XVIII World Water Congress
International Water Resources Association (IWRA)

Cascade reservoirs adaptive refined simulation model based on the mechanism-AI coupling modeling paradigm

基于机理-AI耦合建模范式的梯级水库自适应精细化模拟模型

Boran Zhu

China Institute of Water Resources and Hydropower Research

XVIII WORLD WATER CONGRESS
Water for All
Harmony between Humans and Nature
第18届 世界水资源大会
水与万物:
人与自然和谐共生

XVIII World Water Congress
International Water Resources Association (IWRA)

Content

- Research background
- Method
- Mode application
- Discussion

Research background

- Cascade development has become the main form of basin hydropower resources utilization, and has made important contributions to the development of Low-carbon economy.
- The operation of cascade reservoirs faces various complex working conditions such as extreme natural conditions and engineering failures. Understanding the operating characteristics of cascade reservoirs under various complex working conditions helps to ensure the safe and stable operation of the system.

Cascade reservoir

Operating condition

landslide

exceeding standard flood

generator malfunction

Spillway failure

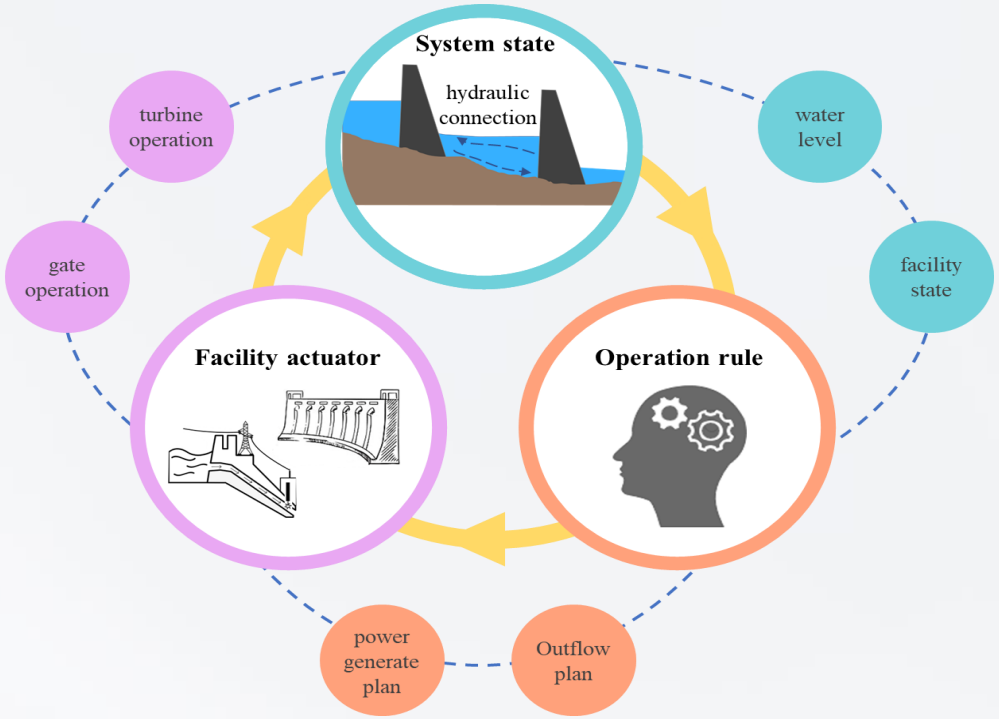
Research background

XVIII World Water Congress
International Water Resources Association (IWRA)

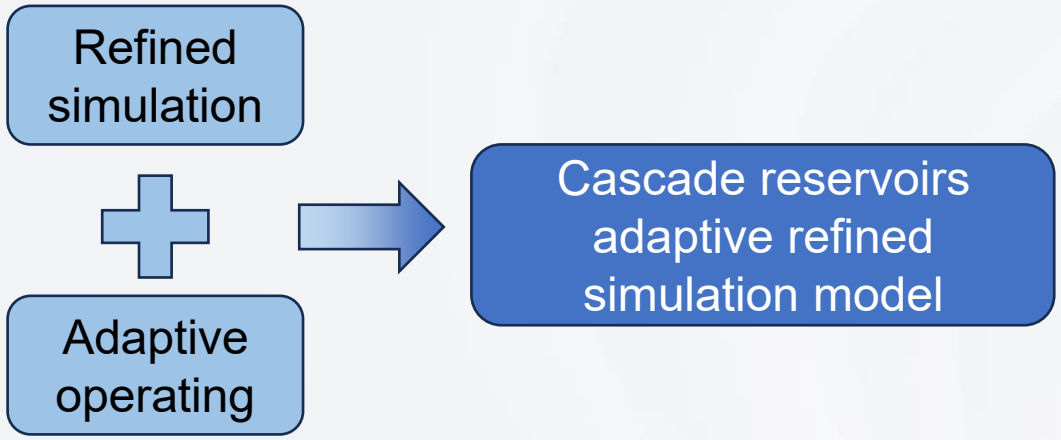
Important means of reservoir operation research—Simulation

- Many general simulation models developed based on physical processes cannot reflect the dynamic processes of the internal operation of the system, and lack refined simulation of the internal system.
- System dynamics method can reflect the complex structure inside the cascade reservoir system, but the decision preference for reservoir operation cannot be considered in deterministic rule simulation.

Operation logic of cascade reservoir



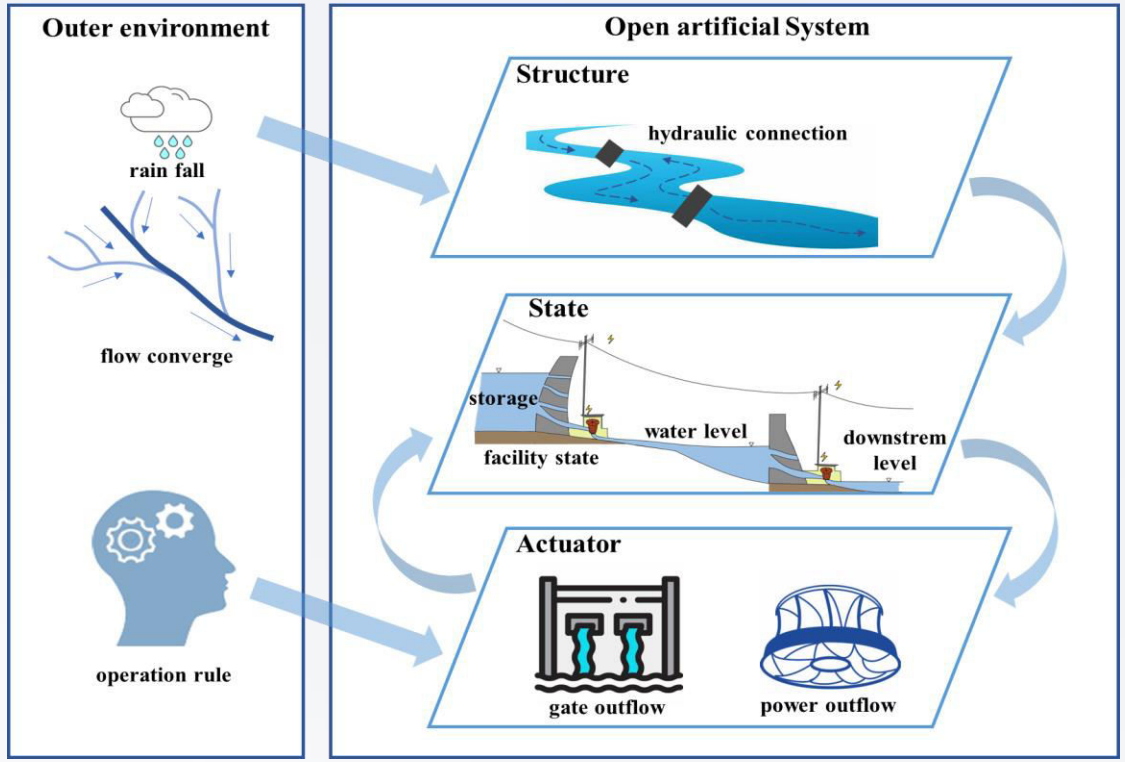
Research objective



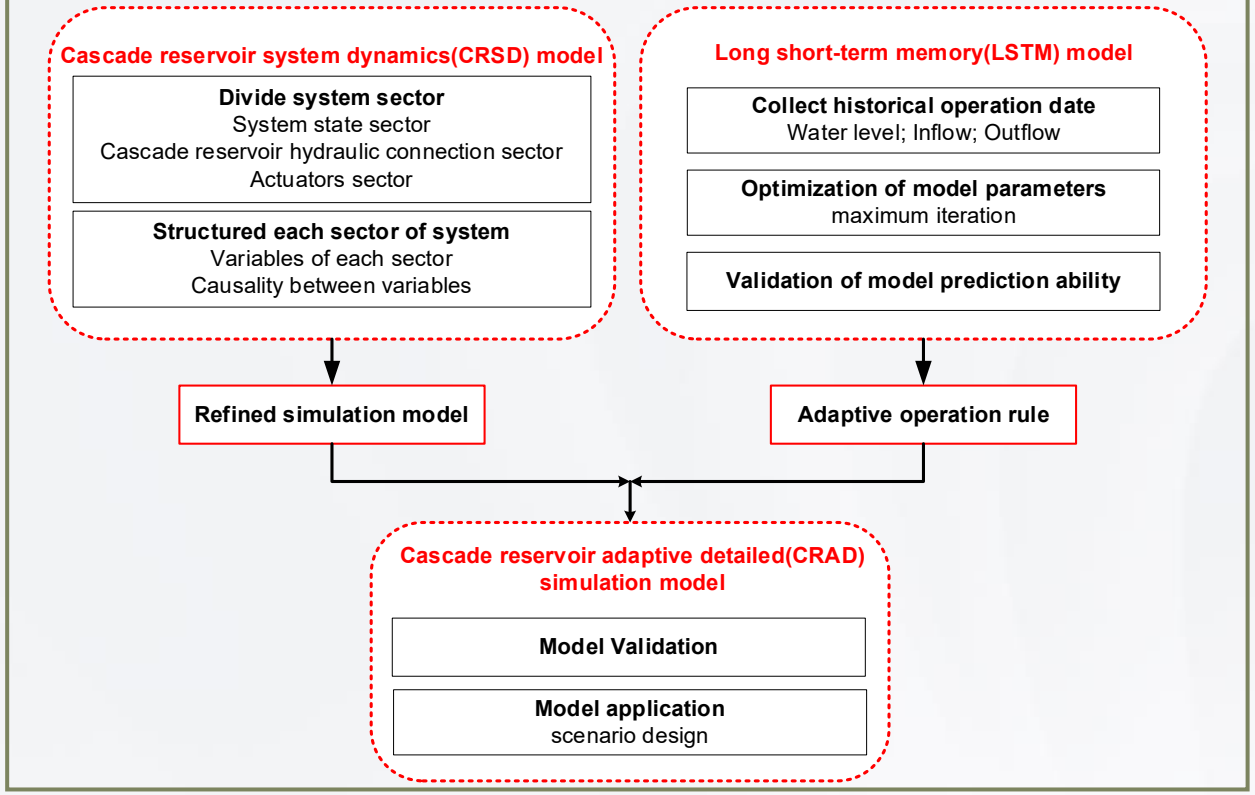
Method

- Cascade reservoir operation process can be seen as an interactive process between the external environment (rainfall runoff process) and open artificial systems. Structure, state, and actuator are the typical three dimensions that describe artificial systems.
- This study uses system dynamics methods to refine the characterization of artificial systems, extracts adaptive operating rule for reservoirs using AI model, and couples them to construct adaptive refined simulation model for cascaded reservoir.

Cascade reservoir operation process



Model construction framework



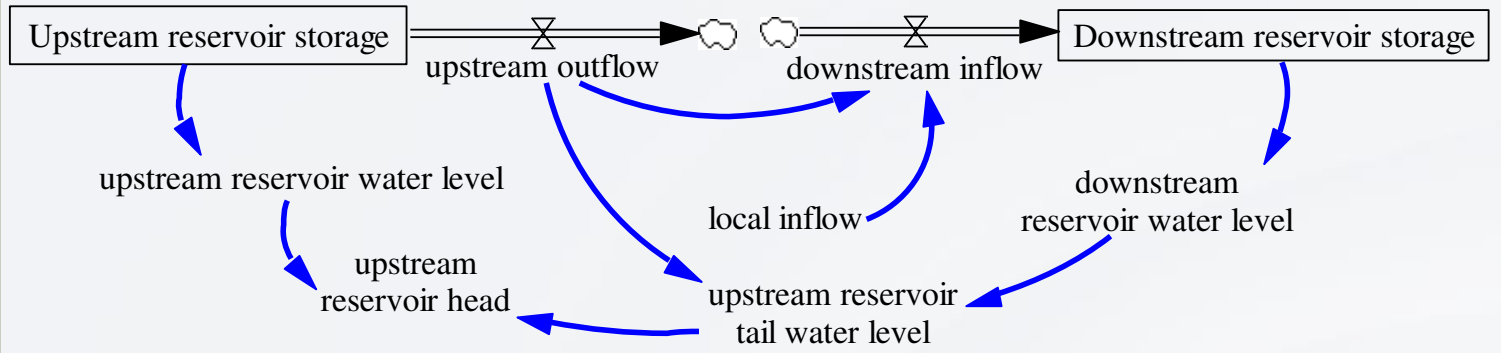
Method

XVIII World Water Congress
International Water Resources Association (IWRA)

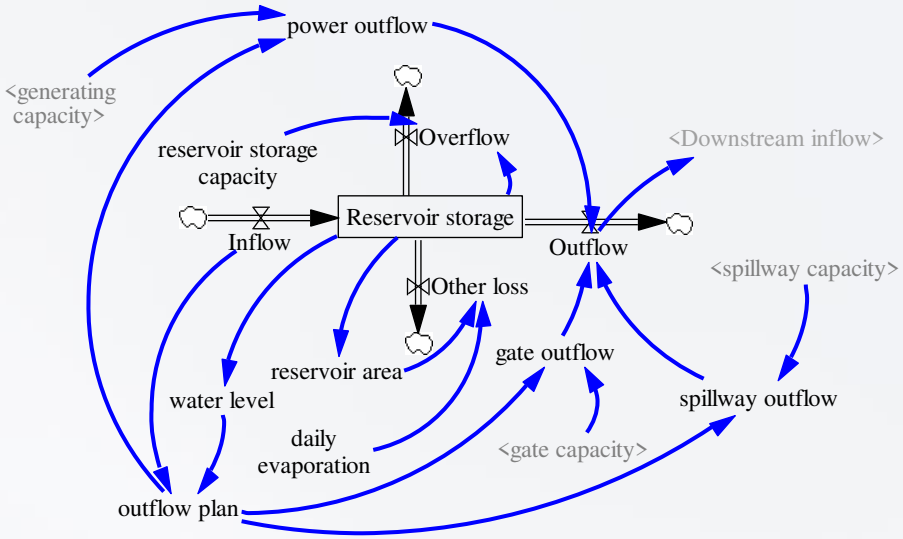
Cascade reservoir system

- System structure
- System state
- Actuator

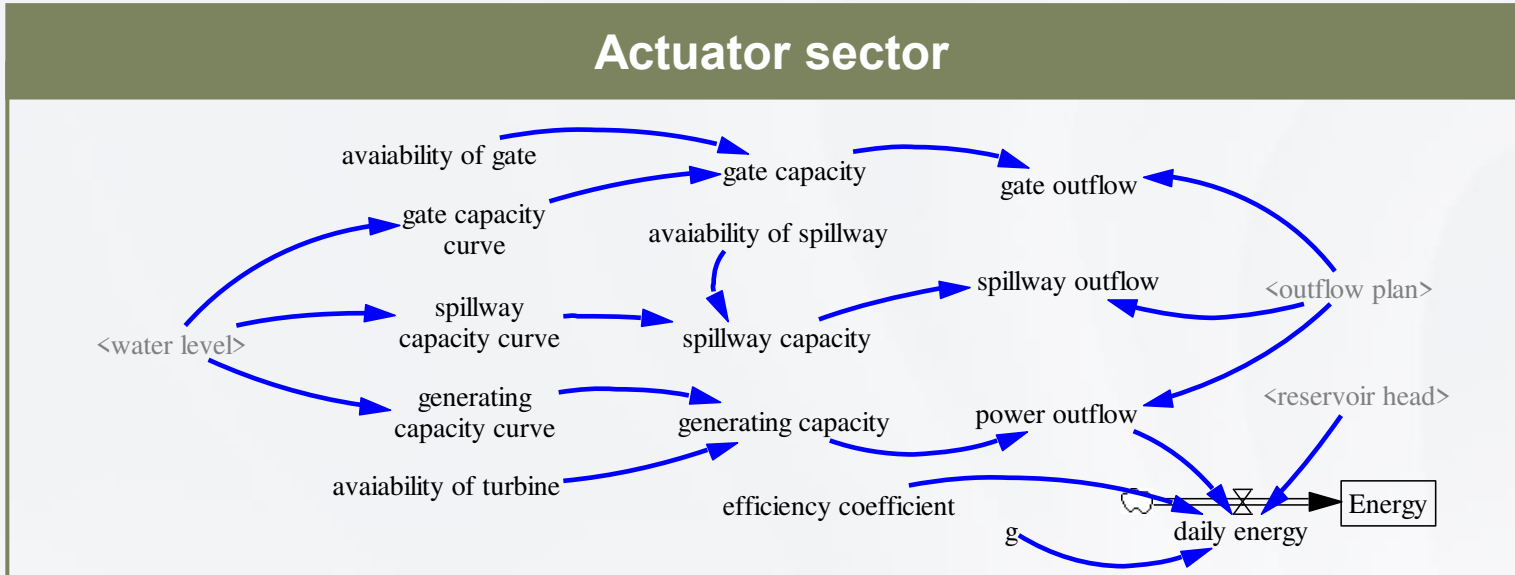
System structure sector



System state sector



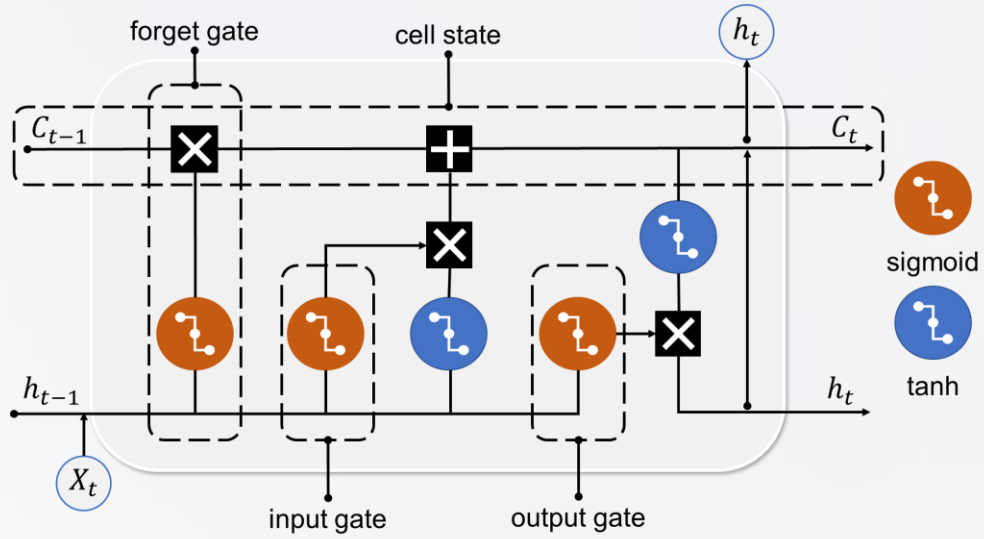
Actuator sector



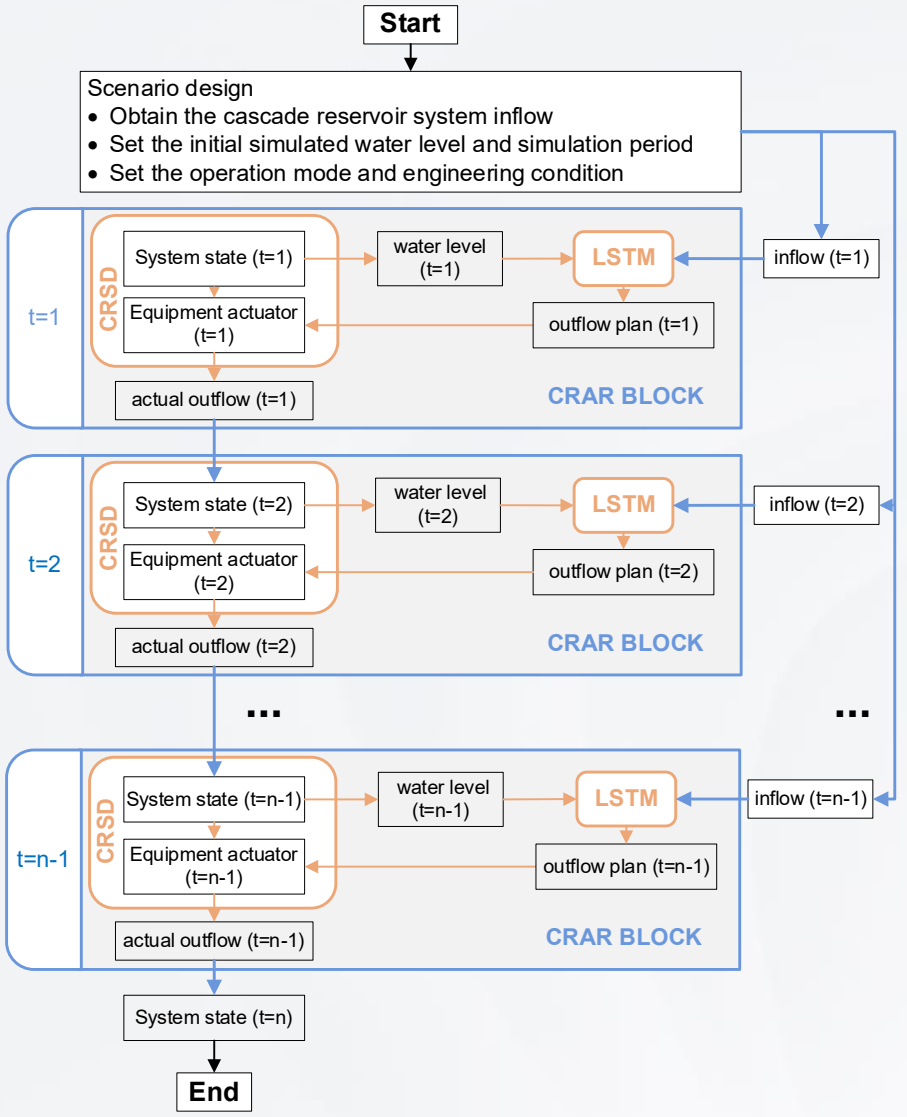
Method

- The LSTM in the AI model is used to extract the reservoir adaptive operating rule.
- Consider the water balance relationship between different time periods, solve the model through sequential cyclic iterative solution method.

Structure of the LSTM cell



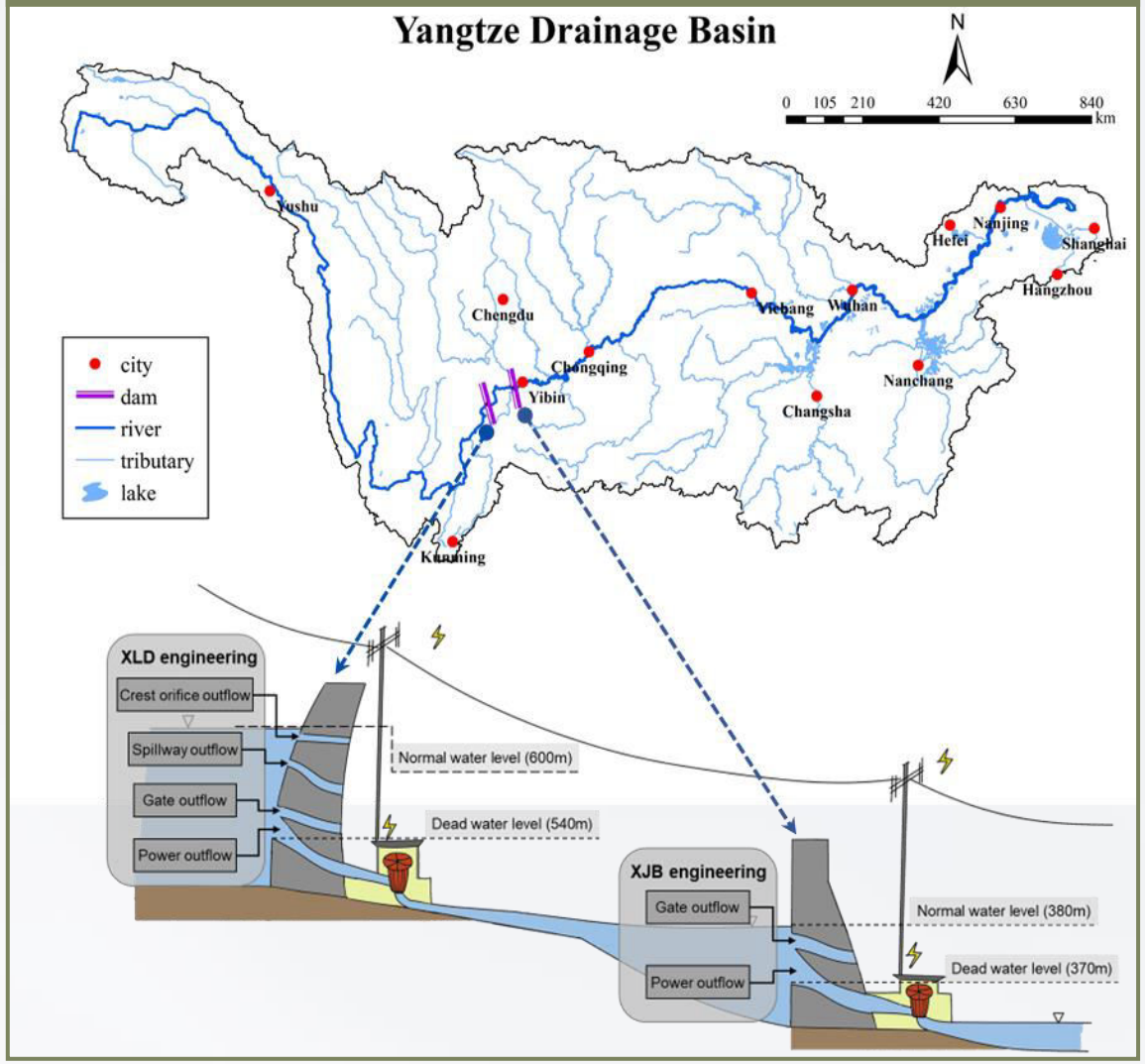
Iterative solution method of the CRAR model



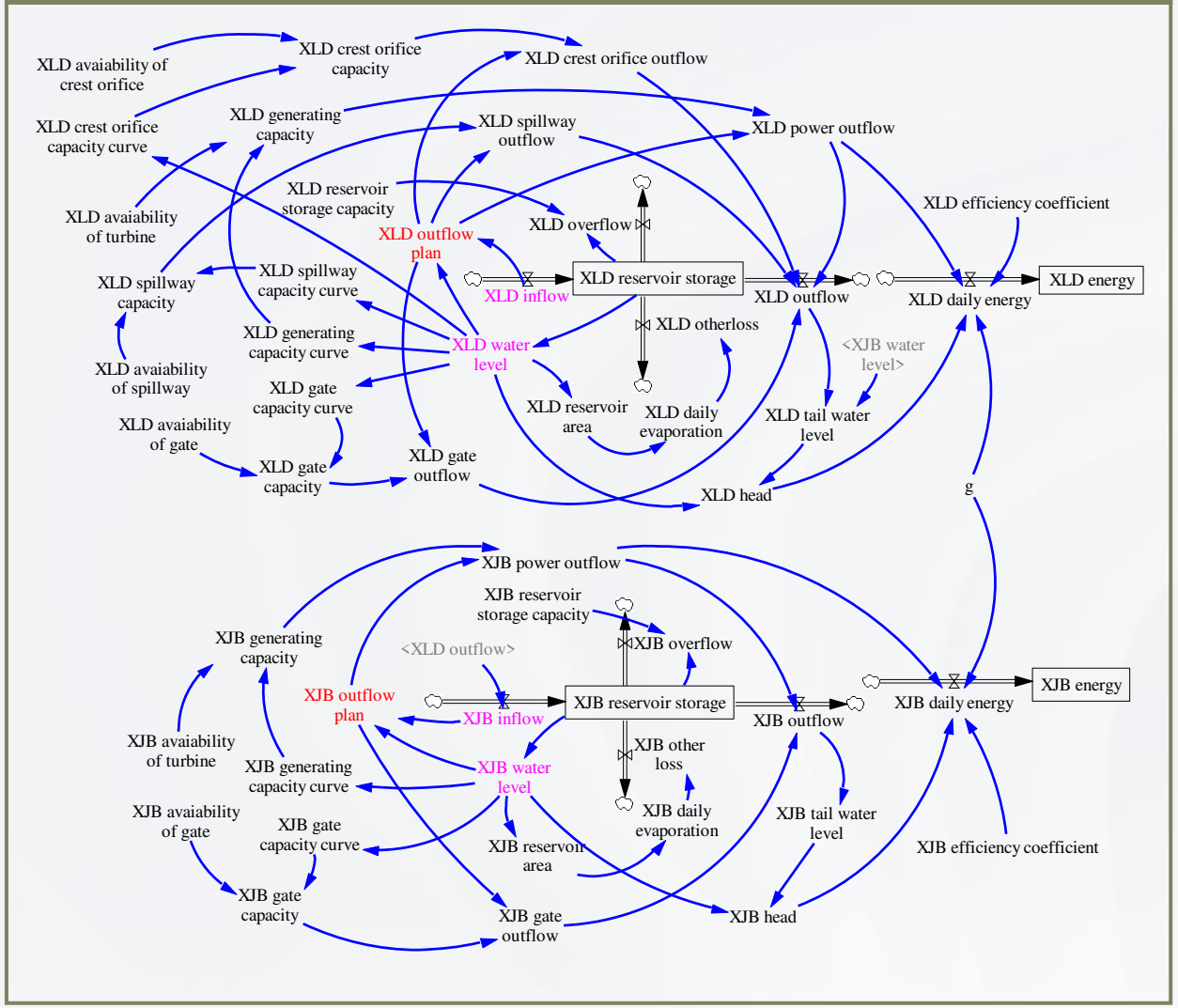
Mode application

XVIII World Water Congress
International Water Resources Association (IWRA)

Study area



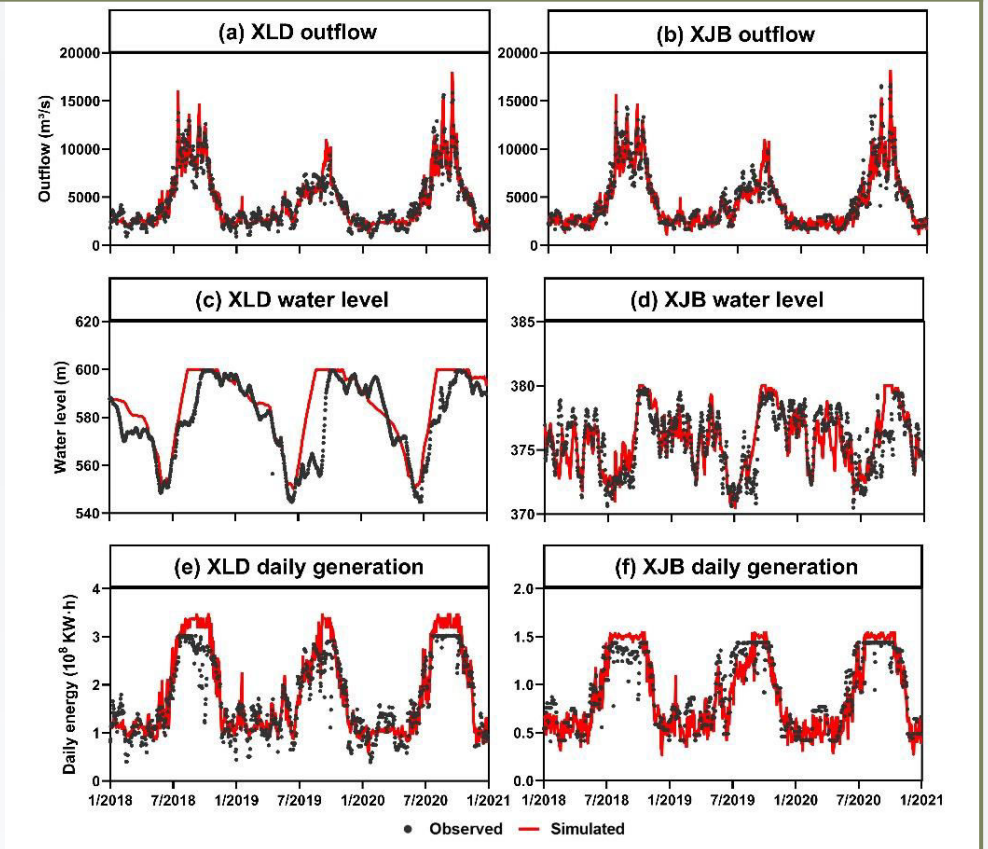
CRAR model of XLD-XJB



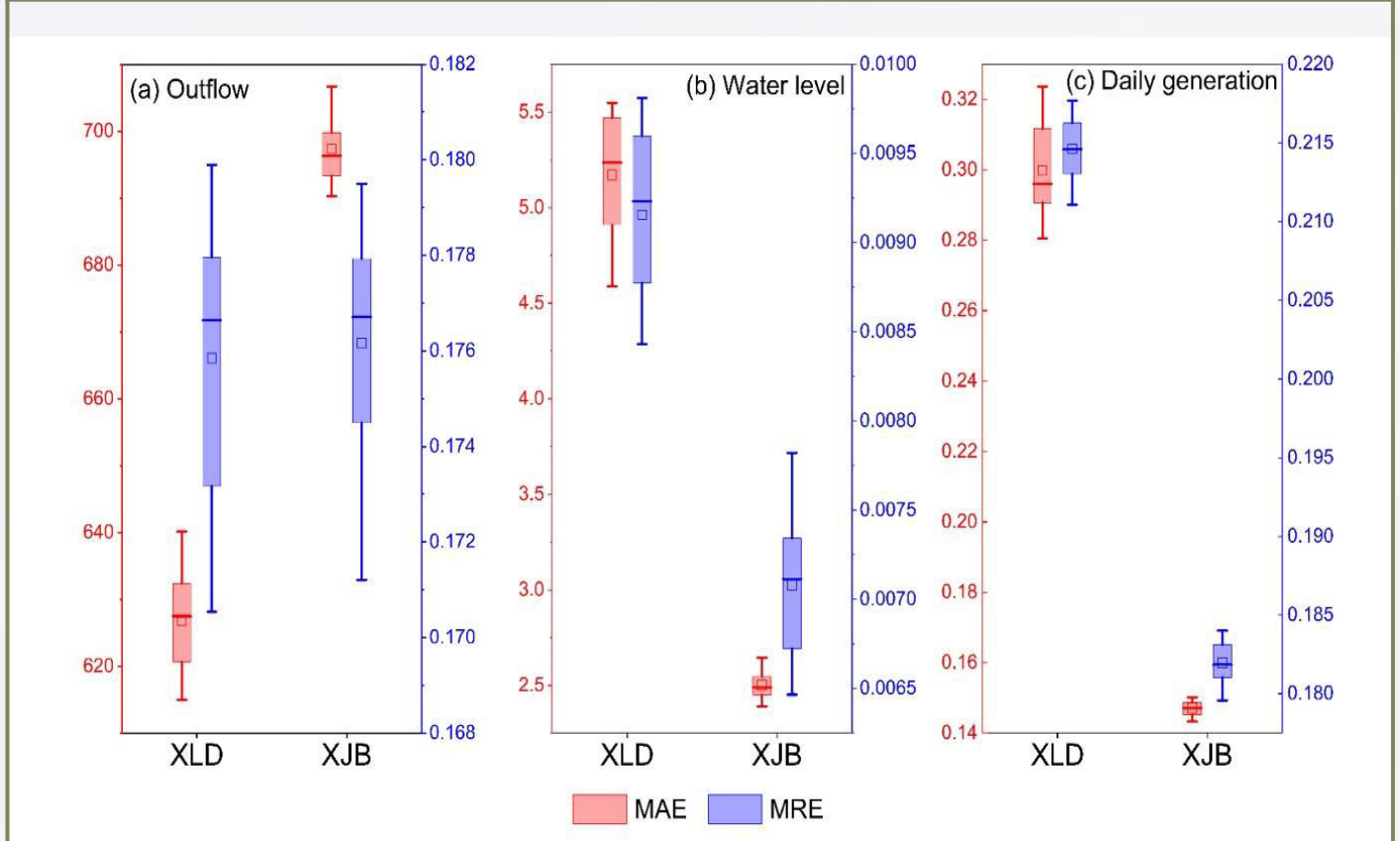
Mode application—Applicability

XVIII World Water Congress
International Water Resources Association (IWRA)

Accuracy of CRAR model



Error of CRAR model



Mode application—Scenario simulation

XVIII World Water Congress
International Water Resources Association (IWRA)

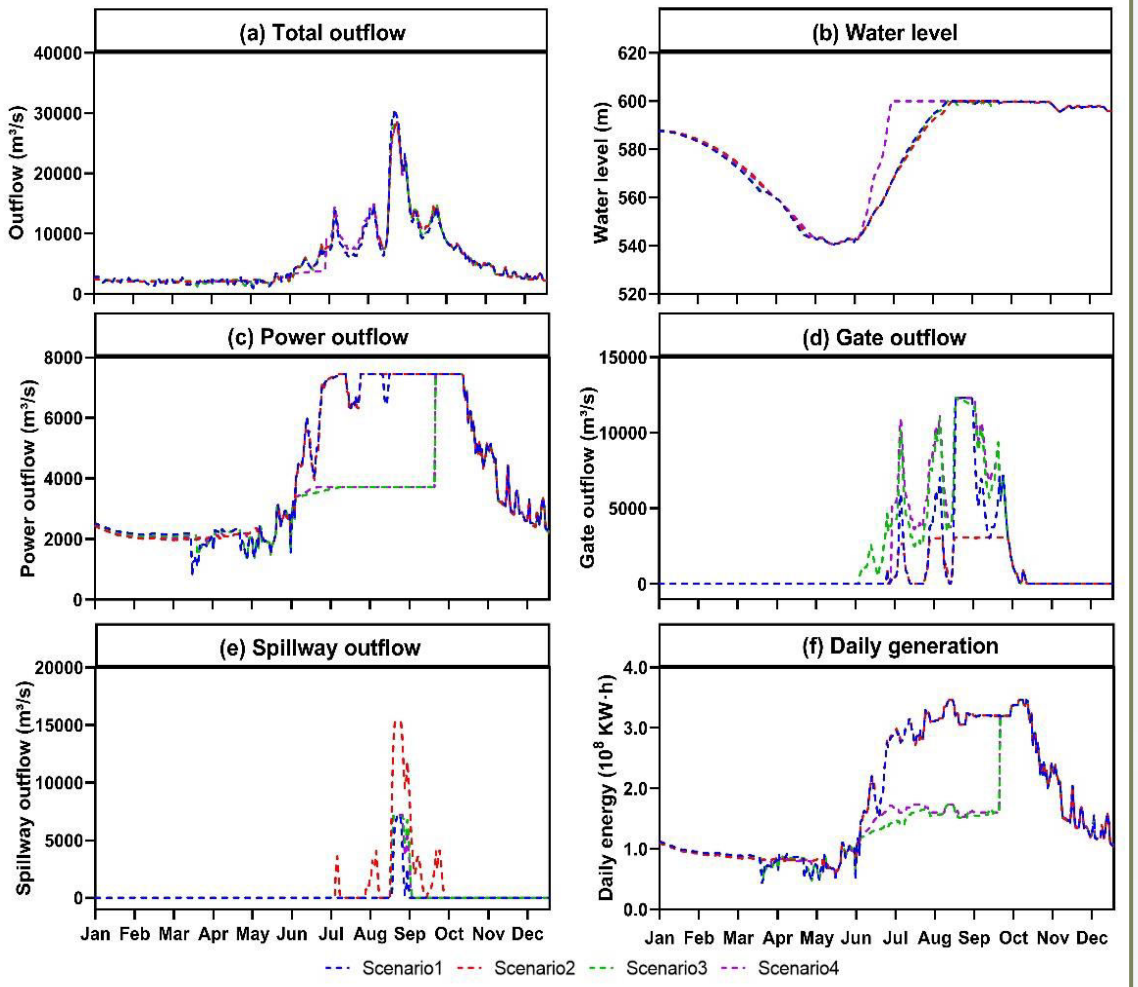
Scenario design

Simulated scenario	Condition of engineering components	Operation mode of discharge facilities
Scenario 1	Functioning well	The power outflow is preferred for both of the two reservoirs. When the planning outflow exceeds the maximum outflow capacity of the generator units, XLD gives priority to the gate outflow, then the spillway outflow, and in XJB, discharge occurs through the gates.
Scenario 2	Functioning well	When the planning outflow exceeds the maximum outflow capacity of the generator units, XLD adopts the operation mode of the discharge facilities coordinated by the gates and spillways. Two gates and all spillways are preferred for outflow, and then other gates are used. The other operation modes of the discharge facilities are the same as Scenario 1.
Scenario 3	At the beginning of the simulation, due to an earthquake, reservoir aging, or other reasons, half of the generator units of the two reservoirs are shut down, and have a nine-month maintenance period.	The same as Scenario 1.
Scenario 4	The same as Scenario 3.	Abandoned water is minimized during the maintenance period. The two reservoirs are controlled so that the normal water level is not exceeded, and no other outflow, except the power outflow, is carried out before the end of the maintenance period. When all generator units resume operation, their operation is carried out according to the planning outflow. The other operation modes of the discharge facilities are the same as Scenario 1.

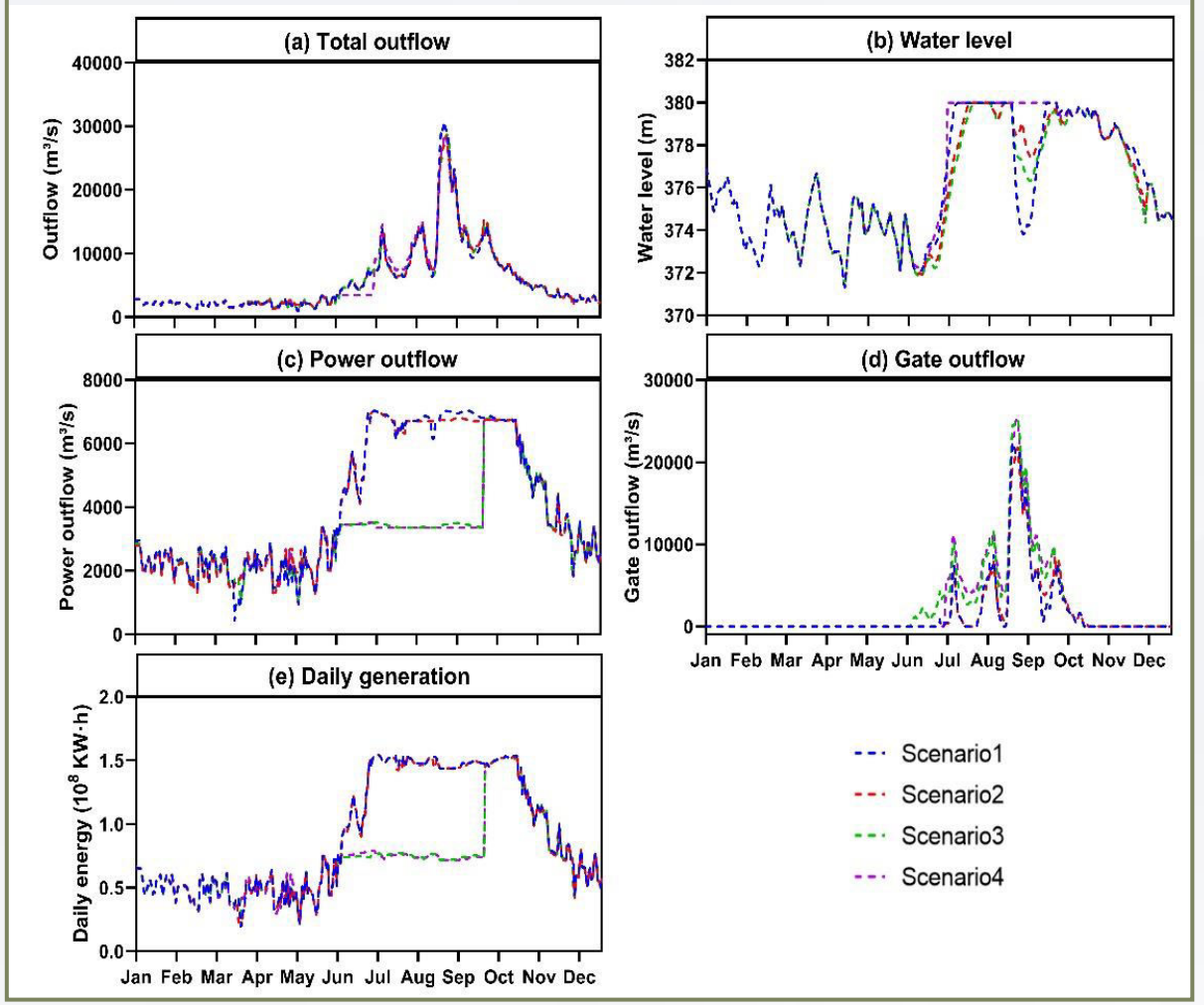
Mode application—Simulated result

XVIII World Water Congress
International Water Resources Association (IWRA)

Results of XLD under four scenarios



Results of XJB under four scenarios



Discussion

Model advantages:

- Intelligibility: Transparent graphical modelling.
- Intellectuality: Artificial Intelligence Method Solving.
- Universality: Universal system composition.
- Extendibility: Fixed model composition forms.

Future research:

- Refine and extend the structure of the model to simulate more complex conditions.
- comparing the rule extraction effects of various AI models and selecting the most appropriate AI model.

XVIII World Water Congress
International Water Resources Association (IWRA)

Thanks for your attention