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A statistical technique for designing the lowest navigable water level under changing environment

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Content

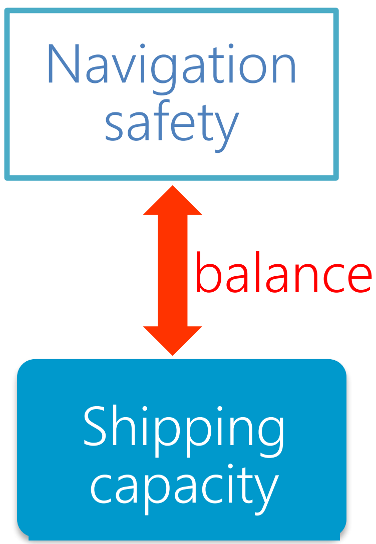
1. Background &Purpose

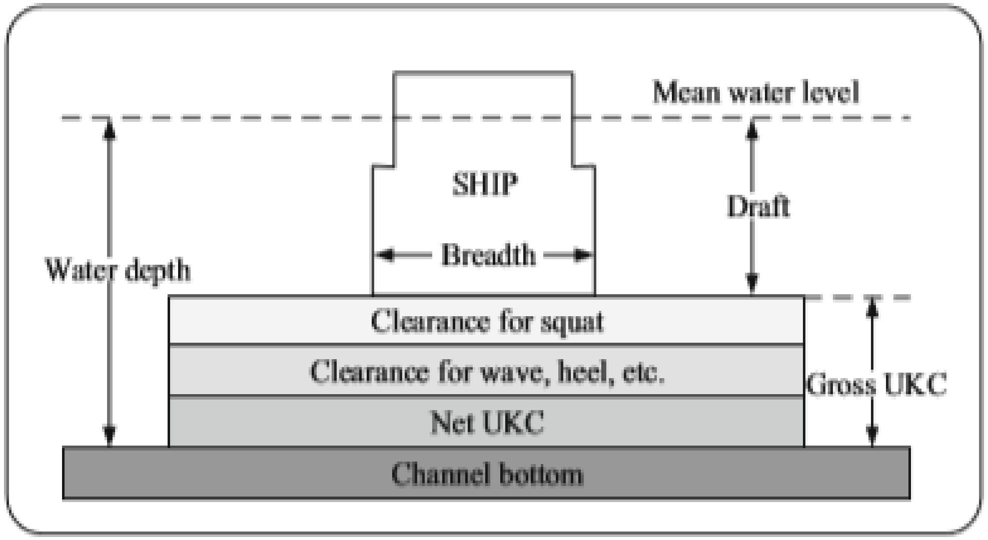
➢ The lowest navigable water level

- Definition

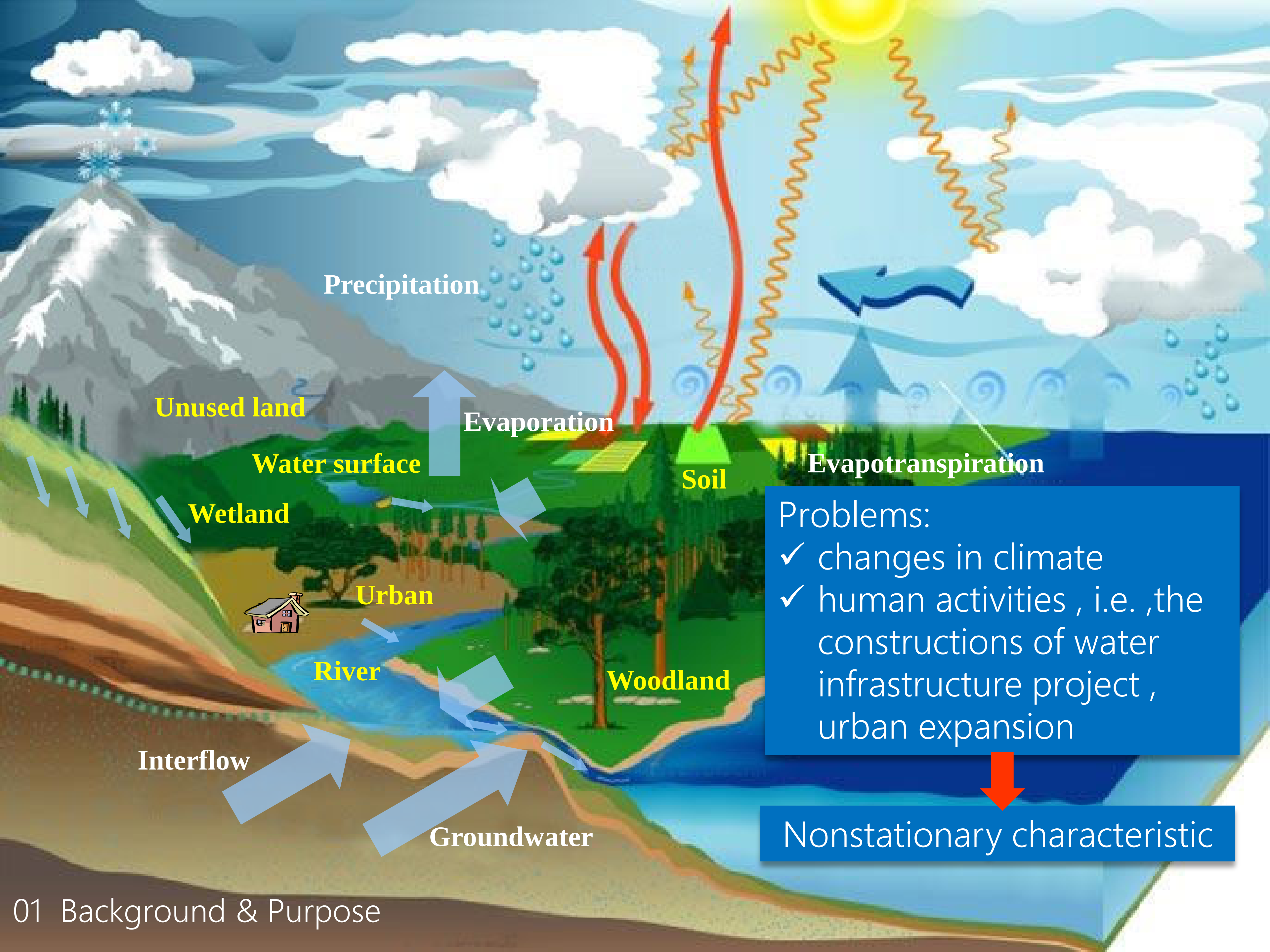
The minimum water level which allows standard ships or fleets to navigate safely in inland rivers.

- Purpose





Relationship between water level, ship draft and UKC



Problems:

- ✓ changes in climate
- ✓ human activities , i.e. ,the constructions of water infrastructure project , urban expansion

Nonstationary characteristic

POLICYFORUM

CLIMATE CHANGE

Stationarity Is Dead: Whither Water Management?

Climate change undermines a basic assumption that historically has facilitated management of water supplies, demands, and risks.

P. C. D. Milly,[1*] Julio Betancourt,[2] Malin Falkenmark,[3] Robert M. Hirsch,[4] Zbigniew W. Kundzewicz,[5] Dennis P. Lettenmaier,[6] Ronald J. Stouffer[7]

The high-order moments of water level series become time-varying

A more reliable way

A statistical technique based on decomposition and integration idea and second-order moment variation analysis was proposed

2. Methodology

- Decomposition and integration idea
- Second-order moment variation analysis
- Guaranteed rate-frequency method

Using non-stationary frequency analysis models

- Time-varying probability distribution model
- Mixed distribution method for hydrological frequency analysis

Converting the hydrological time series from non-stationary to stationary

- Decomposition and integration idea

Transform the original non-stationary series into stationary ones corresponding to different environmental conditions (i.e. the past, the current, or the future). Provided that stationary hydrological data in different periods are gained, conventional design methods can be used.

➢ Preliminary assumption

- Additive function

hydrological time series

↑

$$X_t = Y_t + S_t$$

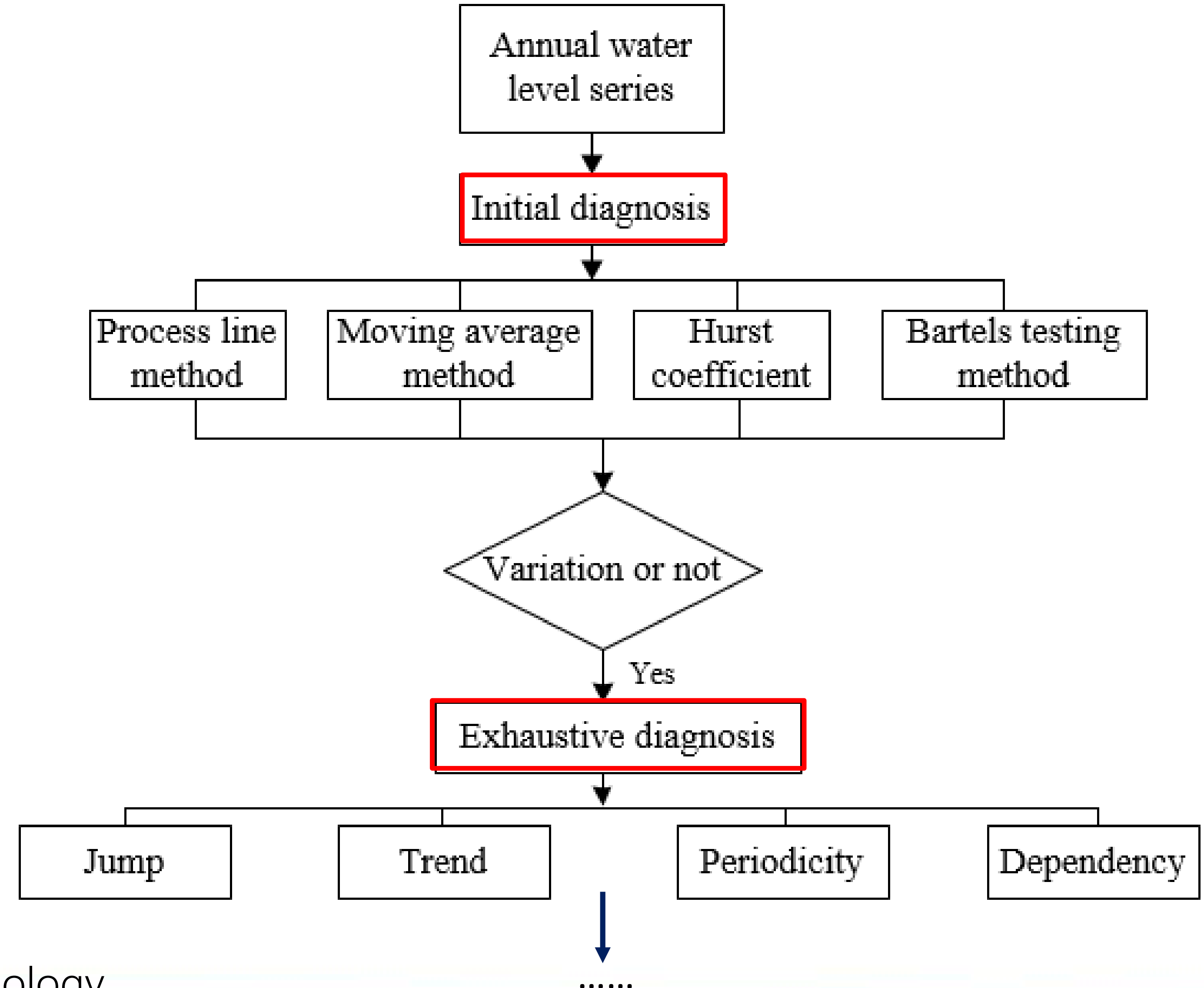
↓ ↓

deterministic components
- trend
- jump
- periodicity

(time domain)

stochastic components
(frequency domain)

Step I *Detect the trend, jump, periodicity and dependence of the annual water level series*

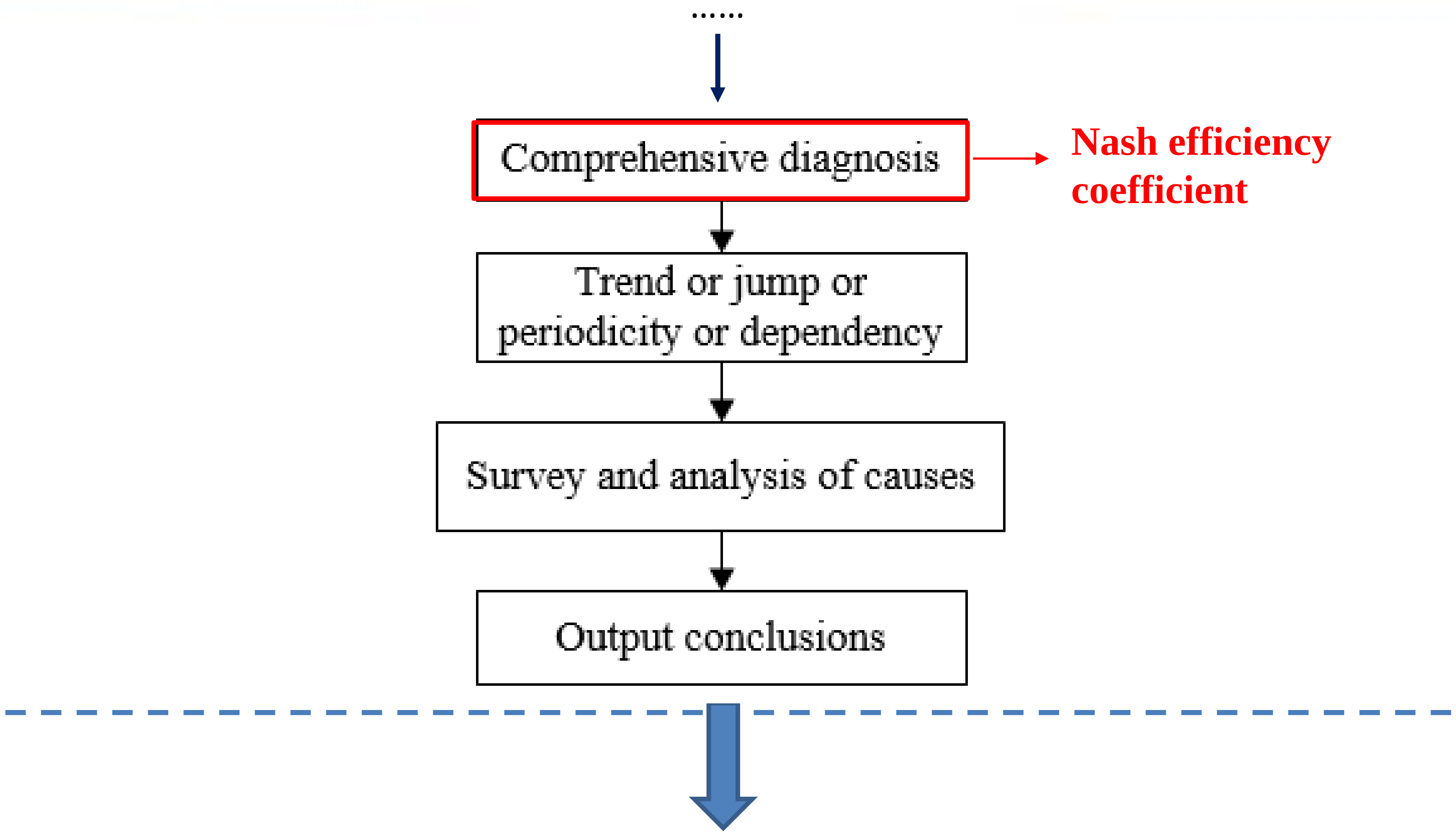


Exhaustive diagnosis

……

Jump	1. Moving F test 2. Moving T test 3. Moving run test 4. Moving rank sum method 5. Sequential cluster method 6. R/S method 7. Lee-heghinan method 8. Brown-Forysthe method 9. Mann-Kendall method 10.Bayesian method 11. Optimal information division method
Trend	1. Linear regression method 2. Spearman rank correlation method 3. Kendall rank correlation method
Periodicity	1. Power spectrum analysis 2. Maximum entropy spectrum analysis 3. Harmonic analysis method 4. Simple partial wave method
Dependency	1. Autocorrelation coefficient method 2. Variance spectral density method

……



Hydrological alteration diagnosis system

Step II All deterministic components detected should be removed from the observed series to gain stochastic parts.

$$x_t' = \frac{x_t - a_t}{b_t}$$

Where x_t is observed water level series;
x_t ′ is the stochastic part of the original series;
a_t is the deterministic component of observed series;
b_t is the deterministic component of residual square series;

Step III Detect the trend, jump, periodicity and dependence of residual square series

- To analyze whether the variance of the observed series has changed over time.

Step IV Compose the stochastic component and the deterministic component under each certain environment

$$x_{t,t_0} = a_{t_0} + b_{t_0} x_t' = a_{t_0} + \frac{b_{t_0}}{b_t}(x_t - a_t)$$

Where x_{t,t_0} is the stationary annual water level series corresponding to the environment of the year t_0;
x_t is original water level series;
x_t ′ is the stochastic part of the original series;
a_t is the deterministic component of original series;
a_{t_0} is the deterministic component of original series of the year t_0;
b_{t_0} is the deterministic component of residual square series of the year t_0;

Step V Design the lowest navigable water level corresponding to different circumstances

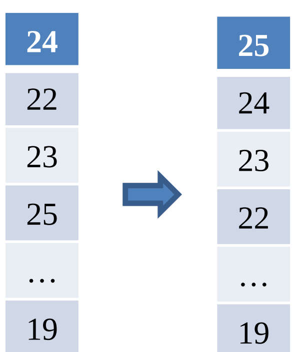
- Based on new reconstructed series by using guaranteed rate-frequency method.

Guaranteed Rate-Frequency Method

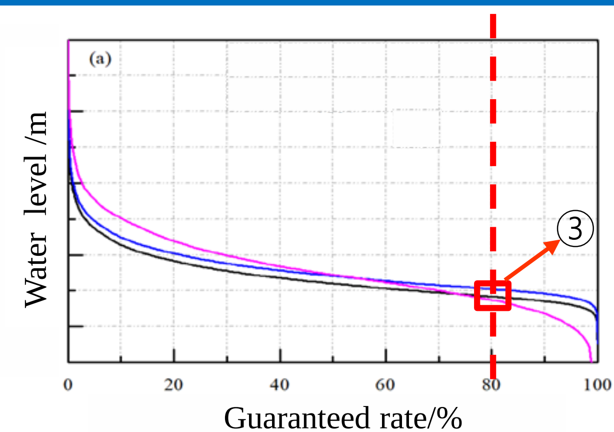
① The observed daily water level data each year should be arranged in descending order.
② Draw the water level duration curves of each year.
③ Obtain the water level value at the certain guaranteed rate from each curve .
Considers the duration of the navigation damage in a year
④ Compose a new annual water level series and use hydrological frequency calculation to obtain the frequency distribution.
Considers the frequency of this damage occurs among the years

Suitable for basins where:

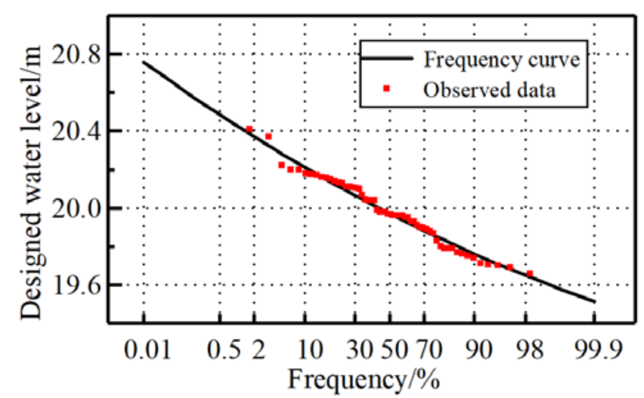
- ✓ Runoff varies greatly between years
- ✓ High-grade waterways



①

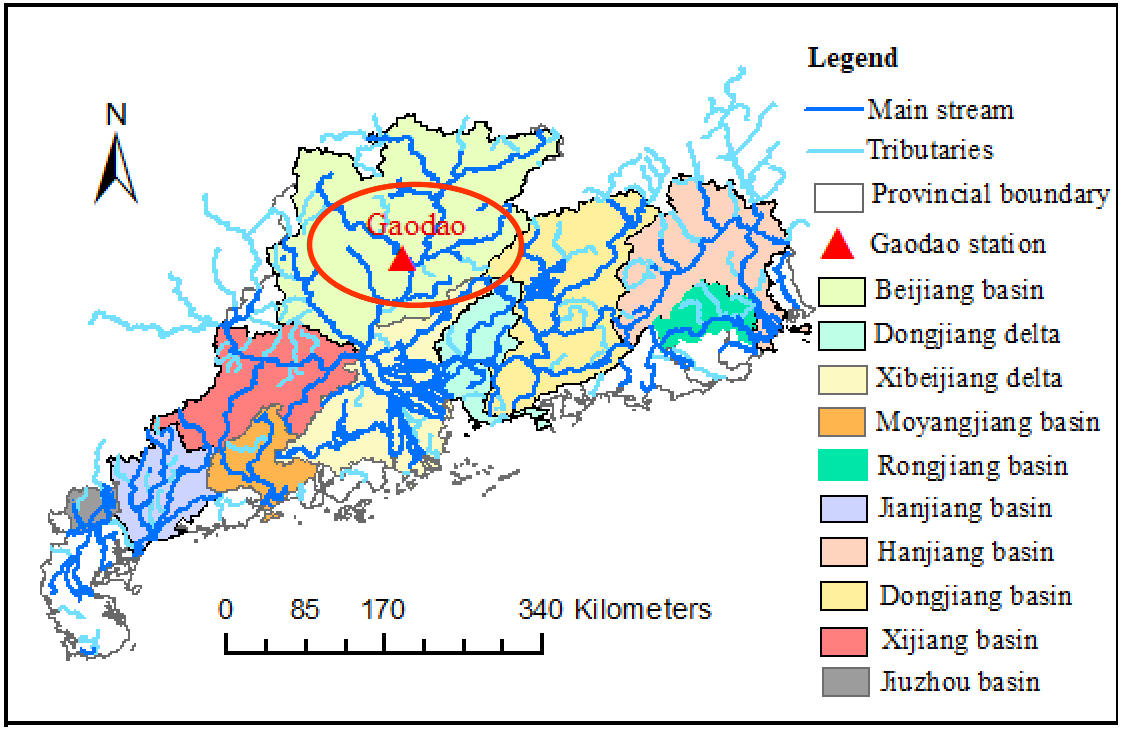


②



④

3. Study area & Data

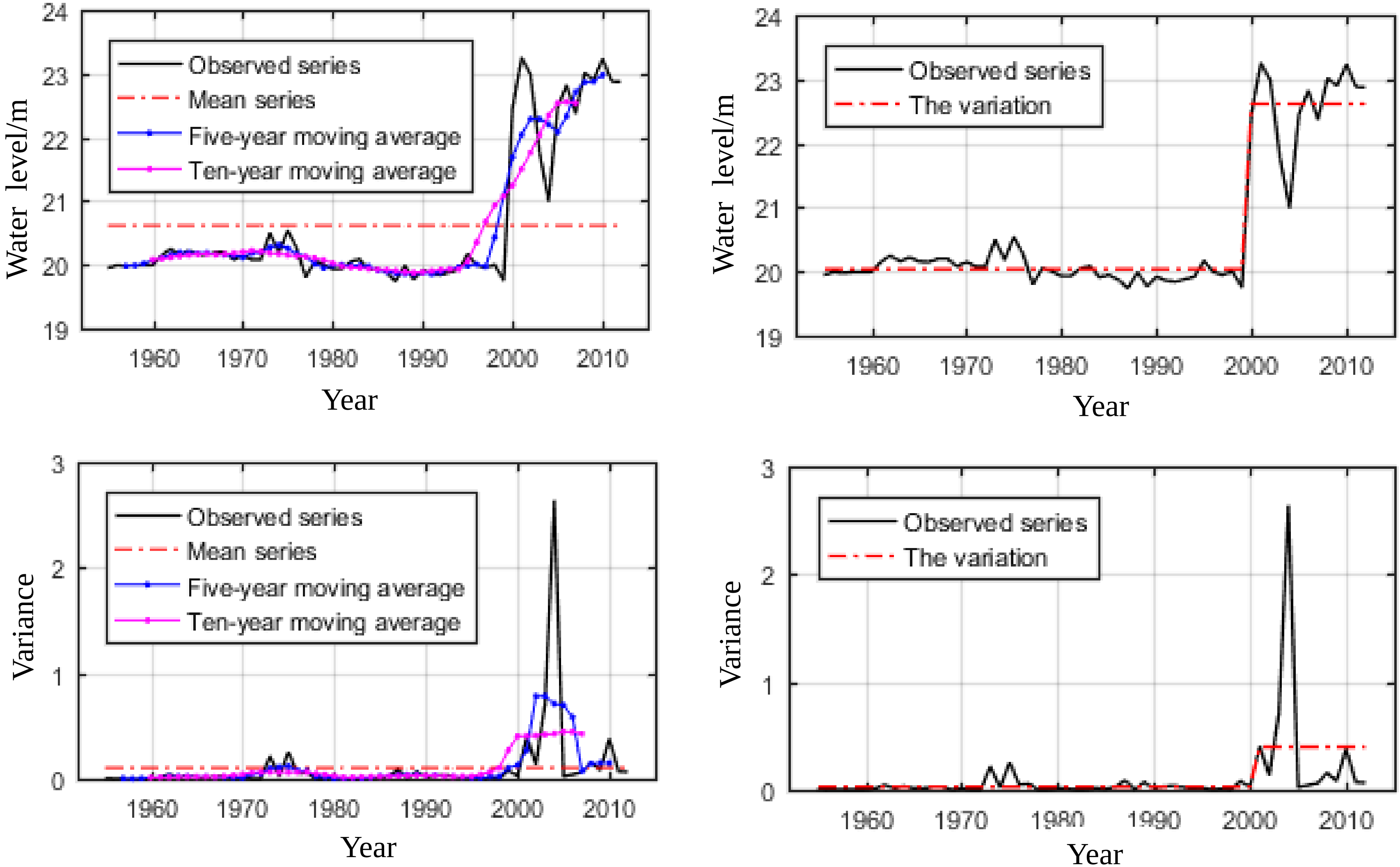


Main basins in Guangdong province

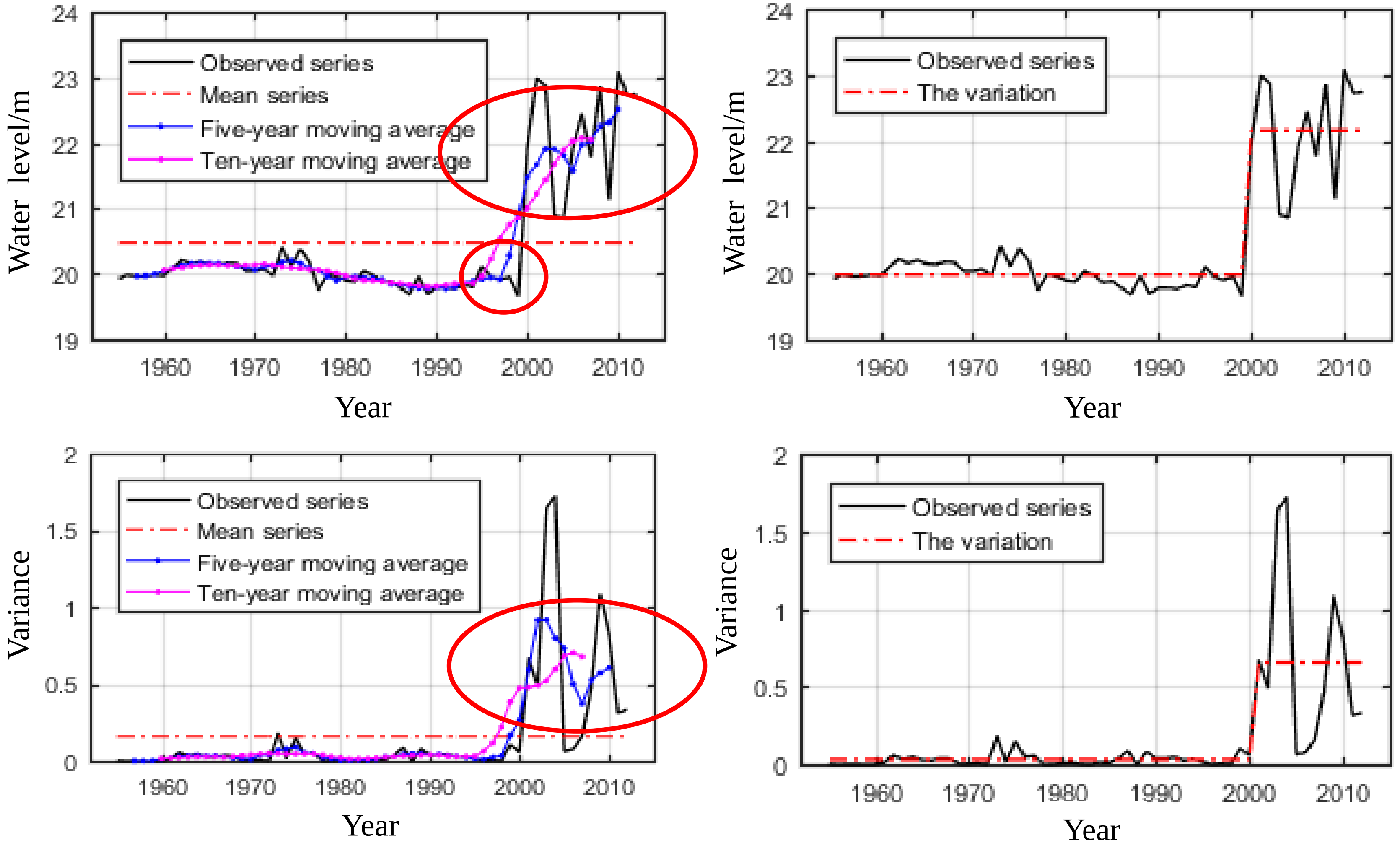
- Study area: Guangdong Province , China
  Inland waterways: 11,883 km

- Study object: Gaodao hydrological station
  Catchment area: 9007km^2
  Data series: Daily water level data from 1955 to 2012

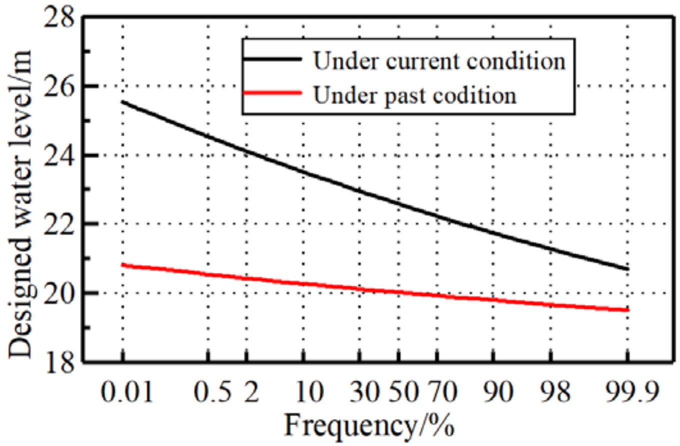
4. Results & Conclusion



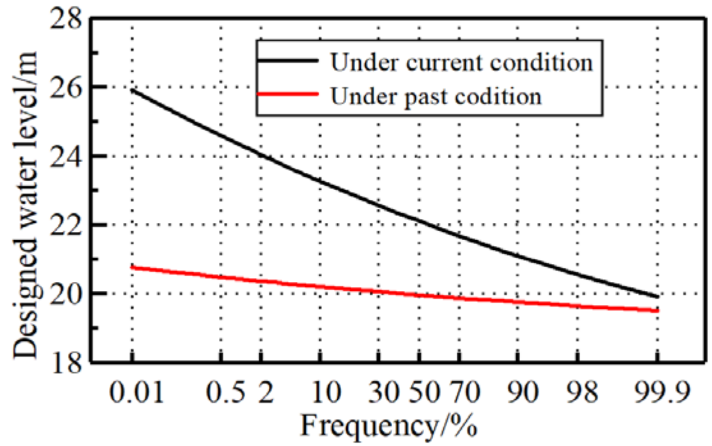
Water level series of Gaodao station at 95% guaranteed rate



Water level series of Gaodao station at 98% guaranteed rate



(a) At 95% guaranteed rate



(b) At 98% guaranteed rate

Comparisons of frequency curves between past and current

Design values in different periods considering variance variation

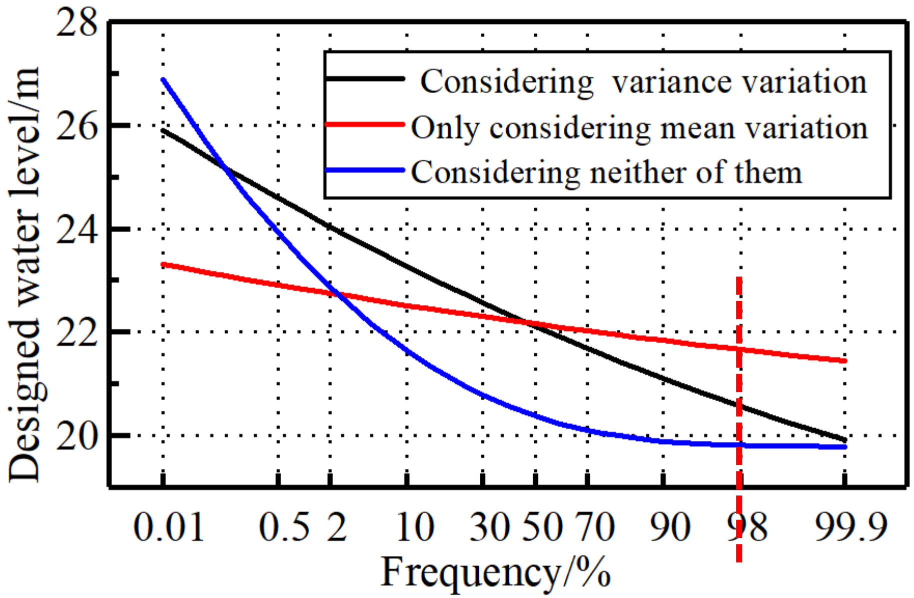
Water level series	95% guaranteed rate			98% guaranteed rate		
Design frequency/%	P=75%	P=80%	P=90%	P=75%	P=80%	P=90%
Designed values in the past/m	19.91	19.88	19.80	19.86	19.83	19.76
Designed values in current/m	22.13	22.02	21.74	21.56	21.43	21.11
Difference/m	2.22	2.15	1.94	1.71	1.60	1.34

- ✓ The difference of the lowest navigable water level between the current and past environments accounts for around 21%-37% of the ship draft.

→ The water level variation is an important factor that cannot be ignored for navigation **safety.**

Variation Coefficient Cv of Frequency Curve under Different Conditions

	95% guaranteed rate		98% guaranteed rate	
Condition	past	current	past	current
Considering variance variation	0.0093	0.0305	0.0088	0.0382
Considering mean variation only	0.0110	0.0100	0.0130	0.0120
Considering neither	0.0400		0.0380	



Comparison of frequency curves at 98% guaranteed rate (current)

- ✓ The differences of the designed values among three situations are prominent.
- ✓ Confirming the necessity of the mean variation and variance variation analysis.

Design values only considering mean variation

Water level series	95% guaranteed rate			98% guaranteed rate		
Design frequency/%	75%	80%	90%	75%	80%	90%
Designed values in the past/m	19.88	19.85	19.77	19.80	19.76	19.66
Designed values in current/m	22.45	22.42	22.34	21.99	21.95	21.84
Difference between the current with and without considering variance variation /m	-0.32	-0.41	-0.63	-0.33	-0.40	-0.60

Design values without considering any variation

Water level series	95% guaranteed rate			98% guaranteed rate		
Design frequency/%	75%	80%	90%	75%	80%	90%
Designed values/m	20.14	20.07	19.95	19.89	19.84	19.74
Difference between the current with and without considering non-stationarity /m	2.24	2.18	2.00	1.51	1.44	1.21

✓ The influence of variance variation increases with the increase of design frequency.

→ This design method has greater guiding significance for the lowest navigable water level design in high-grade waterways.

5. Prospect

THE NEXT STUDY

Higher-order moments (i.e. skewness coefficient)

- Be time-varying or not?
- How they change with time?
- How to apply the theory?

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Thank you!

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