XVIII World Water Congress

# The Integrated Decision Support System for Three Gorges Included Giant Reservoirs

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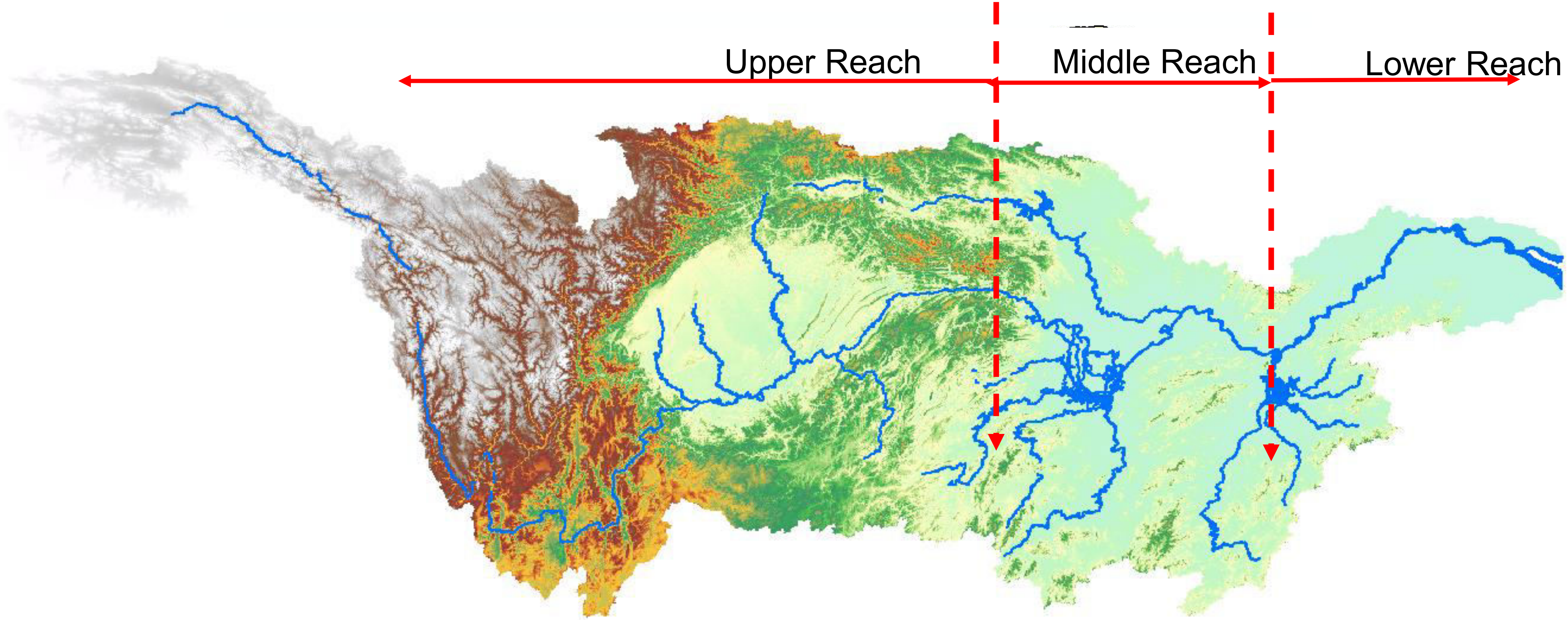
# Topics

1. Background
2. Rule Based Operation
3. Integrated Decision Support System
4. Conclusions

# 01 Background

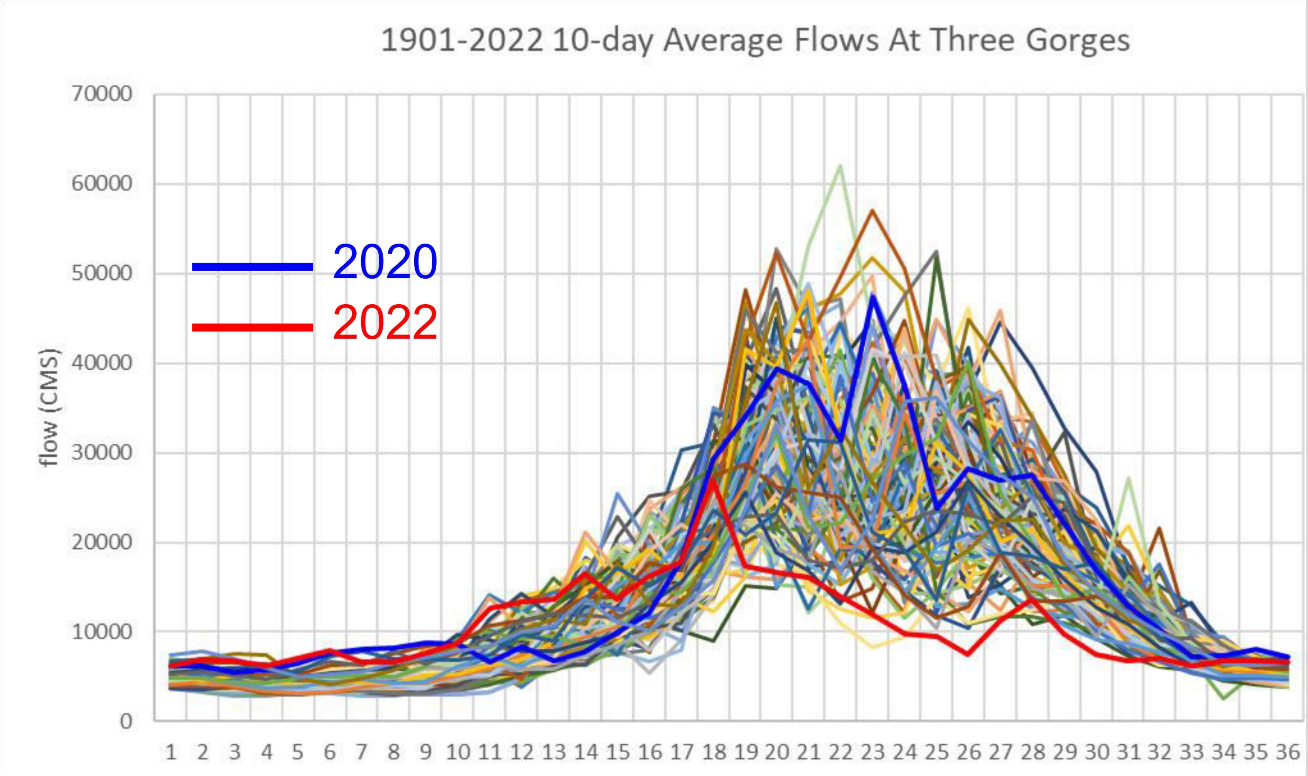
# The Yangtze River Basin

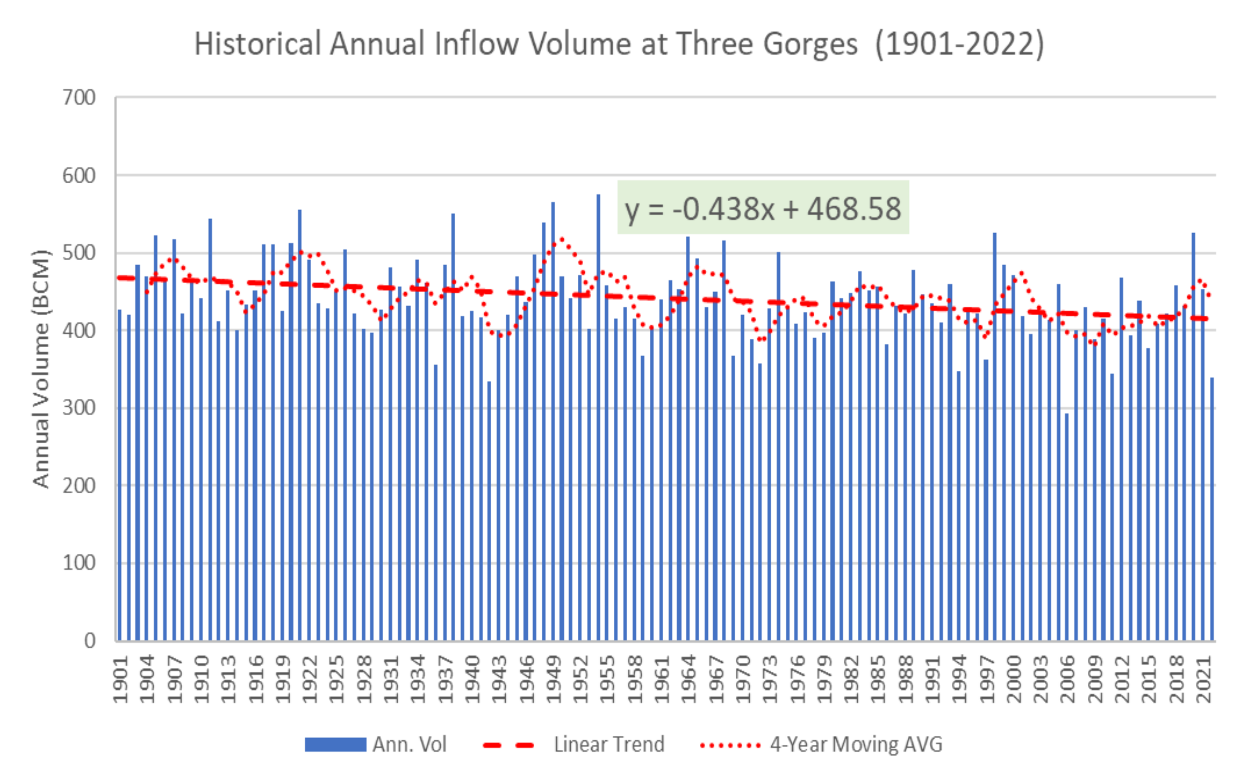
- **Basin Area： 1800 thousand square km, 18.8% national area; crossing 19 provinces.**
  **Length: 6390 km, first in the nation, third in the world.**
- **Annual flow volume: 975.5 bcm， 36% of national total, ranked third in the world.**



# Historical Inflows of Yangtze at Three Gorges

- **Two hydrological seasons: Flood Season (Jun-Sept), Dry Season (Oct-May)**
- **Maximum inter-annual volume difference: 100 %**
- **Long term trend: decreasing at 4.3 bcm/yr**
- **Big flood years since 1900: 1905、1921、1931、1935、1949、1954、1998、2020**



# Historical Flood Years in the Yangtze River Basin

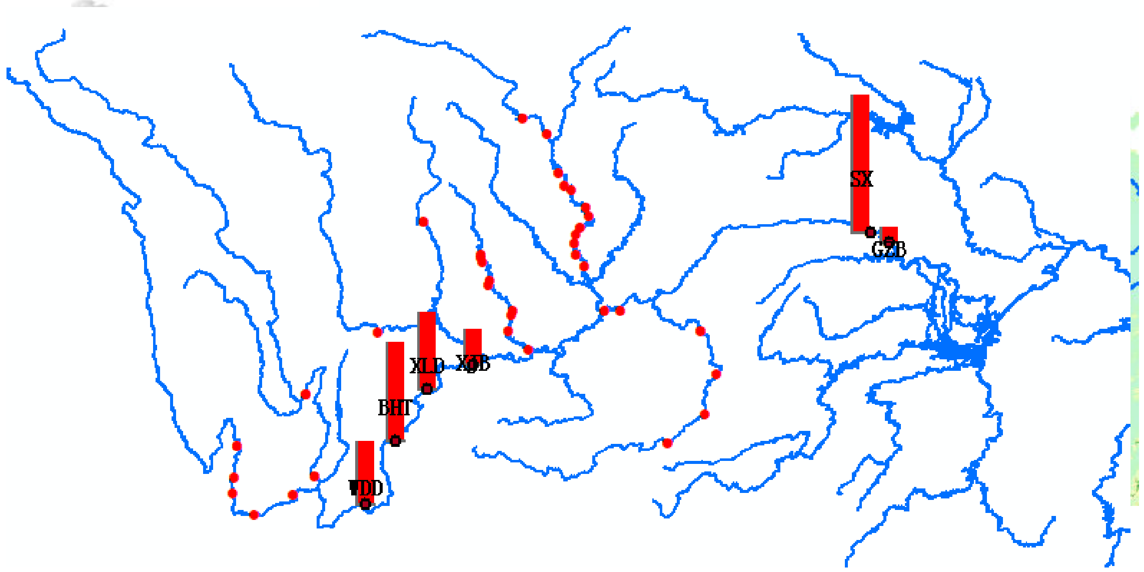
1153、1227、1520、1560、1788、1860、1870、1896、1905、1921、1931、1935、1949、1954、1998、2020。

**Huangling Temple Near Three Gorge Dam：Water mark at 81.16 m on July 20, 1870, the peak flow reached 105,000 cms, the flood event lasted about two weeks.**


Climate Change



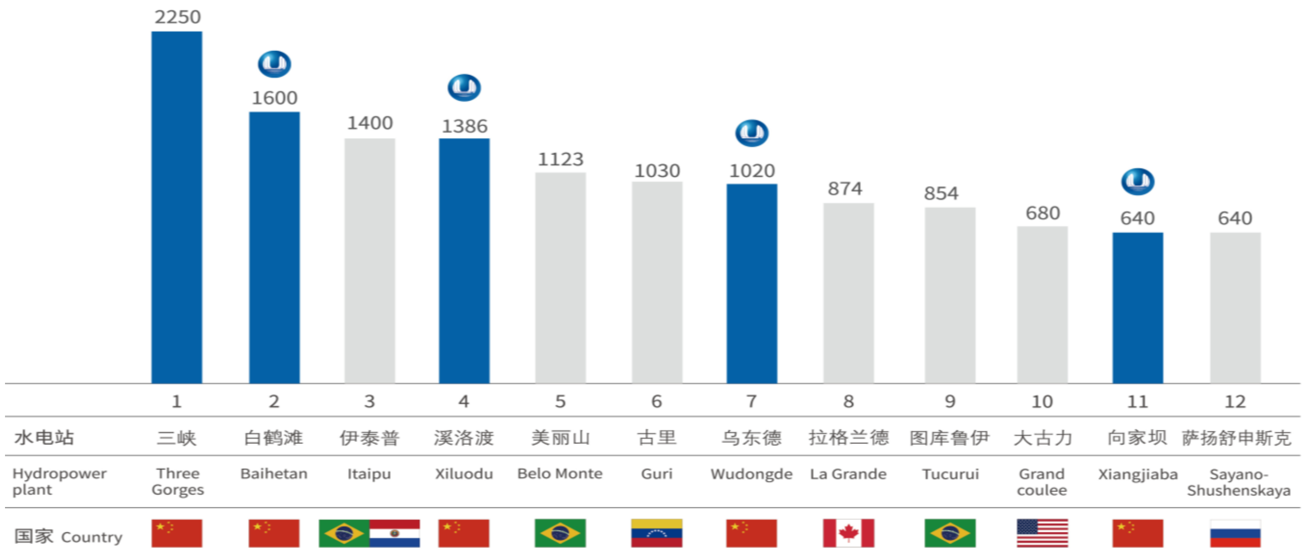
# Major Reservoirs in the Upper Yangtze River




**CHALLENGES:**

- Multi-Objectives (flood protection, hydropower generation, navigation, ecological and environment protection, water supply, etc. )
- Dynamic and continuous
- Non-linearity
- High dimension (temporal and spatial)
- Uncertainty
- Multi disciplines

| | Total Storage bcm | Flood Storage bcm |
|---|---|---|
| CYPC | 43 | 37.6 |
| Upper Yangtze | 81.4 | 49.9 |
| CYPC % | 52.8% | 75.4% |



# Cascaded Reservoirs on Upper Yangtze River

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WDD， 2021


BHT， 2020

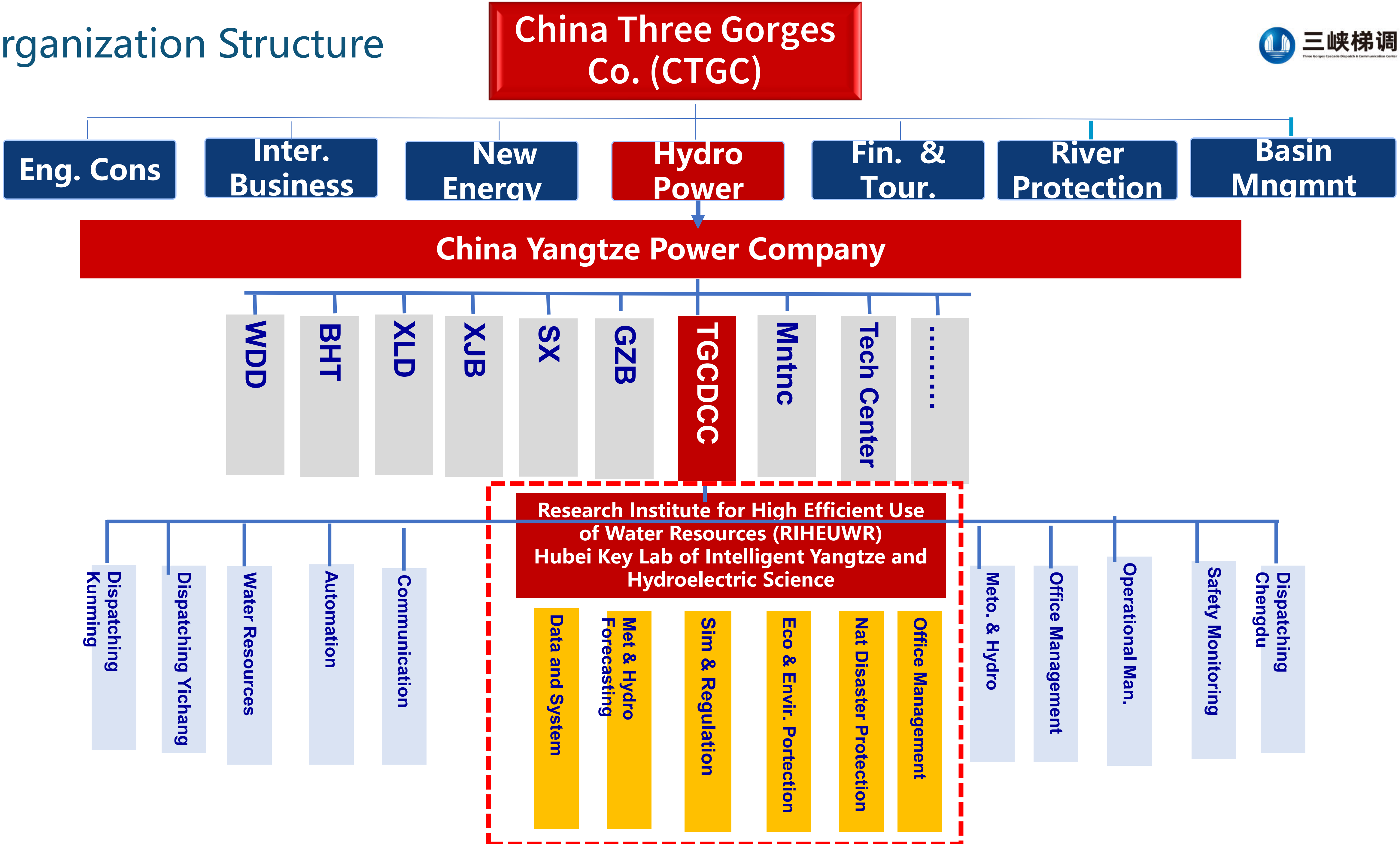

XLD， 2015

XJB， 2015


TG， 2009

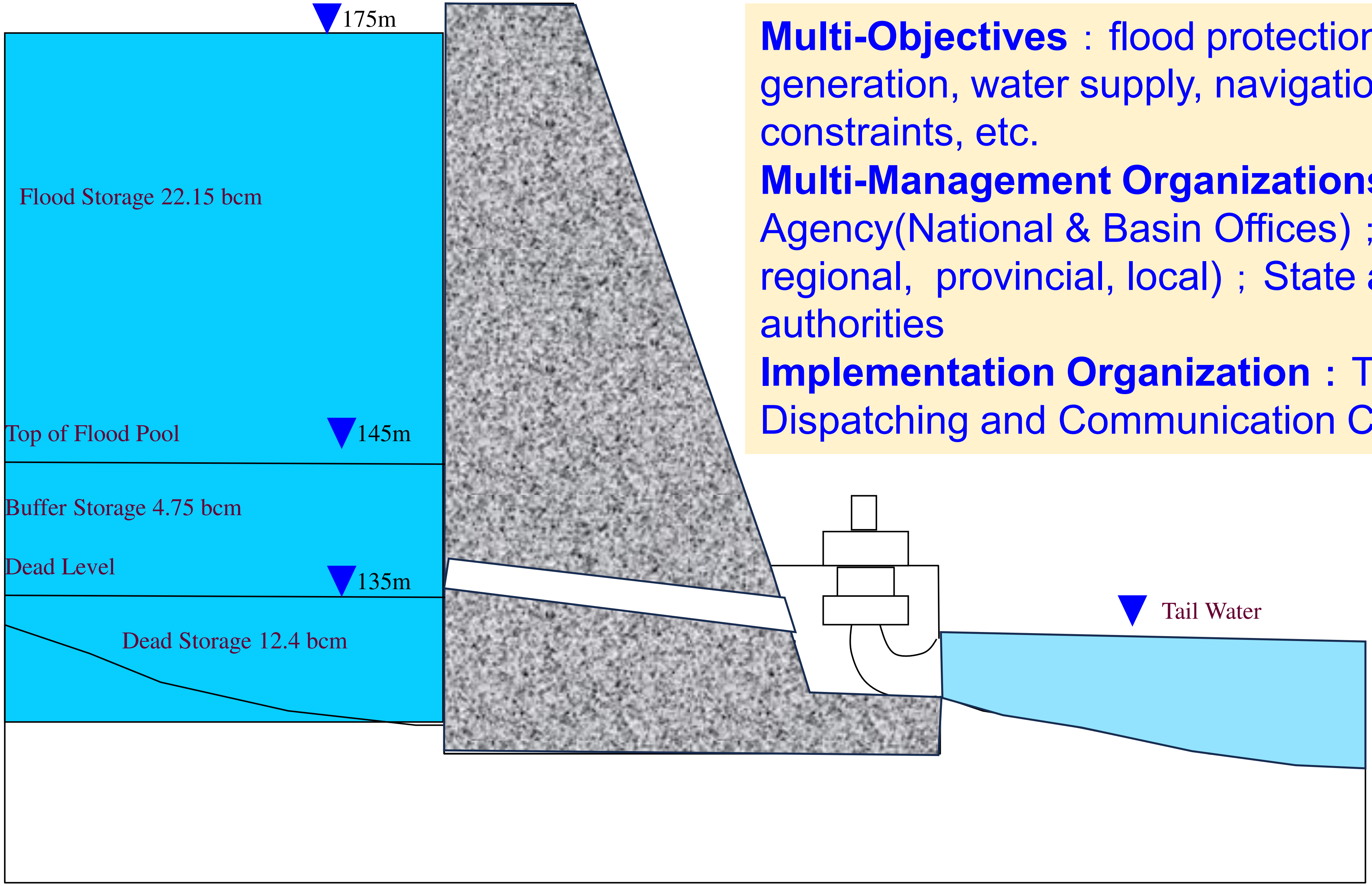

GZB,1988

# Organization Structure



# 02 Rule Based Operation

# TG Reservoir Parameters



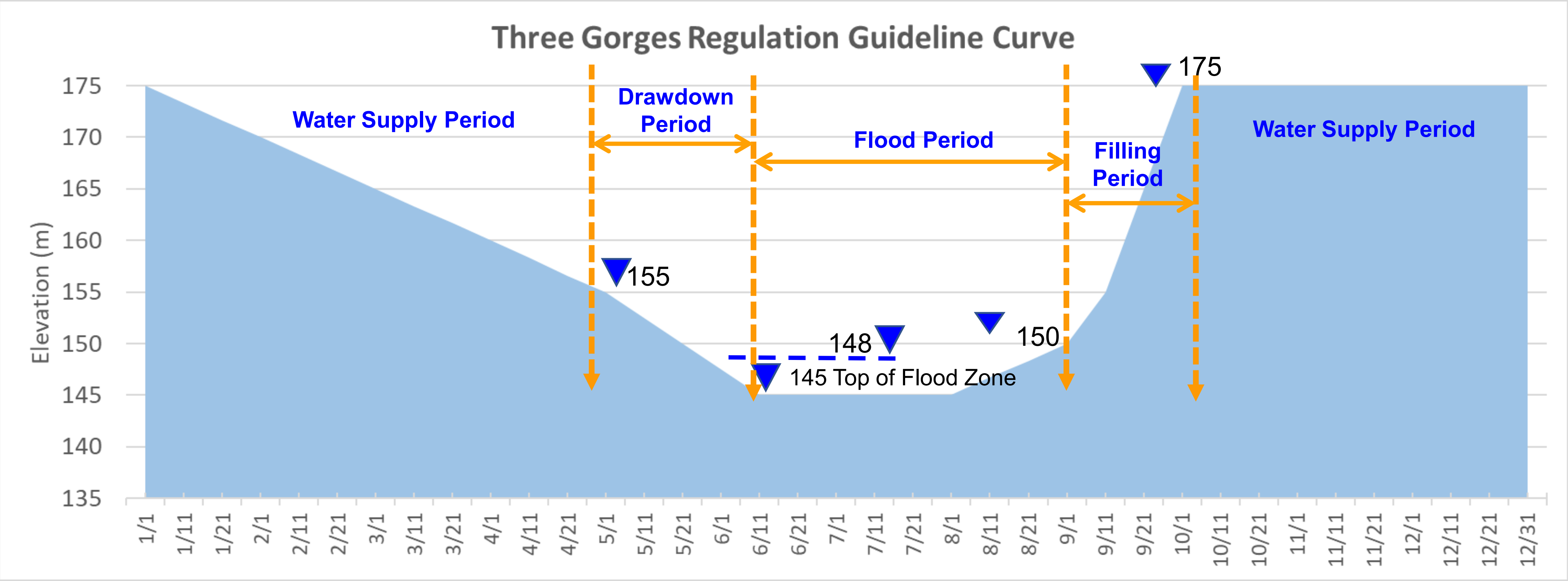

**Multi-Objectives**：flood protection, hydro power generation, water supply, navigation, eco. & environment constraints, etc.

**Multi-Management Organizations**：State Agency(National & Basin Offices)；Power Grids（state, regional, provincial, local)；State and local navigation authorities

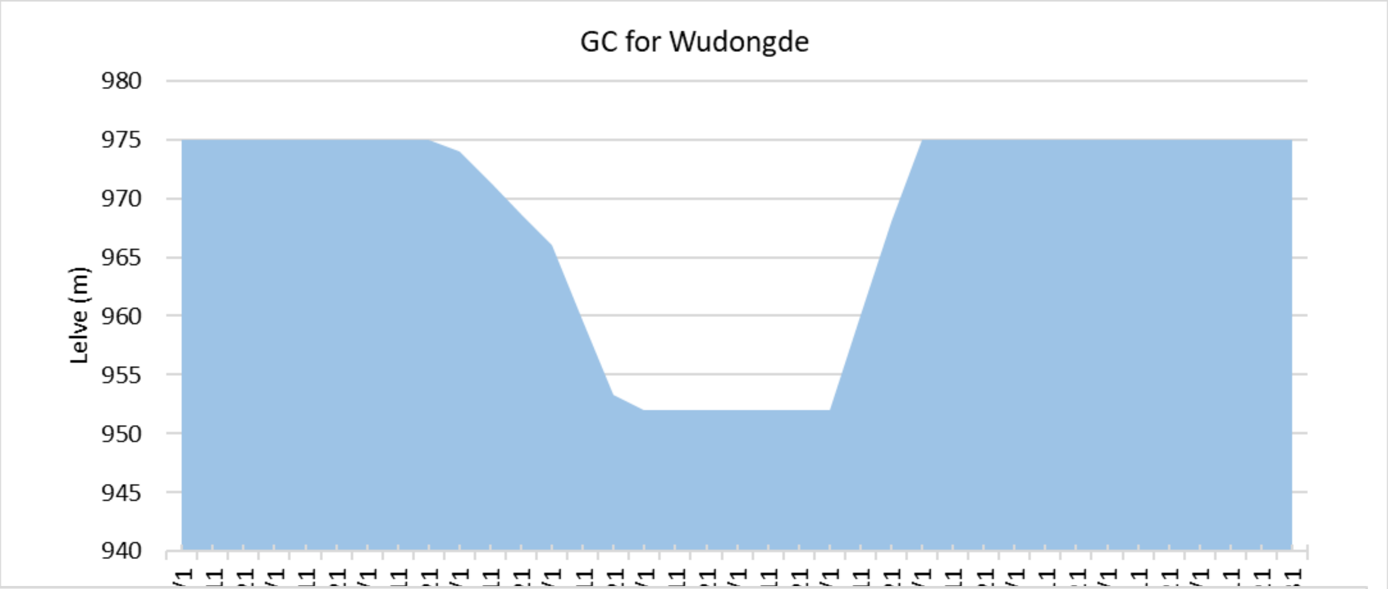
**Implementation Organization**：Three Gorges Cascade Dispatching and Communication Center （TGCDCC）

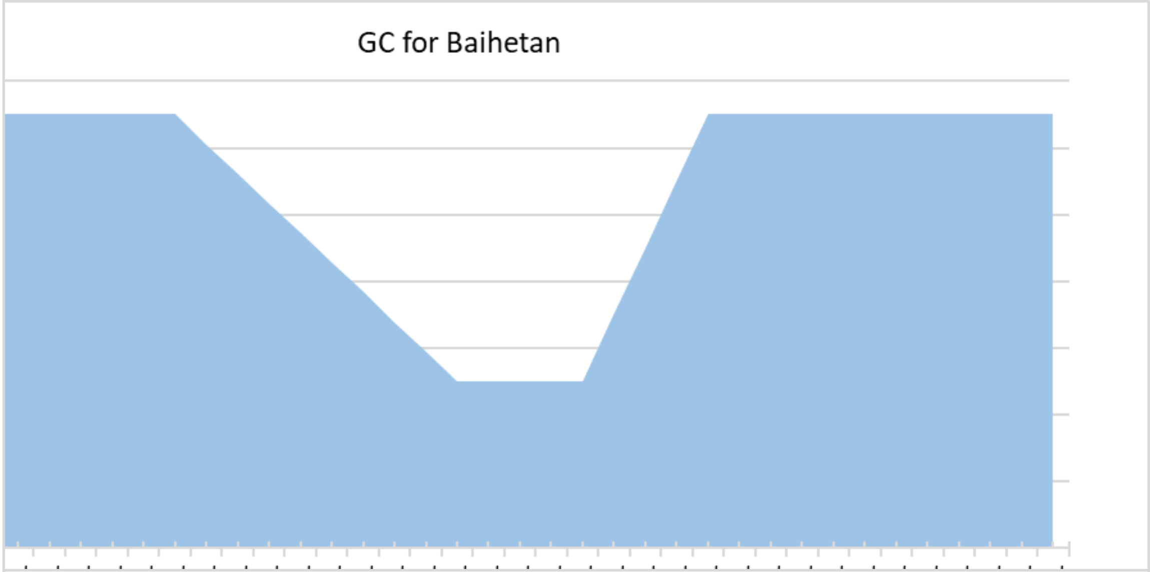
# Current Practice: Operation Guide Curve

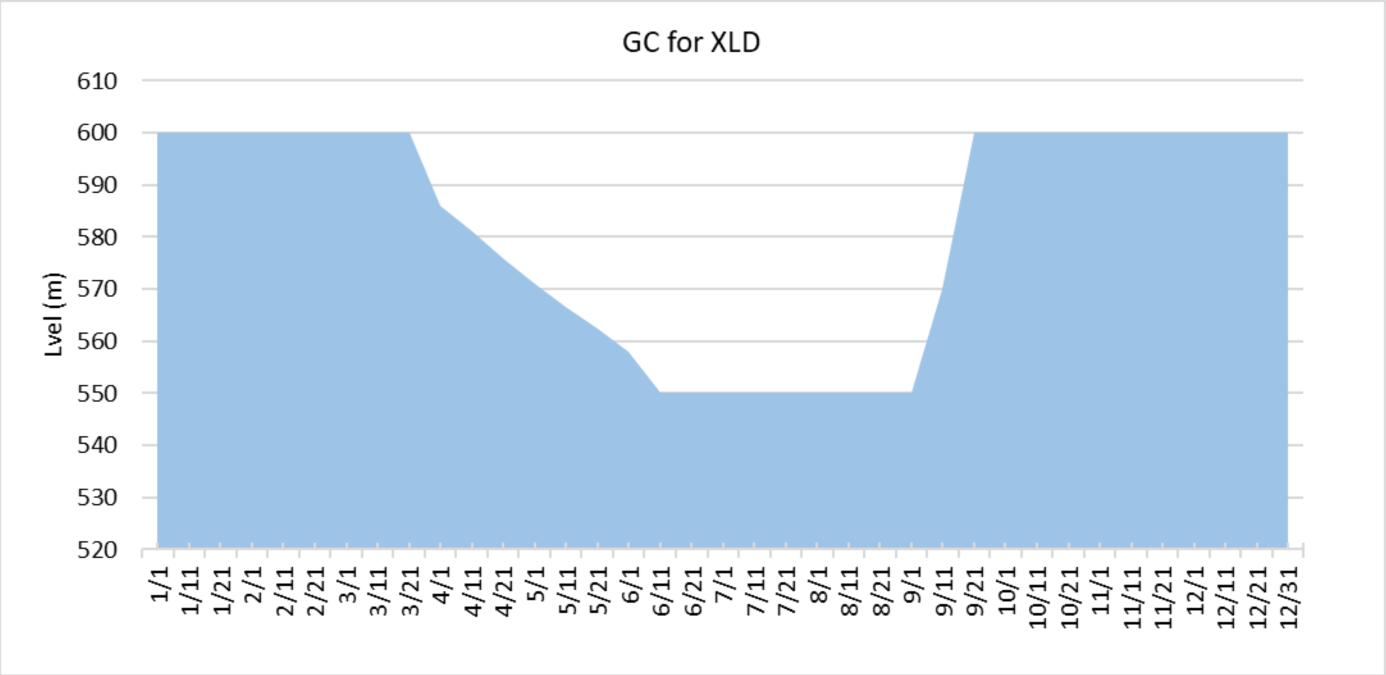
- **Annual Cycle: Four periods (flood, filling, supply, depletion /drawdown);**
- **Key Control Date-Level: June 11-145 m, <148m during flood period; Mid Sept start filling;**
- **Oct 11, filling to maximum level 175 m;**
- **Supply period: Maintain high level, meet ecological, navigation, and M & A water needs.**

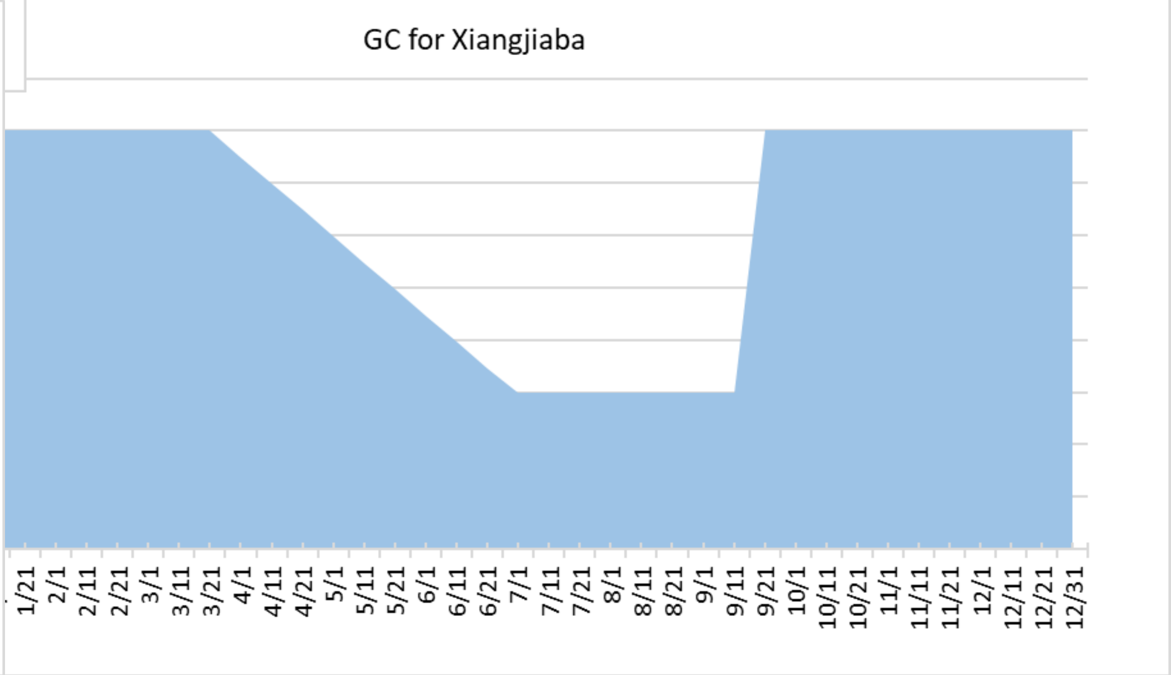


# Guide Curves for Other Reservoirs



# Performance: Annual Energy Generation Record in 2020



- At 2020/11/15 20:20, TG annual generation reached **103.1 TWh**, broke the old record of 103.098 TWh set by Itaipu hydro power station.
- New world record of annual energy generation set in 2020: **111.8 TWh**

# Performance: Multi-objectives Met in Dry Year 2022

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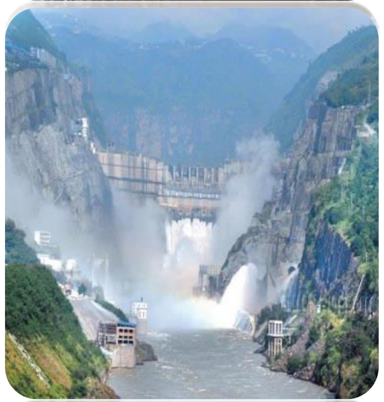
## 2022 Extreme Low Rainfall

- From July to Oct 2022, total rainfall is 368.8mm, 40% less than average, the lowest since 1951。
- WDD rainfall is the fourth lowest since 1959;
- SX/TG rainfall is the lowest since 1881.



## TG Filling Target Failed

- From July to Oct,2022, inflows 50% less than average.
- Filling target in Sept is 53.95 bcm, 70% more than 30 bcm average.

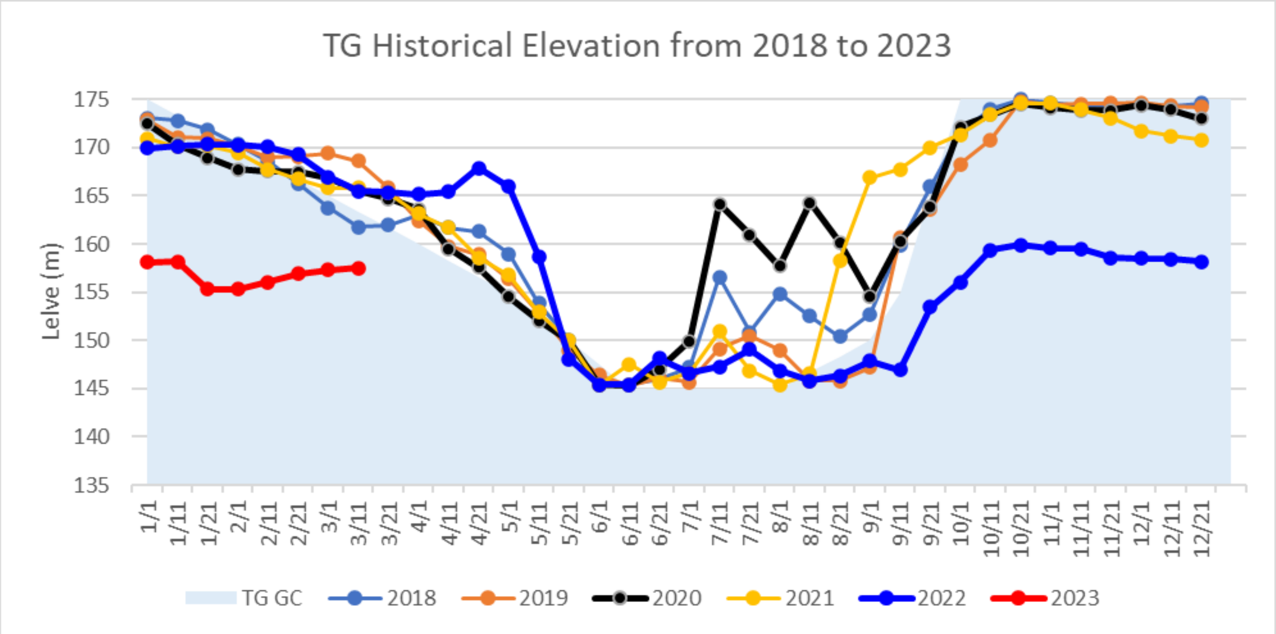
## Multiple Demand Conflicts

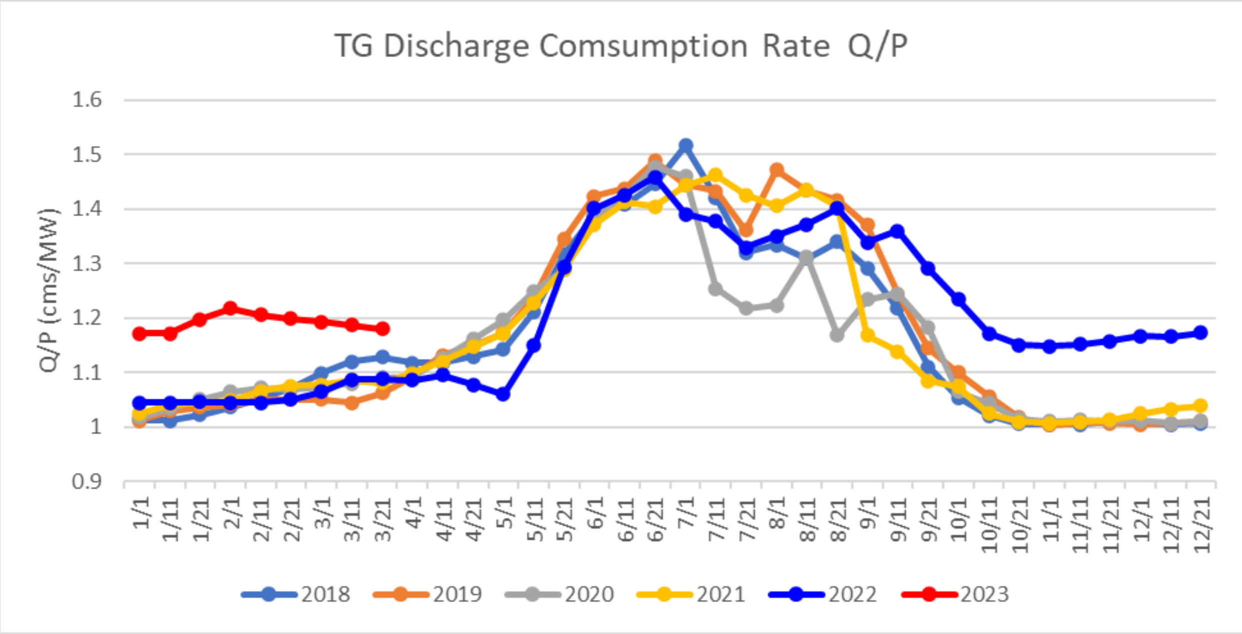
- Main task changes to augment downstream water supply.
- Peak power demands last 40 days from mid July to Mid-August. Twice increased release for downstream irrigation and sea water intrusion.

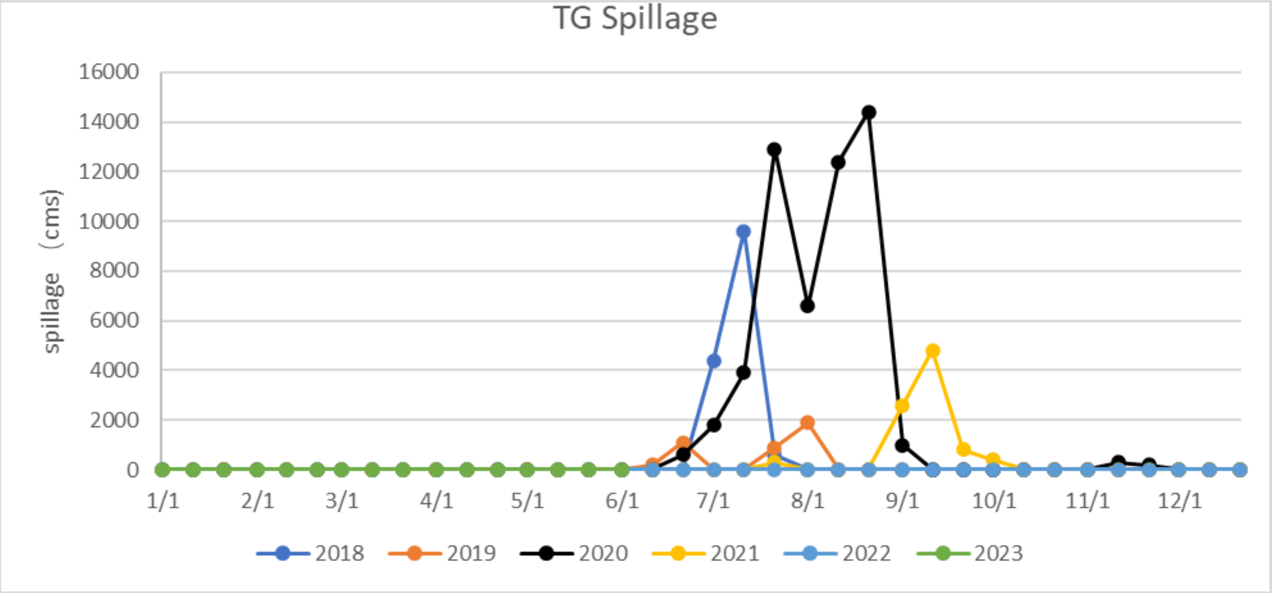
## Satisfactory Performance

- Daily increased generation more than 1 TWh lasted 31 days continuously from July to August.
- Twice increased releases of 1.51 bcm for downstream demand; 4.06 bcm for season water intrusion protection.
- New record of 56 million tons from July to October. for shipping passage。
- Filling target partial fulfillment (upper four reservoirs)

# Close Look: Performance in Recent Years



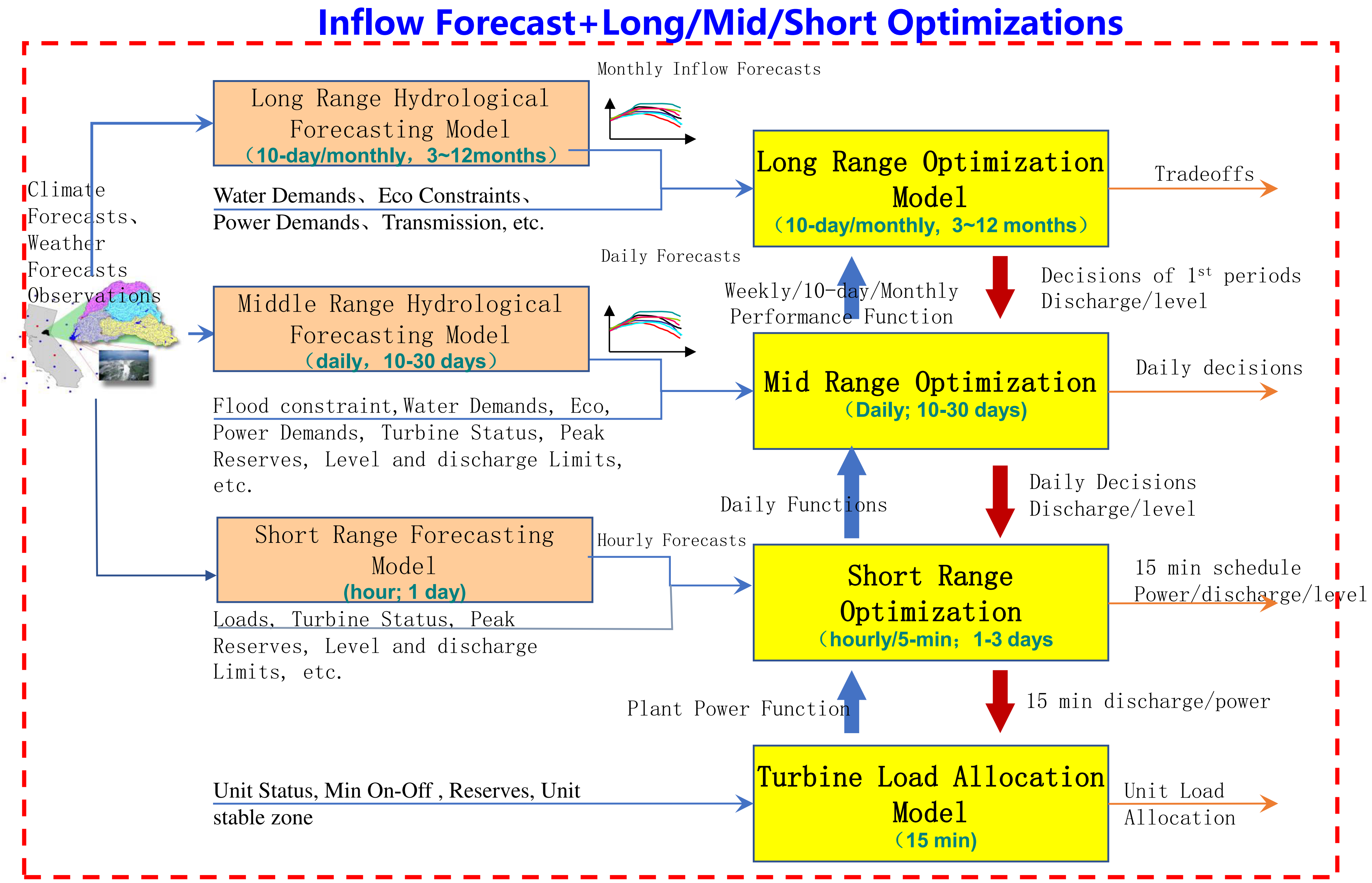

**Dry Year：** 2022.10-2023.3, Q/P value was 1.18, compared to average 1..034 of the same period from 2018 to 2021, increased by 14%, equivalent to energy generation reduction of 4 TWh with same discharge.

**Wet/Normal Year:**

| Spillage (bcm) | | | | | |
|---|---|---|---|---|---|
| Y2018 | Y2019 | Y2020 | Y2021 | Y2022 | Y2023 |
| 12.7 | 3.6 | 49.1 | 7.7 | 0.0 | 0.0 |

# 03 Integrated Decision Support Systems

# DSS Framework for Reservoir Operations




## Main Points

1. System-wide decisions, not single reservoir;
2. Adaptive Process, no fixed heuristic rules. System optimizations subject to constraints, updated forecasting information, and latest observations.
3. Long, mid, short decisions are related, and constrained, so that decisions are implementable.
4. Forecasts and decisions are updated every step, guarantees the latest information is used in the decision process.

# Mathematic Model

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Find a control policy u(k), k=0, 1, 2,…, N-1, such that the following performance index J is optimized：

$$J = \min(max) \sum_{k=0}^{N-1} g[S(k), u(k), w(k), k) + g[S(N), N)]$$

Where：

S(k) is state viable, u(k) is decision variable, w(k) is input variable, g(k) is cost function of period k, g(N) is the terminal cost at period N. S(k)， u(k) satisfy the following state equation:

$$S(k+1) = f[S(k), u(k), w(k), k)], k = 0,1,2,\dots, N-1,$$

Subject to：

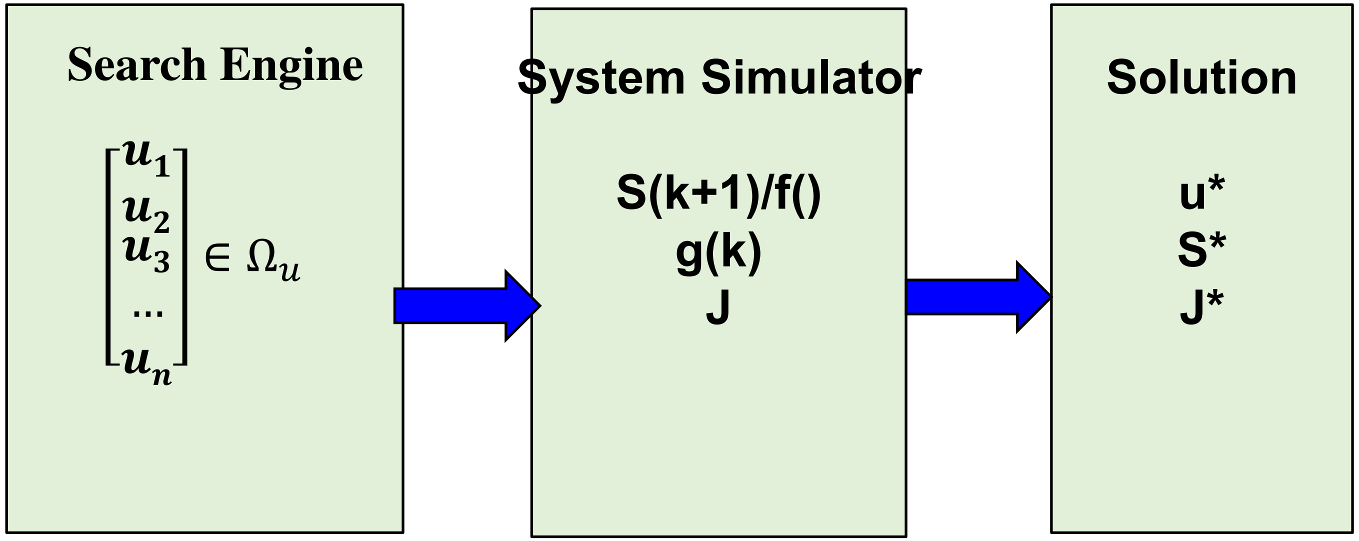
$$S(k) \in \Omega_S(k), k = 0,1,2,\dots, N,$$

$$u(k) \in \Omega_u(S(k), k), k = 0,1,2,\dots, N-1。$$

**Basic Elements：**

1）Decision, State, Input Variables；2）State Equation ；3）Constraints；4）Objective Function / Performance Index

# Optimization Engine / Solver




## Optimization Methods

Math Programming： LP、 NLP 、DP、BSDP、DDDP、 ELQG…
Iterative Involution： POA、 Monte Carlo、 GA、 Ant Colony Optimization,PSO、 Simulated Anneal…
Machine Learning： CNN、RNN、LSTM、AI、ChatGPT…

# Decision Support System for Three Gorges Included Reservoirs

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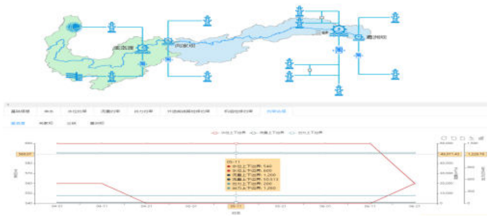
- Real-time data acquisition: 1400 observation stations
- Integrated Models: Forecasting, River Simulation, Long-, Mid-, Short-Range Optimization, Long Term Assessment
- 3-D Animation and GUI
- Easy Extension Capability and Good Generality


Data Processing


3D Display for Inundation


Flood Evolution


Effects by Upper Reservoirs


Various Constraints


Rolling Updating


Comparison Analysis


Benefits

# Latest Results: Operation in 2023 Flood Season

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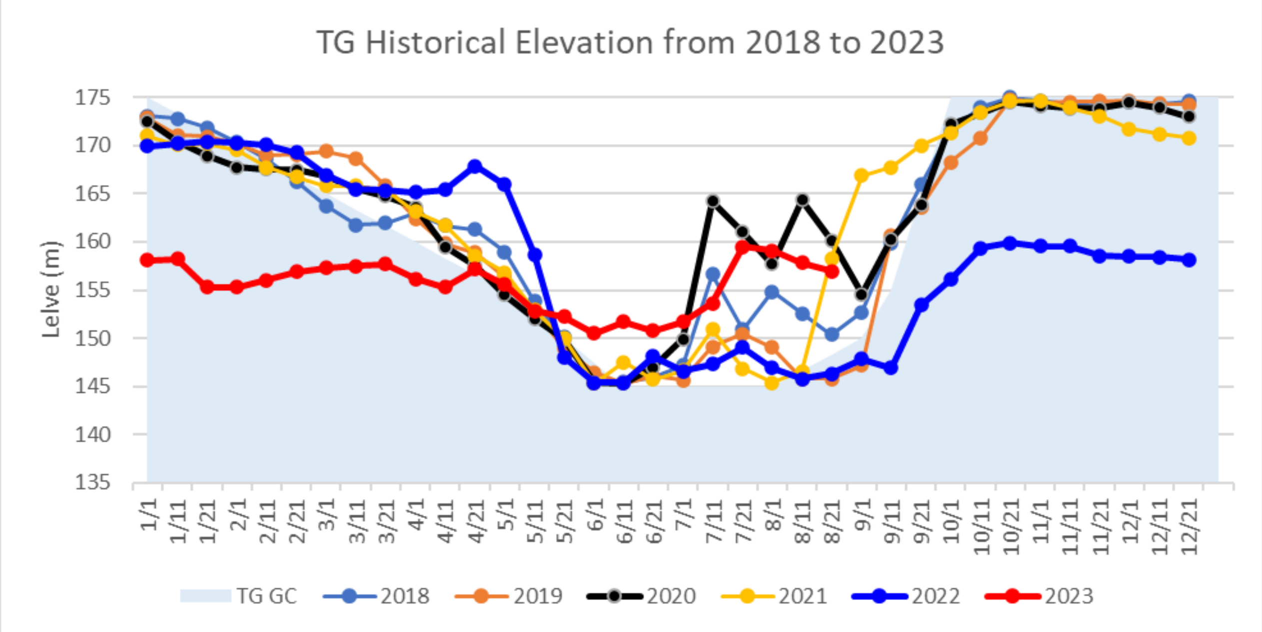
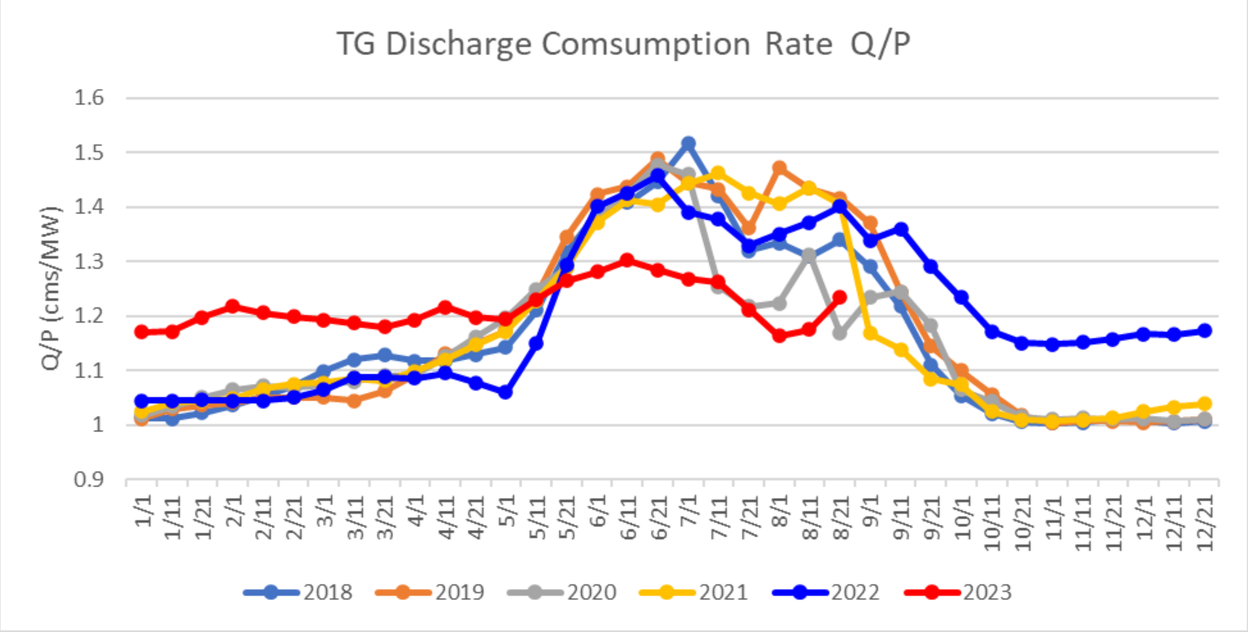
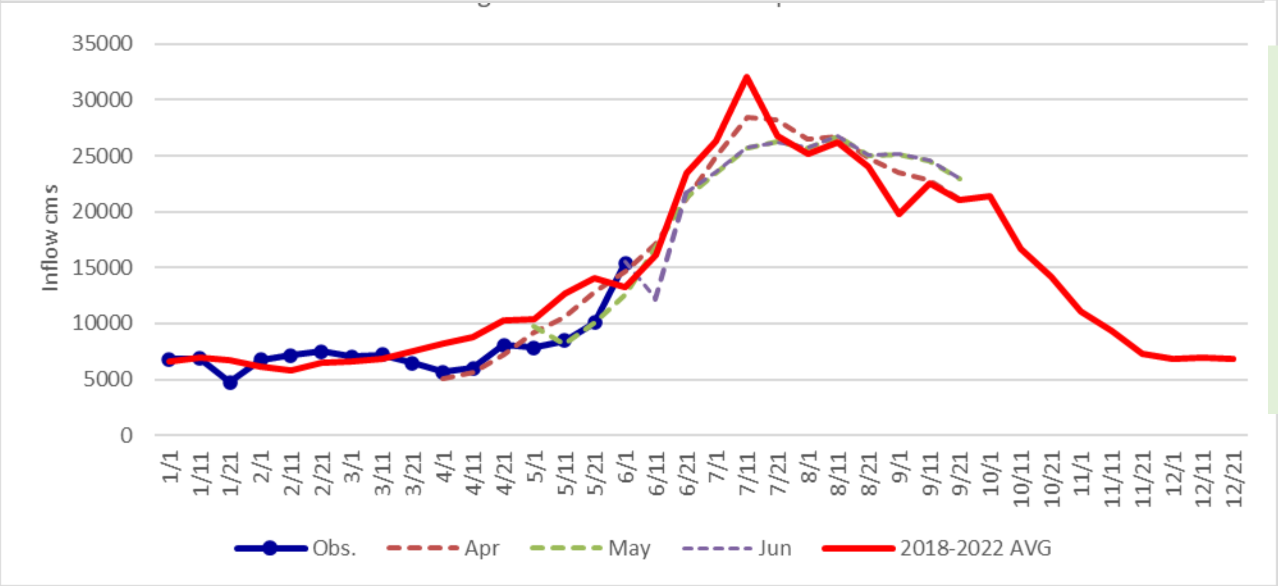


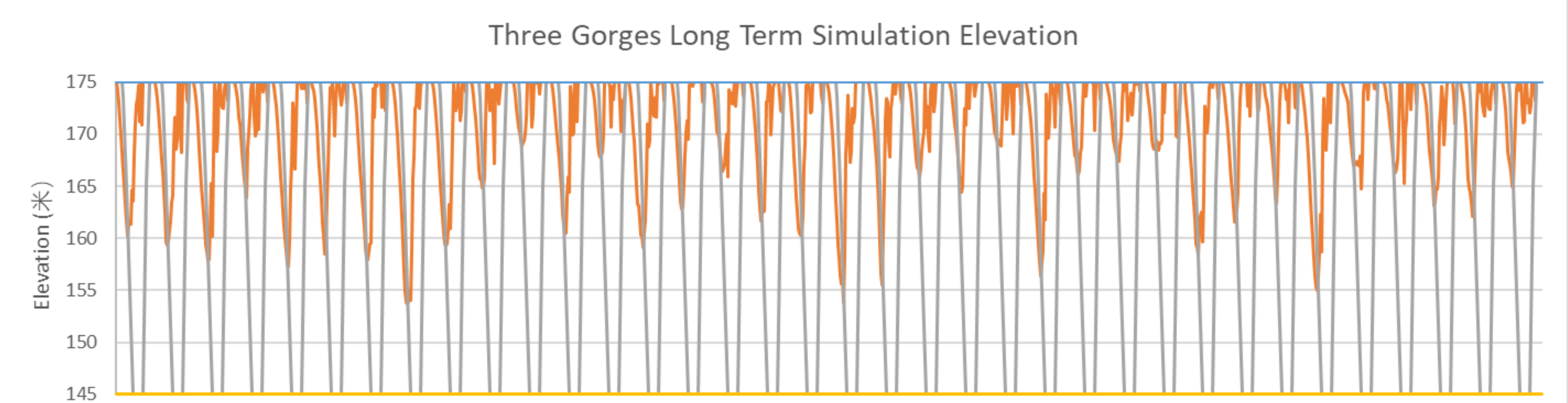




**Compared to average Q/P value 1.4 from June-August of 2018-2023, the average Q/P ratio is 1.24 in 2023, a decrease of 11.4%, equivalent to power generation increase of 3 TWhs under same discharge.**

**Rolling Forecast with adaptive optimization decision scheme improved the system performance.**

# Long Term Simulation Results

**Long range simulation using 1980 to 2015 historical inflow sequence shows the annual energy generation increased by 17 TWh (5.4%) with the DSS control scheme over the traditional rule based operation.**




| Reservoir | Local Inflow (bcm) | Average Generation (TWh) | | |
|---|---|---|---|---|
| | | Targte Elevation /GC | GC + Delayed Spill | DSS |
| WDD | 123 | 40 | 41 | 42 |
| BHT | 14 | 68 | 69 | 70 |
| XLD | 6 | 61 | 65 | 64 |
| XJB | 0 | 34 | 35 | 32 |
| TG | 288 | 93 | 96 | 106 |
| GZB | 0 | 18 | 18 | 17 |
| Total | 430 | 314 | 326 | 331 |

# 04 Conclusions

# Conclusions

1. The traditional heuristic rules are not valid for multi reservoir systems. They don’t use forecasts in the decision process, nor take full advantage of the reservoir storage capacity, can exacerbate the damage under extreme wet or dry conditions, usually lead to low efficiency.

2. Rolling forecast with adaptive optimization decision scheme is more active and stable. It is scientifically sound. Applications show clear advantages over the rule based operation.

# The End

Thank you for listening