ET' \cdot \frac{LAI}{3}$, $E_s = ET' - T$

RESULTS: FOREST GROWTH ALTERS WATER PARTITIONING

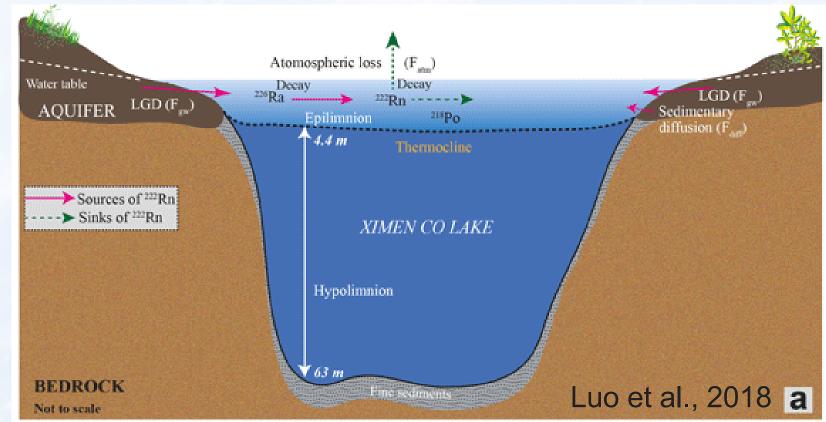


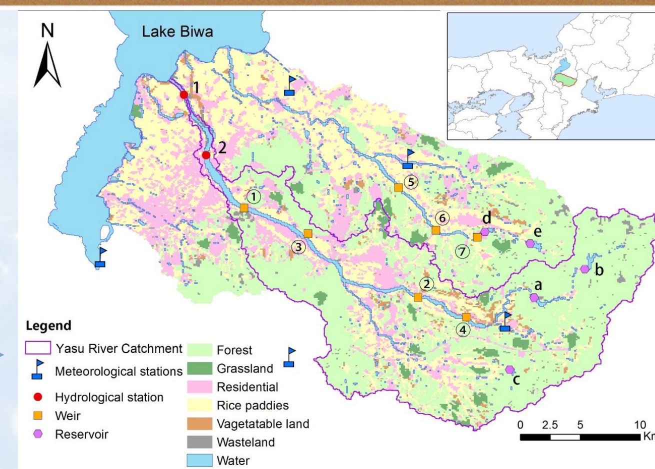
- Forest ET increased significantly since the 1980s due to CO_2 fertilization & forest aging
- Transpiration dominated in mature managed forests; canopy evaporation dominant in dense unmanaged zones

MODELING LAKESHORE PLAINS UNDER DATA SCARCITY

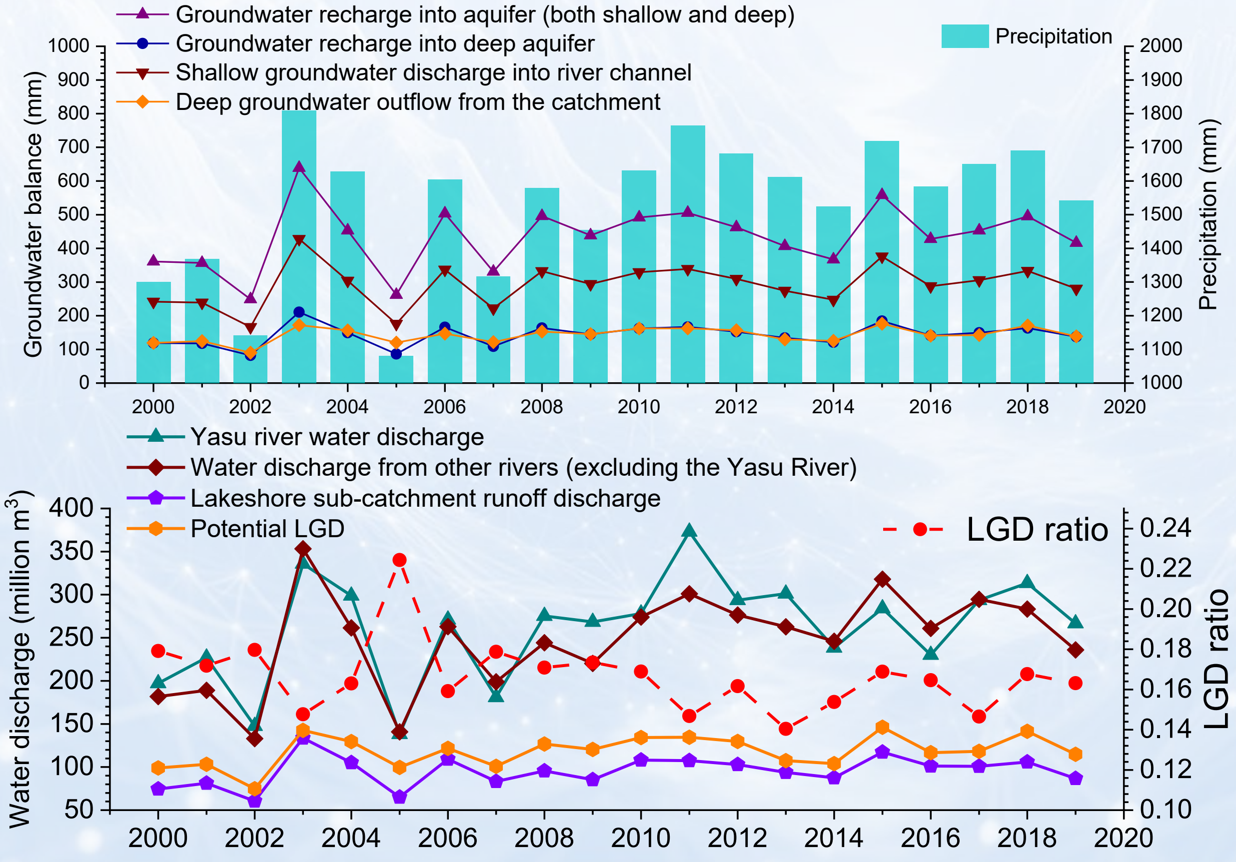
reconstructing the invisible

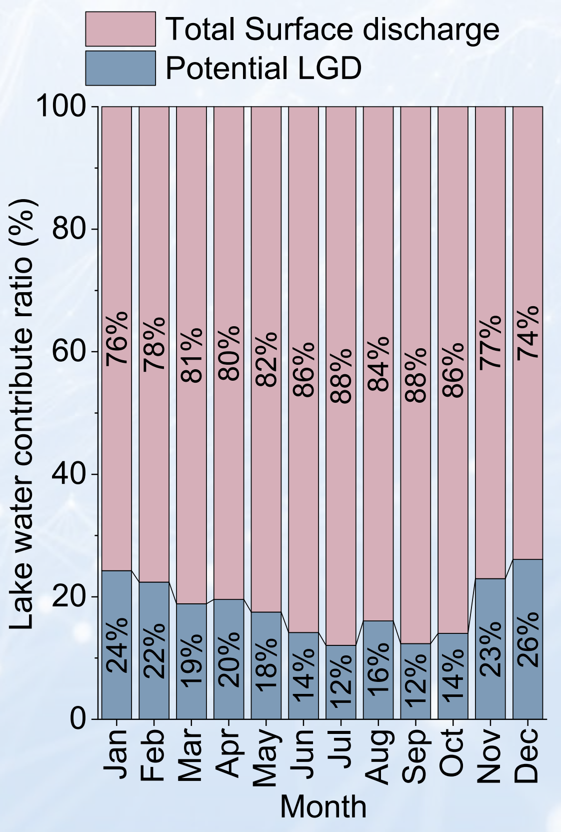
- ## Why It Matters
- **LGD (Lacustrine Groundwater Discharge)**: Key to lake water balance and climate resilience
- ## Why It's Challenging
- **MODFLOW needs deep, site-specific data**
  - Aquifer structure
  - Long-term GW observations
  - Conductivity, boundaries
- These are often **unavailable or not enough**
- ## Our Strategy
- ✓ Use SWAT with RCPs





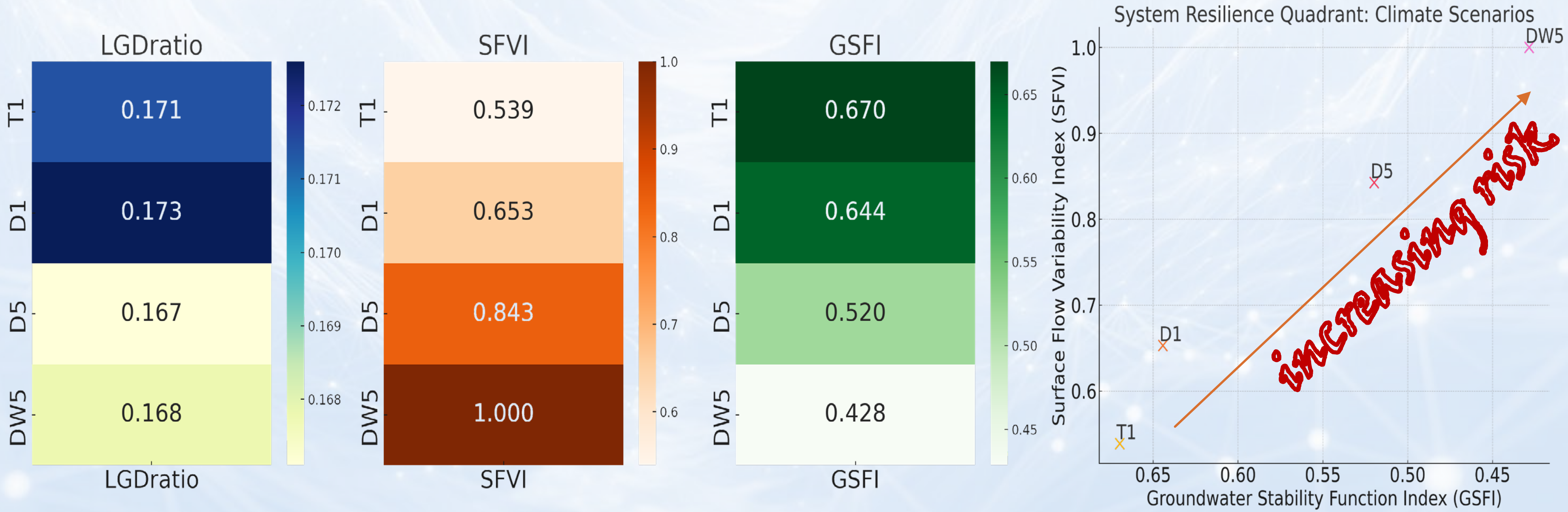
RESULTS: SPATIAL AND SEASONAL DYNAMICS OF LACUSTRINE GROUNDWATER DISCHARGE





GROUNDWATER–SURFACE WATER RESILIENCE UNDER CLIMATE CHANGE SCENARIOS

- ***LGDratio****: Proportion of lake inflow sustained by lacustrine groundwater discharge (LGD)*
- ***SFVI****: Surface Flow Variability Index – interannual variability of surface contribute*
- ***GSFI****: Groundwater Stability Function Index – resilience of LGD*



T1: Temperature rises slightly; D1: T1 + more severe drought; D5: D1 + higher temperature; DW5: D5 + more flash flood

RECONSTRUCTING REALITY IN WATERSHED MODELING

What We Challenged

① Static imperviousness assumptions miss urban evolution

② Forest growth and type ignored in long-term ET balance

③ Lakeshore groundwater dynamic modeling using SWAT

Hydrological Modeling
as a Lens on Catchment Realities

Where This Leads

① Climate-aware and land-sensitive configuration

② Physically reflective model structure and flexible under data limitations

③ Supports resilient, mechanism-aware water management

Beyond prediction—used to explain changes

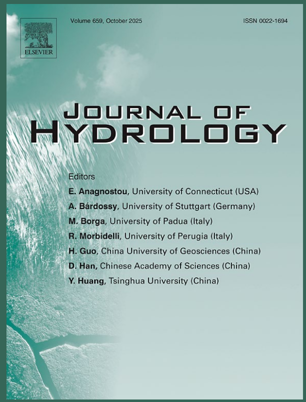
Integrates climate, land, and human drivers

Tailored for spatiotemporal complexity and realism

Reveals not just that change is happening—but how, where, why and to what extent

THANK YOU FOR YOUR ATTENTION

Dr. Kunyang Wang (Hiroshima University)



Wang, K., Onodera, S. I., Saito, M., & Shimizu, Y. (2021). Long-term variations in water balance by increase in percent imperviousness of urban regions. *Journal of Hydrology*, *602*, 126767.
Wang, K., Onodera, S. I., Saito, M., & Ishida, T. (2022). Assessment of long-term phosphorus budget changes influenced by anthropogenic factors in a coastal catchment of Osaka Bay. *Science of the Total Environment*, *843*, 156833.