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IWHR





Research on Key Technologies of Drought Limited Water Level and Its Application in China

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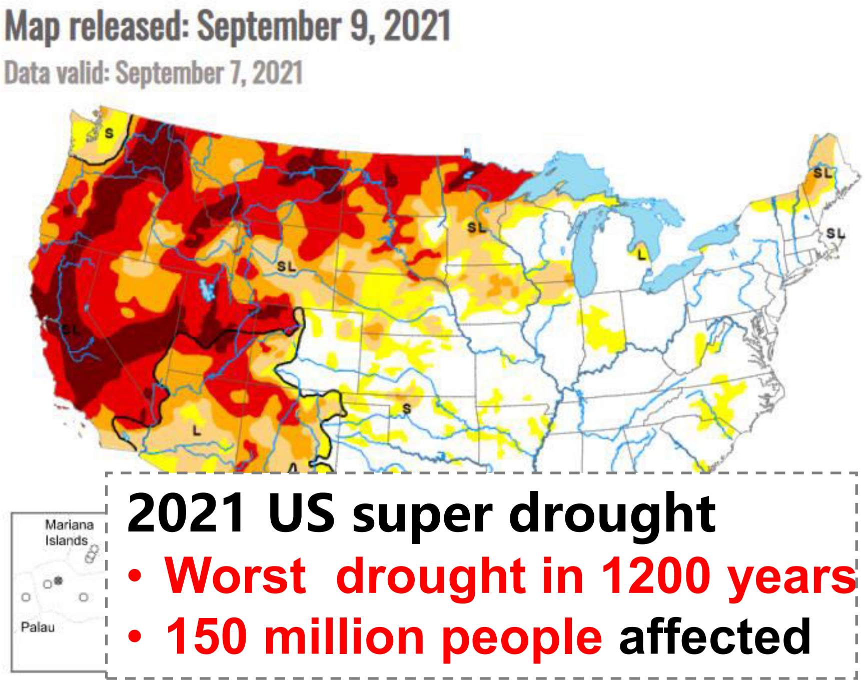
1. Background

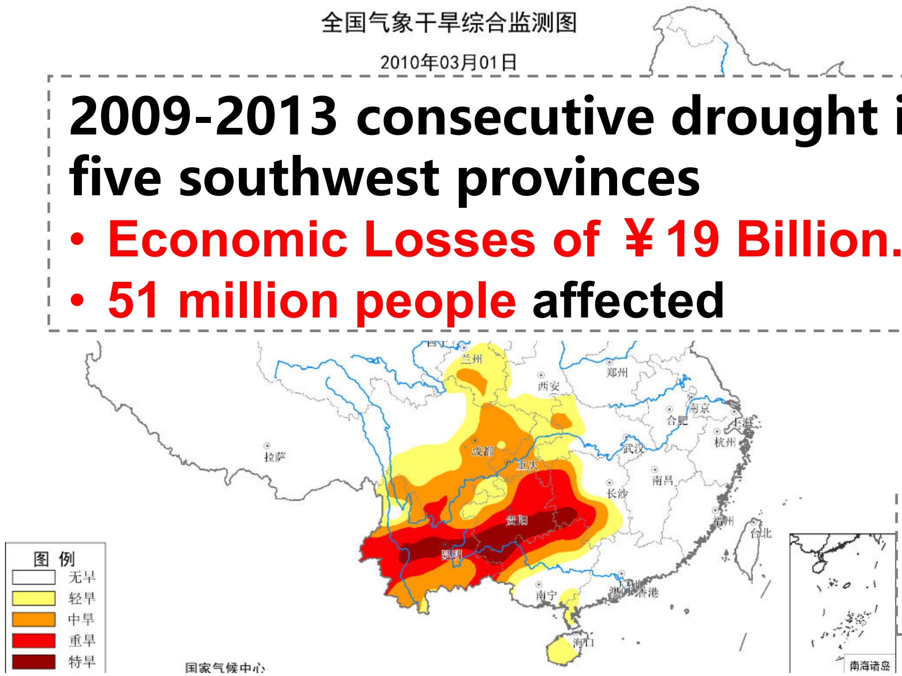
01

Background

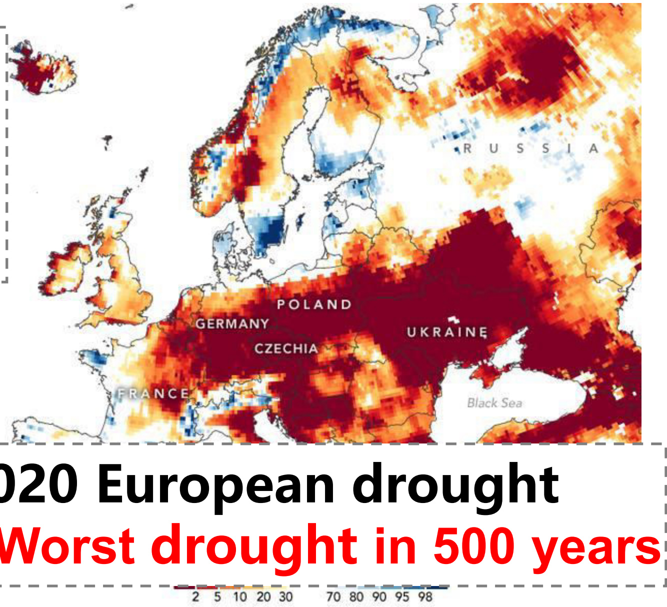
- Climate change is intensifying the water cycle, increasing the frequency of extreme events, and leading to more severe drought in many regions worldwide.
- Long-lasting, widespread, and highly-intense severe droughts are expected to significantly increase in the future, and some regions may even suffer record-breaking super-droughts.



2021 US super drought
- Worst drought in 1200 years
- 150 million people affected



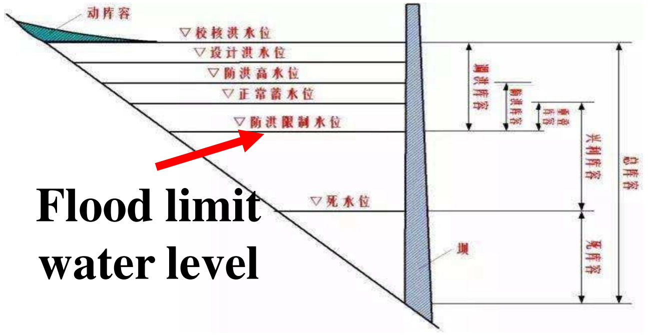
2009-2013 consecutive drought in five southwest provinces
- Economic Losses of ￥19 Billion.
- 51 million people affected



2020 European drought
- Worst drought in 500 years

Background

- China Ministry of Water Resources realized the lack of accuracy and scientific in management of drought prevention measures, including inaccurate timing of decision-making or excessive emergency responses.
- Drought-limited water level （DLWL） is proposed **as a key indicator for drought warning and reservoir operation**, hope to be as useful as the flood limit water level.



Flood limit warning water level
（Yangtze River&Wuhan）

Basic Theory	key Technology	Decision Support	Promotion and Application
National Natural Science Foundation of China "Research on staged drought-limited water level and drought Resistant Regulation of reservoirs at different drought levels"	**The Preliminary Plan of the Ministry of Water Resources** “National pilot for determining the drought-limited water level (flow) of rivers, lakes, and reservoirs"	**Royal Academy Major Consulting Project** "Study on the comprehensive strategy to address droughts and floods in China “	Determination of drought-limited water levels and compilation drought relief regulation of reservoir for six reservoirs, including the Fenhe Reservoir in Shanxi Province

2012 → **2020** → Research for nearly **10** years

Background

➢ The essence of drought is a water shortage. The core of determining the DLWL in the optimization and allocation scheduling of water resources under drought conditions, coupled with the uncertainty of drought development.

Three practical problems

Res-ponse time

The uncertain development of the drought → difficult to accurately study the development trend of cross-monthly scale

Scheduling basis

How much? For whom? How to use?

旱情 需求 工程 区域 部门 用户 时机 次序 水量

decision-making system

pre-plan, forewarning, prolusion, forecast + Engineering measure / Non-engineering measure

Integrated decision-making?

Three scientific problems

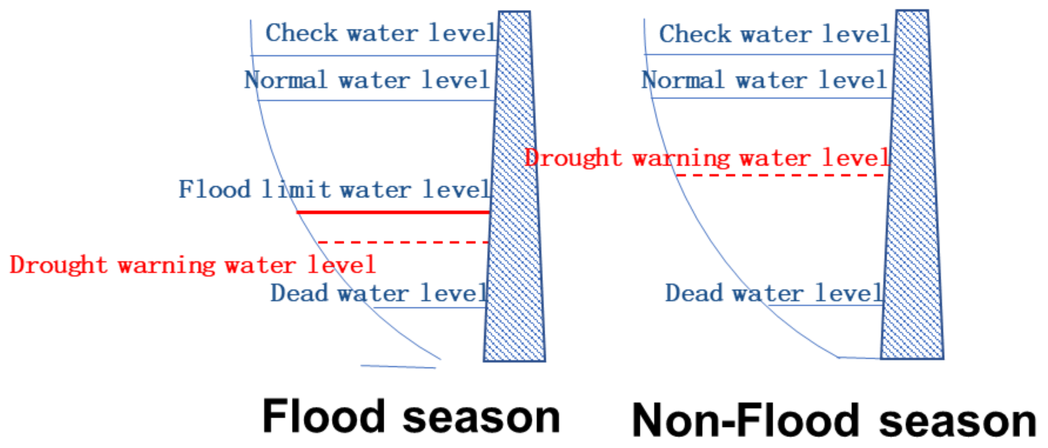
1. Nonlinear evolution of drought and response mechanism of water resources system
2. Basic theory of critical threshold of water resources system & DLWL determination
3. Drought prevention and control mechanism based on DLWL

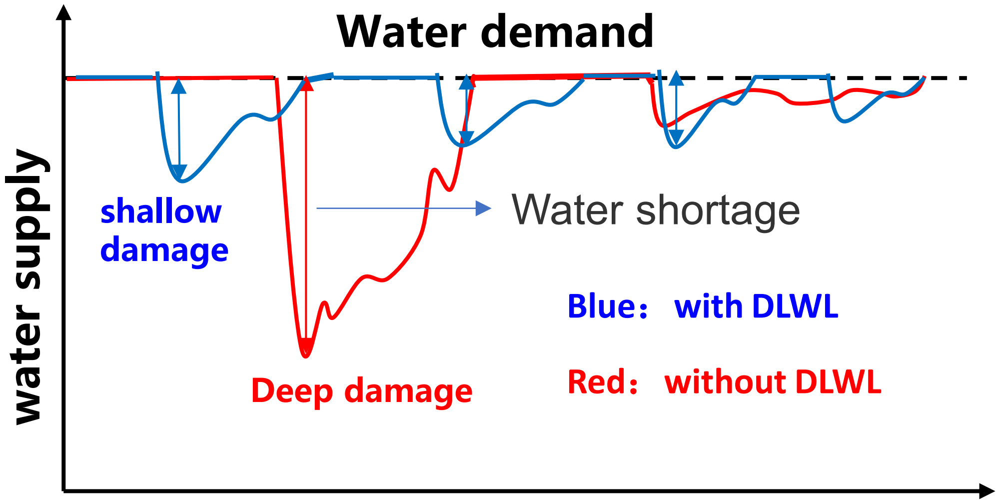
2. Methods

02

Methods

- The DLWL serves as a symbol of **the shift in reservoir operation from normal operation to emergency**.
- **Risk hedging: Hedging Large Risks with Small Risks.** When the water level in the reservoir is below the DLWL, a certain degree of restriction is set on the water supply of each user, thus reserving water in the reservoir for coming drought.
- Method: scientific and practical

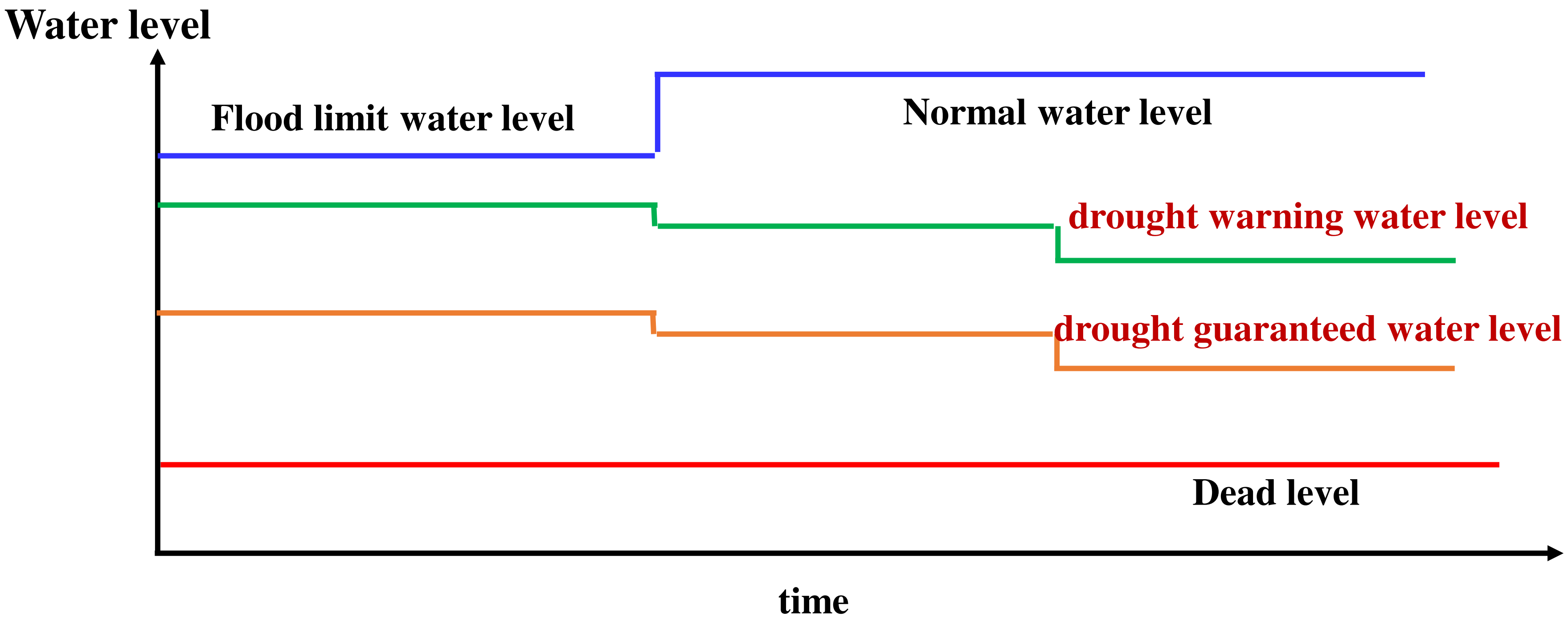




Methods

■ The graded and staged drought-limited water level

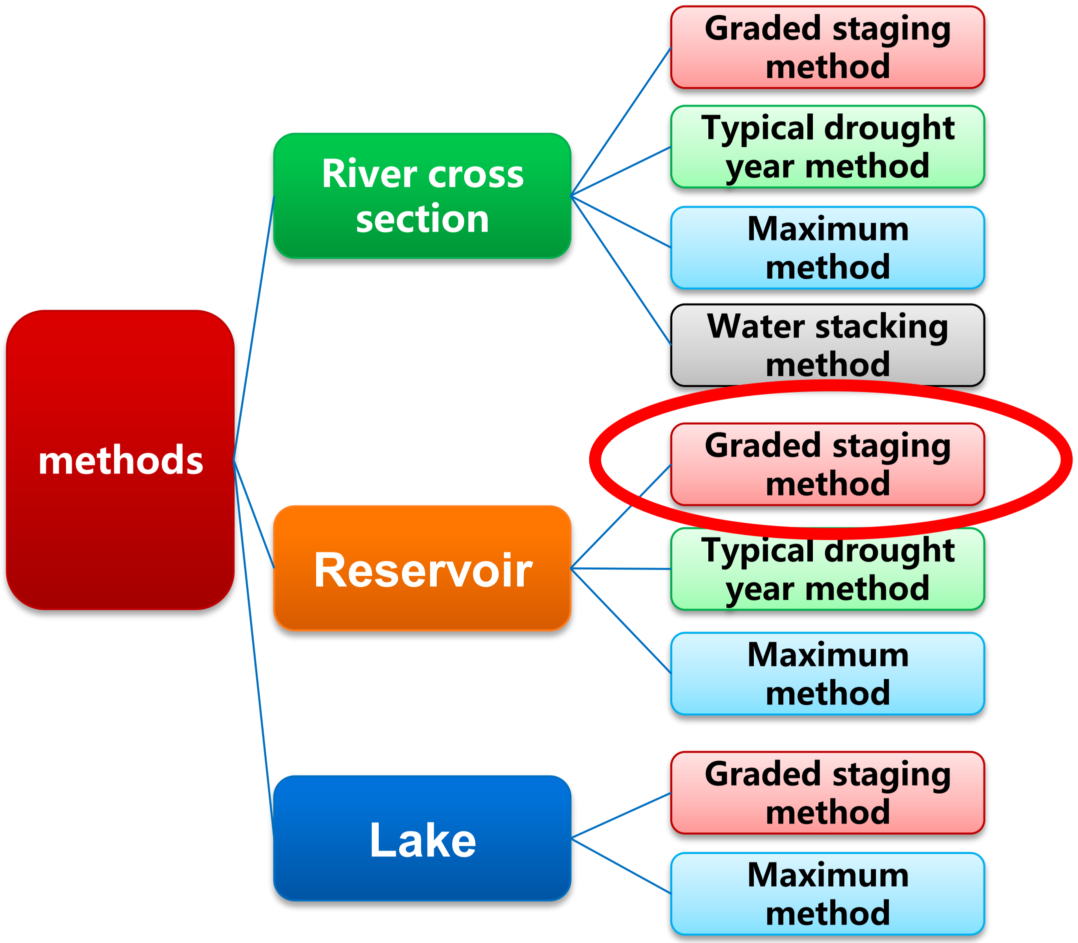
- ◆ **To cope with different degrees of drought, the DLWL is set into drought warning water level for mild drought and drought guaranteed water level for extreme drought.**
- ◆ **the DLWL in a hydrological year are divided into stages such as flood season, drought period, and irrigation period.**



Methods

- **4 major categories of drought-limited water level determination methods were built, solving the problem of applicability of drought-limited water level for different types of rivers, lakes and reservoirs.**

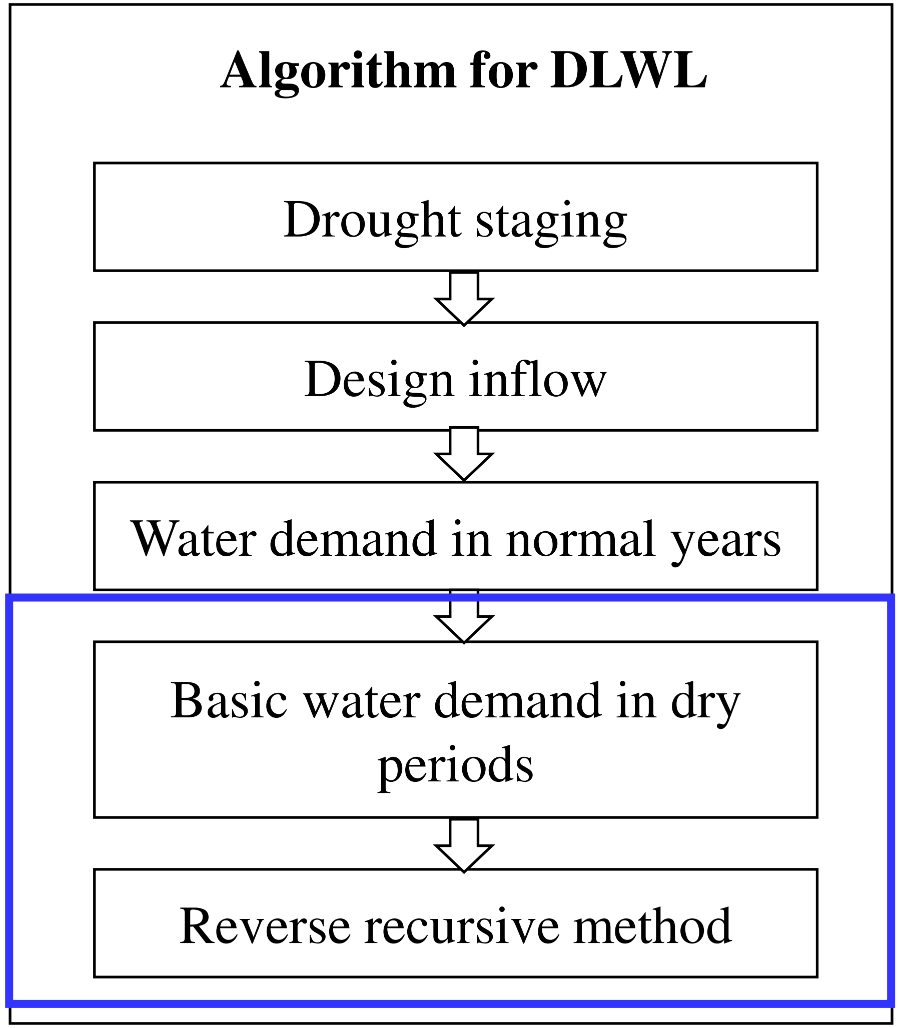
Methods	Key points	Advantages	Limitations
Graded staging method	Considering the requirements of multi-objective water demand and water intake projects in different drought degrees	Strong applicability, high precision and can be graded and staged	The calculation process is complicated
Typical drought year method	The maximum water level during a drought in a typical drought year	Simple operation and clear concept	Only 1 control indicator for the whole year
Maximum method	The maximum water level (traffic) of each type of user	Simple operation and clear concept	Only 1 control indicator for the whole year and the engineering constraint ratio is significant
Water stacking method	The sum of the corresponding ecological flow and water intake flow of the river section	Simple operation and clear concept	Only 1 control indicator for the whole year



2.1 The reverse order recursive algorithm

Main steps

- Hydrological years are divided into stages such as flood season, drought period, and agricultural irrigation period, according to the law of water use
- Use inflow in the drought years(P=75%, 95%) as the design inflow
- Obtain the water demand for normal years through investigation
- Obtain basic water demand for drought years
- Calculate the DLWL with a reverse order method



2.1 The reverse order recursive algorithm

■Water demand analysis——empirical coefficient

- **An empirical water demand adjustment coefficient** is determined according to the "**National Flood Control and Drought Relief Emergency Plan**". The product of water demand in normal years and water demand adjustment coefficient of each industry is used as **the water demand in drought years**.

Socio-economic water	Shipping water	Ecological water
Survey statistics Quota calculation Model adjustment	Inland Waterway Navigation Standards	Tennant method minimum area method

Corresponding grade	Domestic water demand adjustment coefficient	Industrial water demand adjustment coefficient	Agricultural water demand adjustment coefficient
Drought warning water level	0.90~0.95	0.90~0.95	≥0.70
Drought guaranteed water level	≤0.70	≤0.70	≤0.20

2.1 The reverse order recursive algorithm

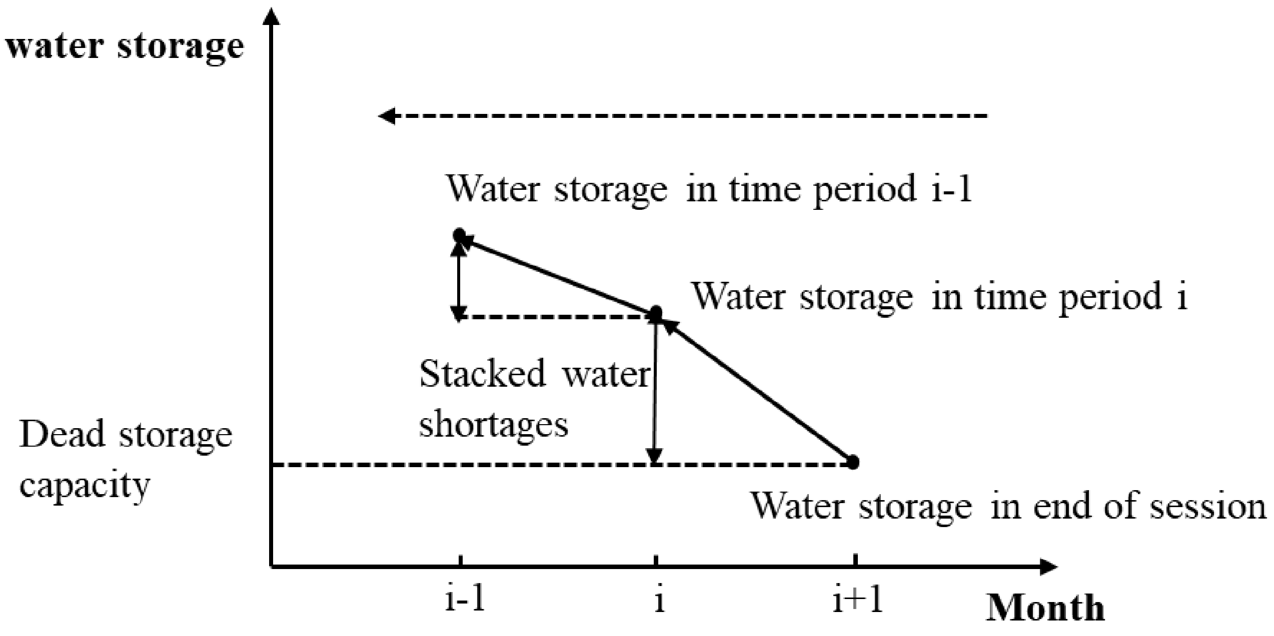
■ Reverse order algorithm

- **Assuming that the dead level is reached at the end of the scheduling period, the reverse order recursive method is used to accumulate the difference between the inflow and water demand of the reservoir in the drought year month by month to obtain the monthly DLWL**

$$Z_{hj,t} = f\left(\sum_{i=1}^{n} N_{i,t} \times a_i + W_{loss,t} - W_{p1,t} + f'(Z_{hj,t+1})\right)$$

$$Z_{hb,t} = f\left(\sum_{i=1}^{n} N_{i,t} \times b_i + W_{loss,t} - W_{p2,t} + f'(Z_{hb,t+1})\right)$$

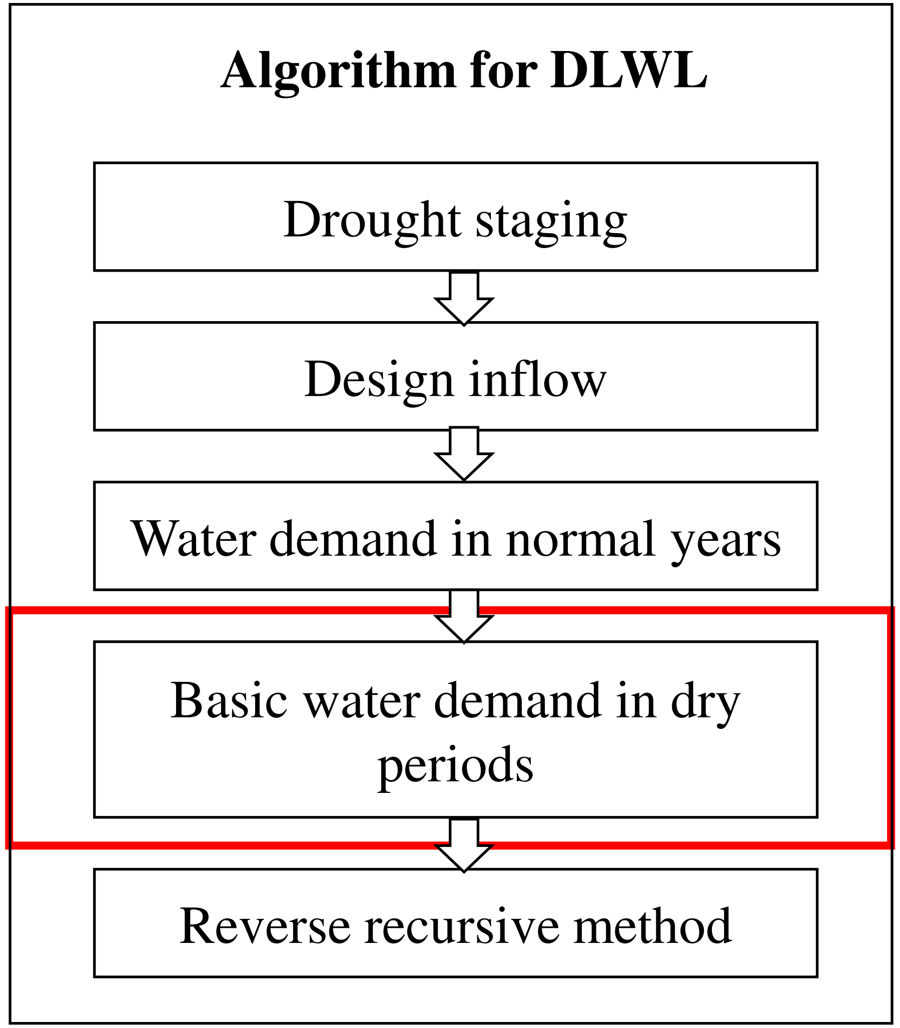
$$Z_E = Z_D$$



2.2 Optimization method for DLWL based on NSGA-II

■Water demand analysis——optimized coefficient

- In order to achieve the most reasonable water supply restriction for each user during the drought period, a multi-objective optimization model for the water demand adjustment coefficient is constructed.
- Based on the principle of wide and shallow damage, the objective function is the average and standard deviation of monthly water shortage rate in drought years (P ≥ 75%);
- The low average water shortage rate indicates a weak degree of water shortage; The small standard deviation of water shortage rate indicates a small change in all periods.



2.2 Optimization method for DLWL based on NSGA-II

■ Optimization coefficient

(1) Objective function:

- The average monthly water shortage rate is minimum

$$SR_t = \left(\sum_{i=1}^{n} N_{i,t} - \sum_{i=1}^{n} W_{i,t}\right) / \sum_{i=1}^{n} N_{i,t}$$

- The SD of the water shortage rate in drought years is minimum

$$\bar{\sigma} = \sqrt{\frac{\sum_{t=1}^{T}\left(SR_t - \bar{SR}\right)^2}{T}}$$

(2) Decision variable:

Adjustment coefficient for water demand

(3) Constraints:

a. Constraints of water balance
b. Constraints of reservoir water level constraint
c. Constraints of water supply flow constraint
d. Constraints of drought limited water level supply strategy

(4) Optimization algorithm:

Multi-objective and non-dominated sorting genetic algorithm (NSGA-II)

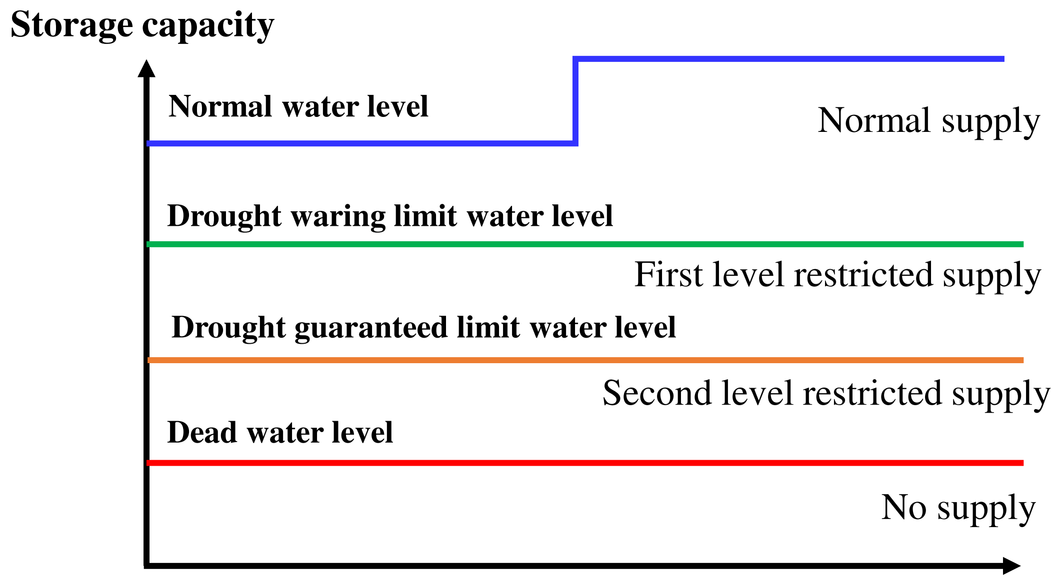
2.3 Drought prevention based on risk prediction and DLWL

Reservoir operation rules based on DLWL

- **when the water level is lower than the DLWL, the water demand of each user should be limited according to the water demand adjustment coefficient.**
- **The water reserved by each user is stored in the reservoir to avoid serious irreparable water shortage damage during subsequent drought periods.**

Water supply rules

$$\begin{cases} WS(i,t) = N(i,t), & Z_t > Z_{hj,t} \\ WS(i,t) = N(i,t) \times a_i, & Z_{hj,t} > Z_t > Z_{hb,t} \\ WS(i,t) = N(i,t) \times b_i, & Z_t < Z_{hb,t} \end{cases}$$

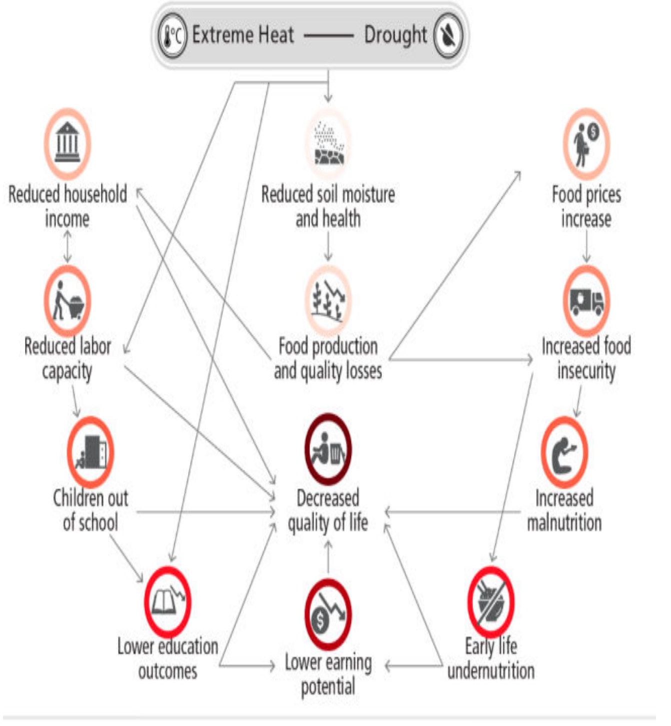


2.3 Drought prevention based on risk prediction and DLWL

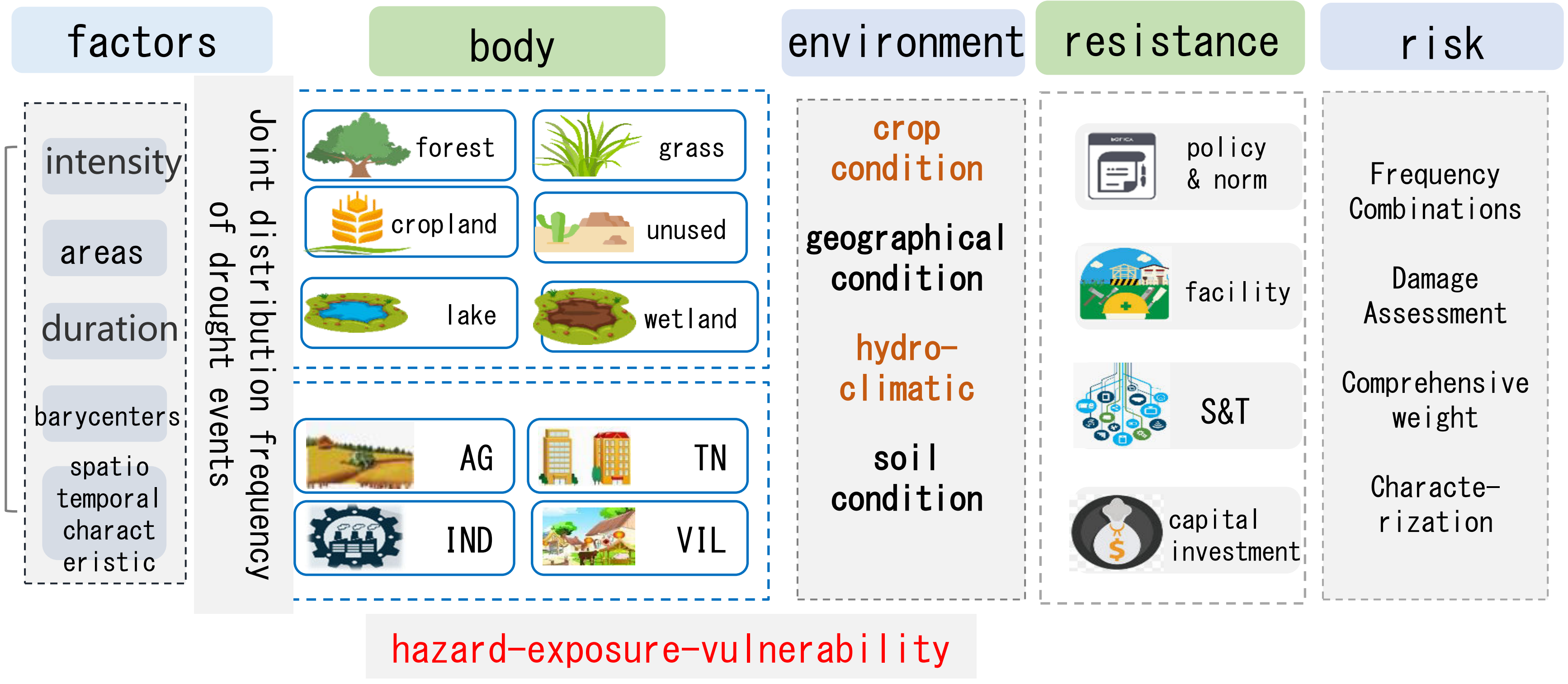
Drought Risk Assessment Techniques

- **Based on the analysis of drought risk impact pathways, the DLWL is integrated into the early warning index, taking into account the inherent uncertainty of risk. A comprehensive Drought Risk Assessment Techniques System is proposed, which comprises diagnostic analysis, damage assessment, resistance assessment, and risk characterization.**

Drought risk impact pathways



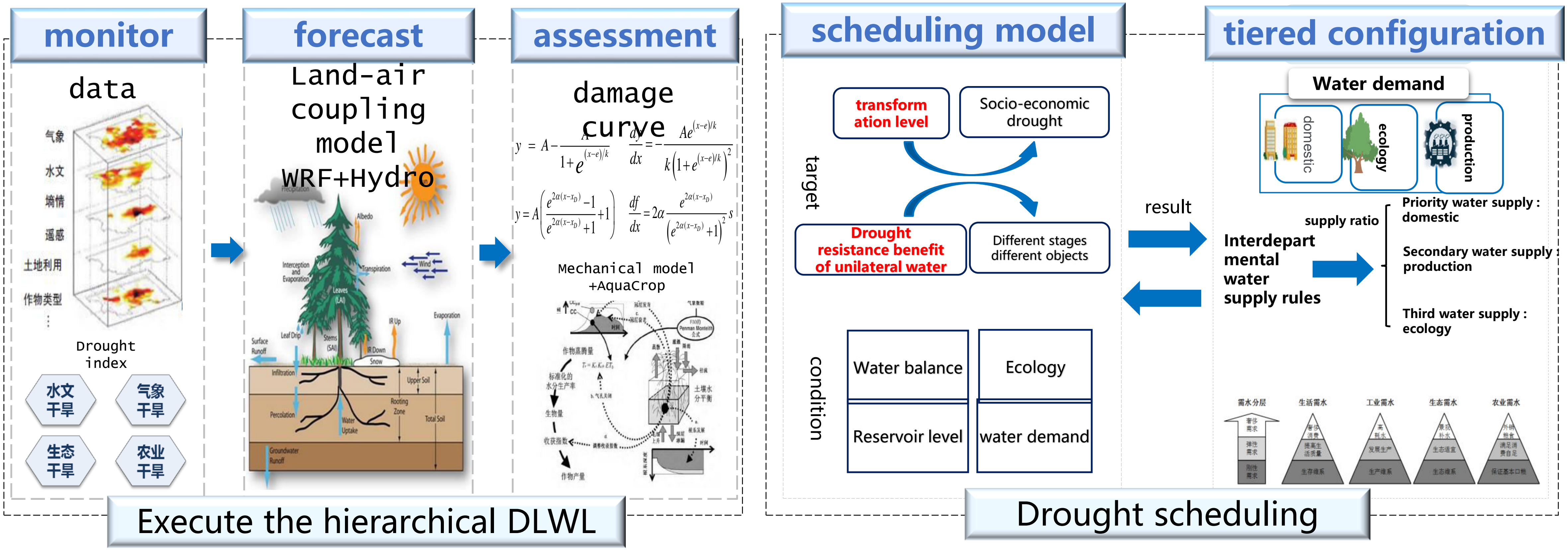
Drought risk assessment



2.3 Drought prevention based on risk prediction and DLWL

Drought scheduling model technology of river, lake and reservoir

- Utilizing **the DLWL as the initial condition for drought scheduling**, a technical system consisting of "**monitoring-forecasting-evaluation**" is established.
- Based on the theory of hierarchical allocation, hedging, and critical control of drought-resistant water sources, the model technology known as "**target analysis - hierarchical scheduling - real-time coupled with forecast information**" has been developed.



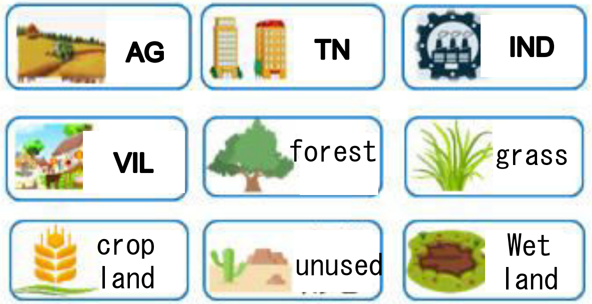
2.3 Drought prevention based on risk prediction and DLWL

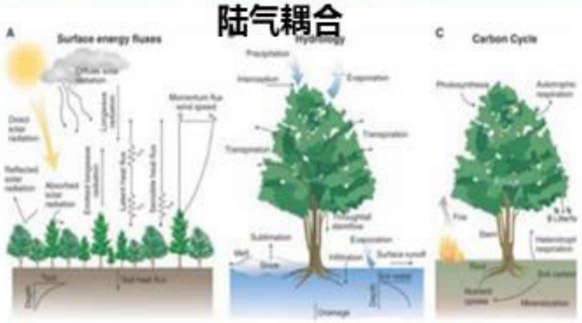
Drought prevention and dispatch decision technology system

- The **DLWL** is used to connect all aspects of drought prevention, and the drought prevention dispatching system of "**monitoring and forecasting - program generation - benefit evaluation and intelligent decision-making**" is established to realize the integrated decision support of "**massive plan pre-storage, automatic response matching, intelligent optimization and recommendation**"

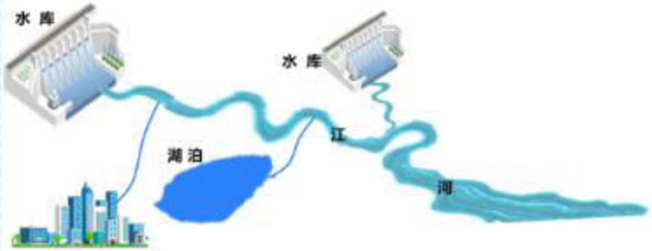
Monitoring & Warning → Initiating response → source Exploitation & Drought simulation → decision → Optimize scheduling& Recommended solutions; feedback ←

Monitoring and forecasting





Defense decision simulation



The "break" rule

α_1 * D_1 Domestic water requirement

α_2 * D_2 Agricultural water requirement

α_3 * D_3 Domestic water requirement

α_4 * D_4 Industrial water demand

Hierarchical control threshold

Evaluation of benefit

Water use efficiency function

$$C(S_i) = P - \frac{1-\gamma}{\gamma}\left[\frac{\alpha(N_i - S_i)}{1-\gamma} + \beta\right]^{\gamma}$$

$$\gamma < 1, \beta \geq 0 。$$

Agricultural	Industrial	domestic
Aquacrop crop growth model Loss curve index method	Var industry and water use coordination degree Water use efficiency function	Water supply Water quality Total population Drinking threshold

3. Applications

03

Application

- **The methods have been adopted by China Ministry of Water Resources and applied to the determination of DLWL of 1278 stations in 2022**

水利部办公厅文件

办防〔2022〕194 号

水利部办公厅关于做好 2022 年旱警水位(流量)确定及应用工作的通知

各省、自治区、直辖市水利(水务)厅(局),新疆生产建设兵团水利局,各流域管理机构:

旱警水位(流量)是指江河湖库因来水偏少,水位(流量)偏低,可能影响相关区域生活、生产、生态用水安全,应予以关注或采取抗旱措施的水位(流量)。为贯彻落实李国英部长在全国水旱灾害防御工作视频会议上"加快推进江河湖库旱警水位(流量)确定工作"的要求,近期水利部防御司会同各流域管理机构、各省级水行政主管部门汇编完成《2022 年江河湖库旱警水位(流量)测站名录》

— 1 —

旱警水位（流量）管理办法

第一章 总则

第一条 为提升干旱灾害防御能力，补强预报、预警、预演和预案等工作的短板，提高公众旱灾风险意识，依据《中华人民共和国水法》、《中华人民共和国抗旱条例》等法律法规，制定本办法。

第二条 本办法所称旱警水位（流量），是指因江河湖库可供水量持续偏少（水位偏低或流量偏小），流域或区域正常生活生产、重要生态敏感区等面临缺水风险，应予以关注或采取抗旱措施的相应监测站点水位（流量）。

第三条 旱警水位（流量）管理工作包括站点规划、确定审核、发布运用、监督评估等部分。

第四条 旱警水位（流量）的管理应与流域、区域防汛抗旱、水资源等规划相衔接，与防洪调度方案、水资源调度方案、应急水量调度方案、生态流量保障实施方案等相协调。

第五条 旱警水位（流量）管理应坚持流域区域统筹、属地管理、分级负责的原则。

水利部负责组织、指导、监督全国旱警水位（流量）管理工作。

流域管理机构负责大江大河及其重要支流的江河断面、湖泊、水库和跨省江河断面、湖泊、水库的旱警水位（流量）

1

附件 2

江河湖库旱警水位（流量）计算方法案例

1 概述

江河湖库旱警水位（流量）是指江河湖库因来水偏少，水位（流量）偏低，可能影响相关区域生活、生产、生态用水安全，应予以关注或采取抗旱措施的水位（流量）。

旱警水位（流量）可根据来水规律、用水需求、工程管理需要等情况，分时段设置不同的水位（流量）。一般将枯水期作为干旱预警时段；对于汛期有抗旱需求的地区，也可将汛期纳入干旱预警时段。干旱预警时段也可根据需水特征划分出农业用水关键时段、生态用水关键时段等。

旱警水位（流量）一般不分级。若确有需要，可分为 2 级。

2 江河旱警水位（流量）计算方法案例

江河旱警水位(流量)计算方法主要包括典型干旱年法、最大值法、水量叠加法和综合法。

2.1 典型干旱年法

技术要点：以典型干旱年干旱期间江（河）段各月月均流量的最大值作为旱警流量，其对应的水位为旱警水位。具体步骤如下：

1

附件 1

2022 年江河湖库旱警水位（流量）测站名录

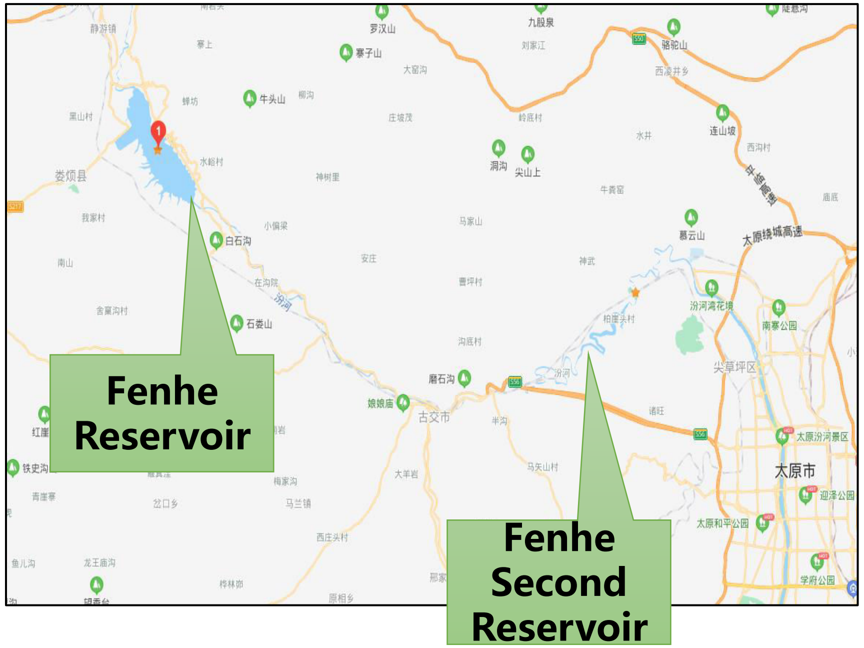
流域（片）	序号	站码	站名	类型	省级行政区	地级行政区	县级行政区	流域	涉及供水对象	责任单位
总计:1278 个										
长江	合计：578 个									
	1	60114700	安庆	河道	安徽	安庆市	大观区	长江	安庆市	长江委
	2	60115000	大通(二)	河道	安徽	池州市	贵池区	长江	池州市	
	3	62913900	襄河口闸上	闸坝	安徽	马鞍山市	和县	长江	和县	
	4	62016400	郭滩	河道	河南	南阳市	唐河县	长江	唐河县	
	5	62011800	新店铺(三)	河道	河南	南阳市	新野县	长江	新野县	
	6	61703000	崇阳(二)	河道	湖北	咸宁市	崇阳县	长江	崇阳县城生态用水	
	7	61802700	丹江口水库	水库	湖北	十堰市	丹江口市	长江	丹江口市，淅川县，郧阳区，襄阳市	
	8	60110100	调弦口	河道	湖北	荆州市	石首市	长江	调关镇以及桃花山镇部分地区	
	9	61004810	高坝洲	水库	湖北	宜昌市	宜都市	长江	高坝洲镇城区居民	
	10	60112200	汉口	河道	湖北	武汉市	江汉区	长江	长江武汉段	
	11	60108900	郝穴(二)	河道	湖北	荆州市	江陵县	长江	江陵县城，荆州新材料新能源产业基地	
	12	61802800	黄家港(二)	河道	湖北	十堰市	丹江口市	长江	丹江口市，襄阳市	
	13	61902580	黄龙滩水库	水库	湖北	十堰市	张湾区	长江	东风首创水务公司、十堰市城区供水	
	14	60112900	黄石港	河道	湖北	黄石市	黄石港区	长江	黄石城区、鄂州花湖、新港物流园区	

1

3.1 Case study

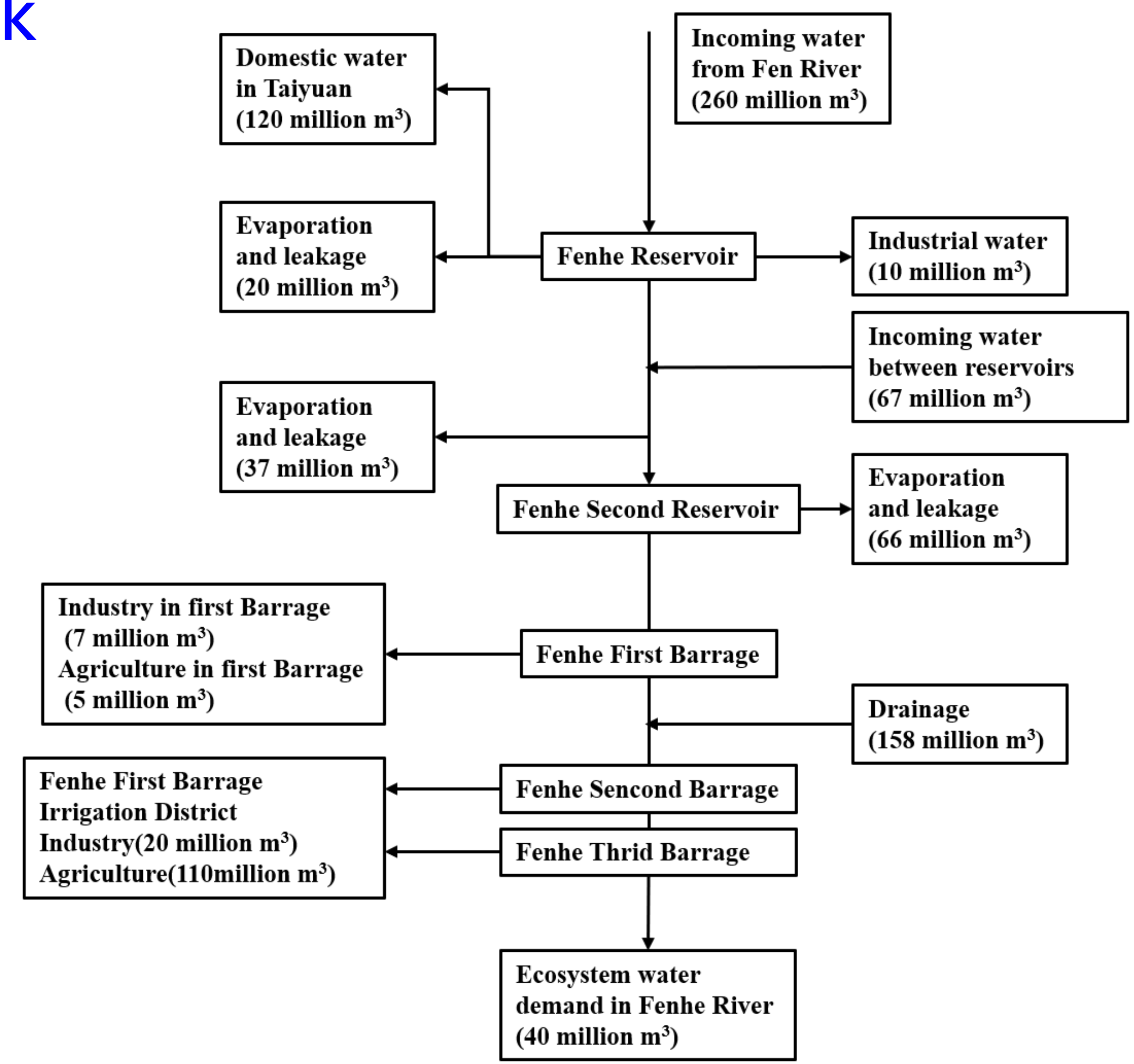
- **Geographical position:** The Fenhe Reservoir is located in the upstream of the main stream of the Fenhe River, in Shanxi province， with a storage capacity of 226 million m³, the Fenhe Second Reservoir is located downstream of Fenhe Reservoir, with a storage capacity of 47.5 million m³。
- According to historical records, the Fenhe River Badin experienced over 300 droughts between the 15th and 20th centuries; In the second half of the 20th century, there were 41 years of drought in the whole watershed, with frequent occurrences of continuous drought.

Cascade Reservoirs



■ Water resource system network

- ◆ The order of water supply objects are: **domestic, ecological, industrial and irrigation**;
- ◆ The main water users are downstream of the Fenhe Second Reservoir , The total water consumption is about 435 million m^3



3.2 water allocation without DLWL

■ Average and standard deviation of water shortage rate during drought years

- **the average monthly water shortage rate in a drought year (P≥75%) is 32%, The fluctuation of water shortage rate is significant**
- **the water shortage rates for domestic and irrigation are 25% and 53% respectively.**

Average and standard deviation of monthly water shortage rate in drought years (P ≥ 75%) under no-drought-limit water level

Water shortage rate	domestic	Ecology	Upstream industry	Downstream industry	Agriculture	Total water consumption
Average	25.1%	36.6%	55.7%	56.2%	52.7%	31.6%
Standard deviation	0.288	0.380	0.495	0.491	0.268	0.283

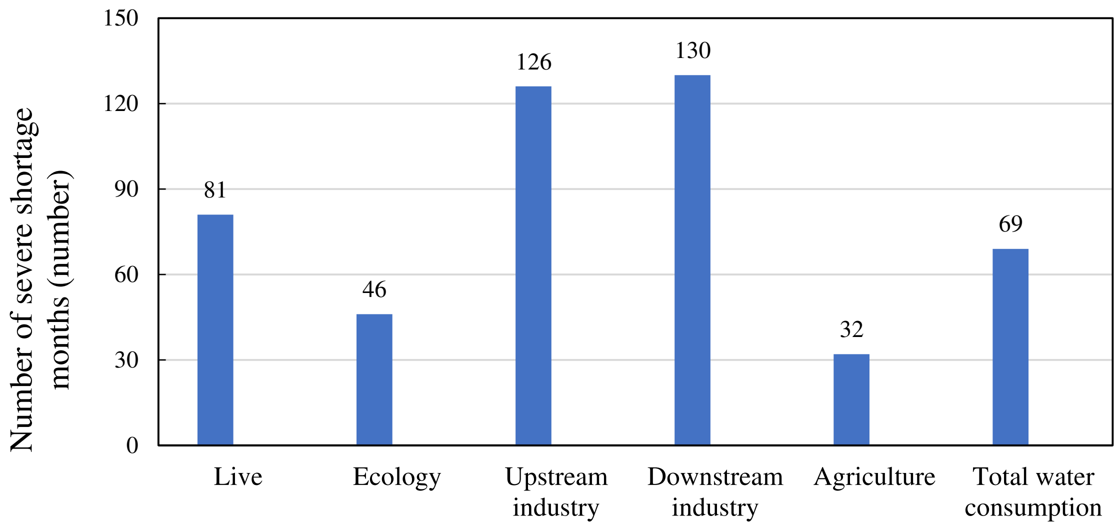
3.2 water allocation without DLWL

■ Number of months with severe water shortage

- **Without DLWL, The situation of water shortage is relatively serious, with more severe water shortage months.**
- **There were 81, 126, 46, 130, and 32 months with severe water shortage in domestic, upstream industry, ecology, downstream industry, and agriculture , respectively.**

Number of severe water shortage months for each user and their proportion in all months under no-drought-limit level

Users	Threshold of water shortage rate	Number of severe shortage months (number)	Proportion of all months
domestic	30%	81	12%
Ecology	80%	46	7%
Upstream industry	50%	126	19%
Downstream industry	50%	130	19%
Agriculture	80%	32	5%
Total water consumption	50%	69	10%



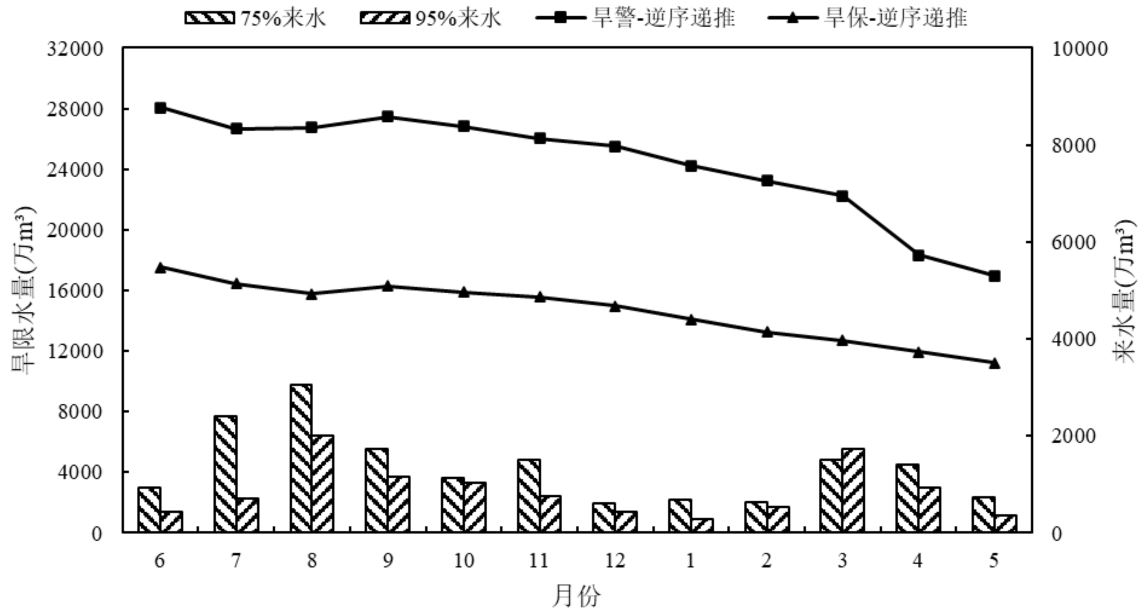
3.3 Determination and application of DLWL

■DLWL based on empirical water supply coefficient

- Referring to the " **National Flood Control and Drought Relief Emergency Response Plan** ", the water demand adjustment coefficients of each user are set for DLWL.
- **the DLWL(storage)** of Fenhe Reservoir and Fenhe Second Reservoir can be obtained with reverse order algorithm based on **empirical coefficient**
- When the **total water volume** of two reservoirs **is lower than the DLWL**, the water demand of each user is limited by the water demand adjustment coefficient.

Water adjustment coefficient for each user in drought years

Users	domestic	Ecology	Upstream industry	Downstream industry	Agriculture
Drought warning water volume	0.95	0.7	0.9	0.9	0.7
Drought guaranteed water volume	0.7	0.2	0.7	0.7	0.2

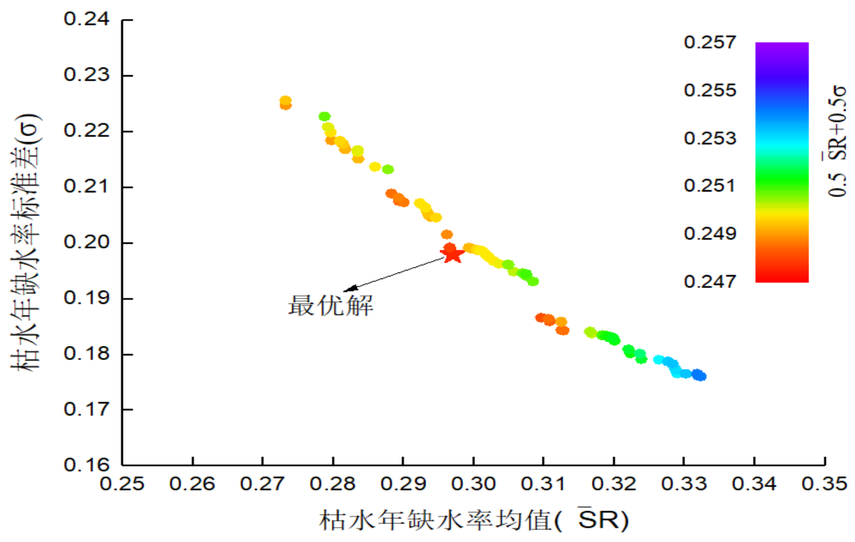


Drought-limited water level determination based on the reverse order recursive algorithm

3.3 Determination and application of DLWL

■DLWL based on optimized water supply coefficient

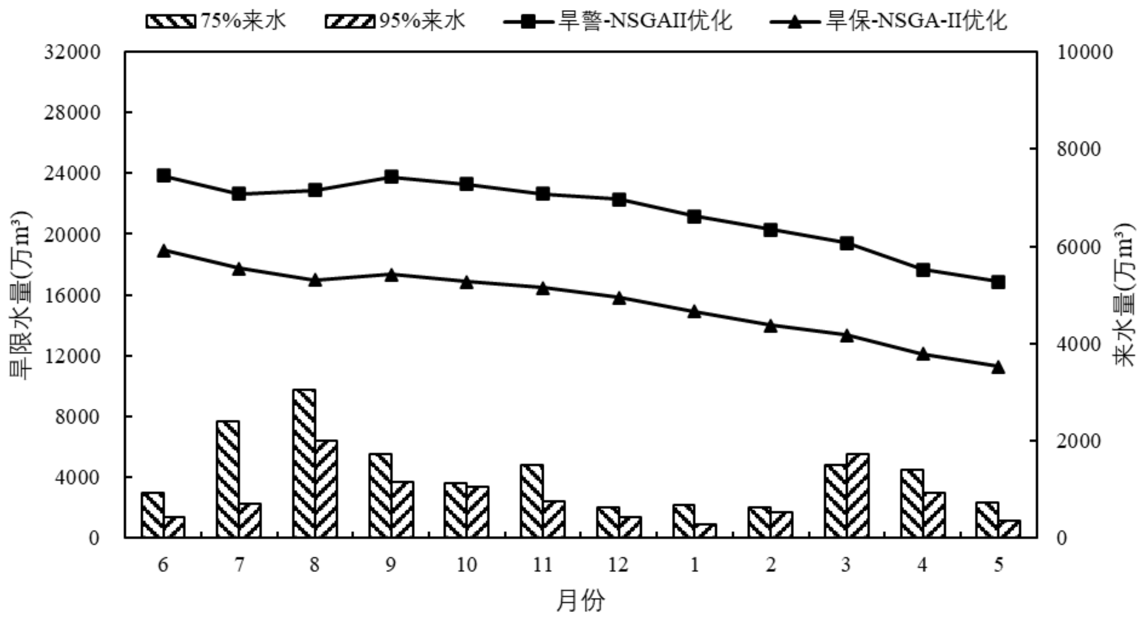
- **Based on the optimization algorithm, the optimized coefficients of water demand for each user are determined, and the optimized monthly drought-limited water storage is obtained with the reverse order recursive algorithm.**



Water adjustment coefficient for each user in drought years based on NSGA-II optimization

Users	Live	Ecology	Upstream industry	Downstream industry	Agriculture
Drought warning water volume	0.88	0.69	0.74	0.74	0.29
Drought guaranteed water volume	0.72	0.43	0.59	0.59	0.29

Drought-limited water level based on optimization of NSGA-II

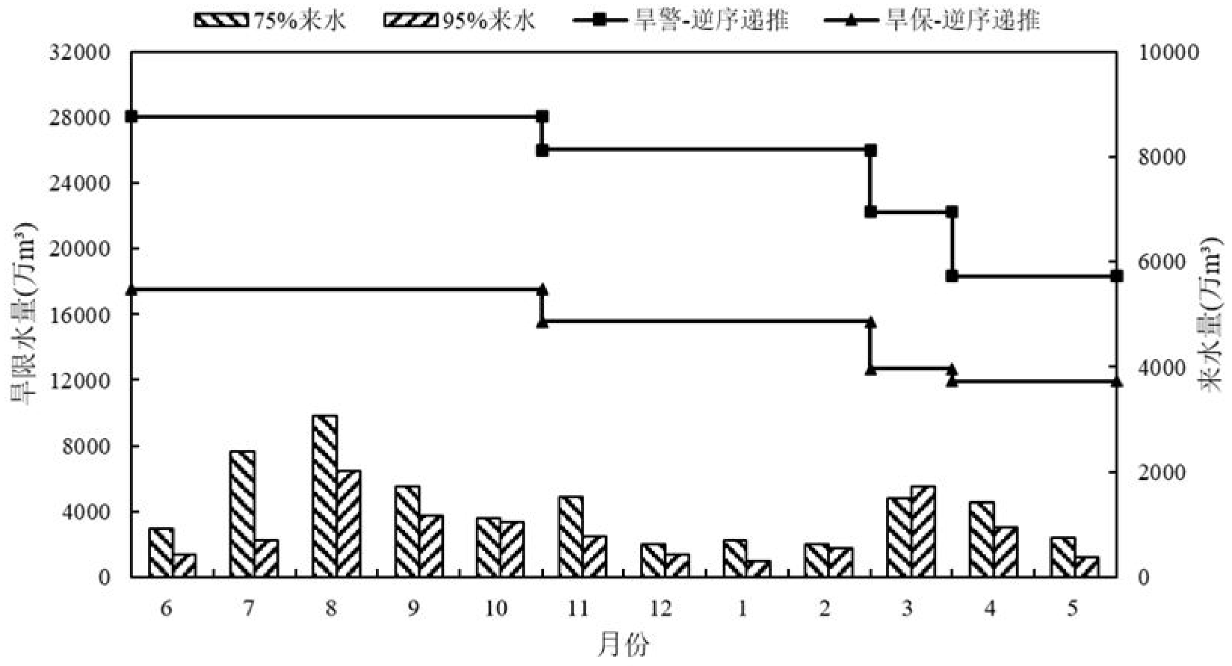


3.3 Determination and application of DLWL

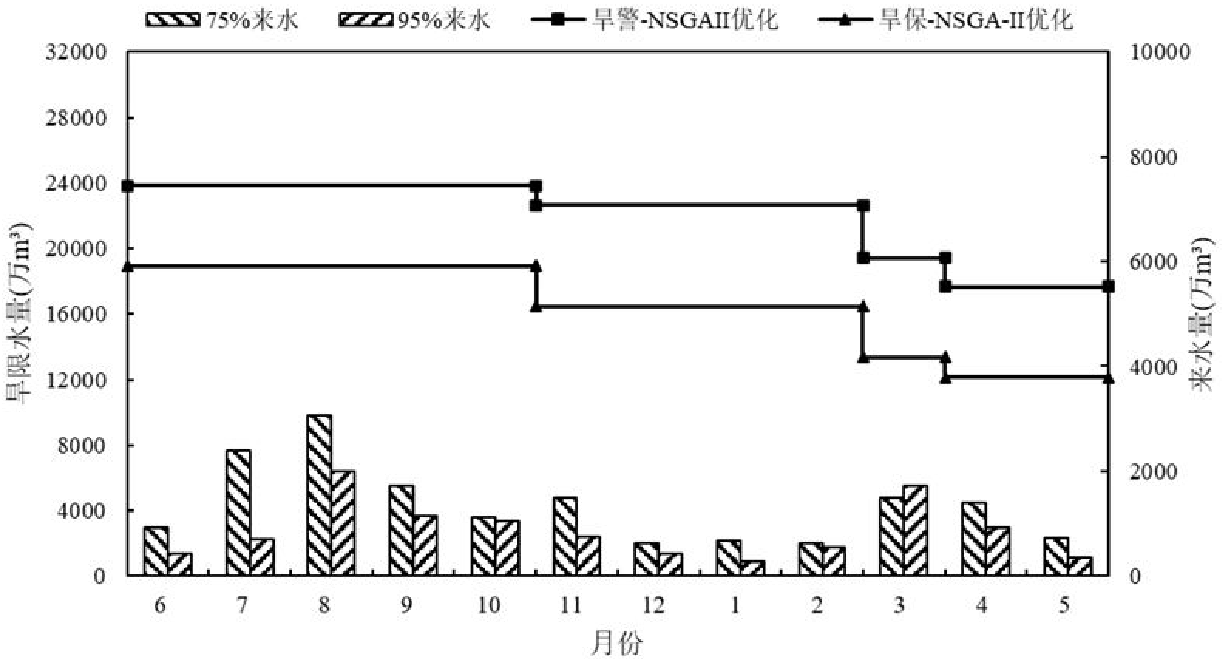
■Determination of drought limit water level

- **For the convenience of management, envelope lines are taken to obtain the DLWL for each stage.**
- **DLWL are divided in 4 parts: June-October, November-February of the following year, March, and April-May.**

Empirical DLWL



Optimized DLWL



3.3 Determination and application of DLWL

■ Effect of DLWL- Water shortage rate during drought years

- **With the empirical DLWL, compared to the situation without drought-limited water level, the average and standard deviation of the water shortage rate during the drought year have decreased, with the average water shortage rate decreasing from 31.1% to 30.9% and the standard deviation decreasing from 0.283 to 0.212.**
- **With the optimized DLWL, the total water shortage rate further decreased from 30.9% to 29.7%, and the standard deviation further decreased from 0.212 to 0.198. The average and fluctuation amplitude of water shortage rate further decreased.**

Average and standard deviation of monthly water shortage rate in drought years (P ≥ 75%)

Drought-limited water level	Water shortage rate	domestic	Ecology	Upstream industry	Downstream industry	Agriculture	Total water consumption
No-drought-limited water level	Averages	25.1%	36.6%	55.7%	56.2%	52.7%	31.6%
	Standard deviation	0.288	0.380	0.495	0.491	0.268	0.283
Drought-limited water level based on the reverse order recursive algorithm	Averages	25.0%	55.6%	51.5%	31.0%	41.1%	30.9%
	Standard deviation	0.218	0.265	0.494	0.283	0.202	0.212
Drought-limited water level based on optimization of NSGA-II	Averages	24.1%	45.5%	41.2%	40.6%	43.6%	29.7%
	Standard deviation	0.176	0.242	0.295	0.287	0.24	0.198

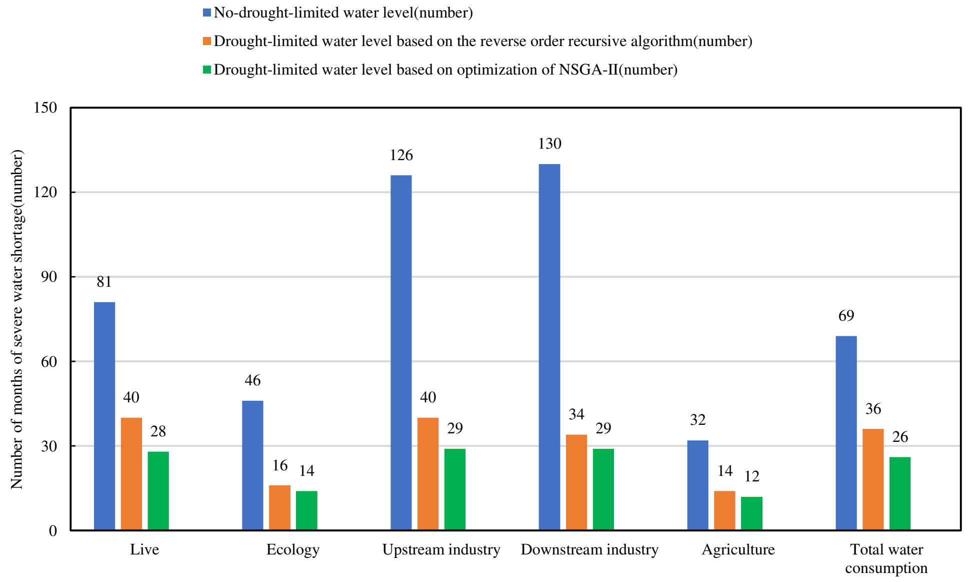
3.3 Determination and application of DLWL

■ Effect of DLWL – Number of months with severe water shortage

- ◆ with the empirical DLWL, the number of severe water shortage months for domestic, upstream industry, ecology, downstream industry, and agriculture decreased from 81, 126, 46, 130, and 32 to 40, 40, 16, 34, and 14, respectively, and the number of severe water shortage months for total water consumption decreased from 69 to 36.
- ◆ with the optimized DLWL, the number of severe water shortage months for domestic, upstream industry, ecology, downstream industry, and agriculture further decreased to 28, 29, 14, 29, and 12, and the number of severe water shortage months for total water use decreased from 36 to 26.

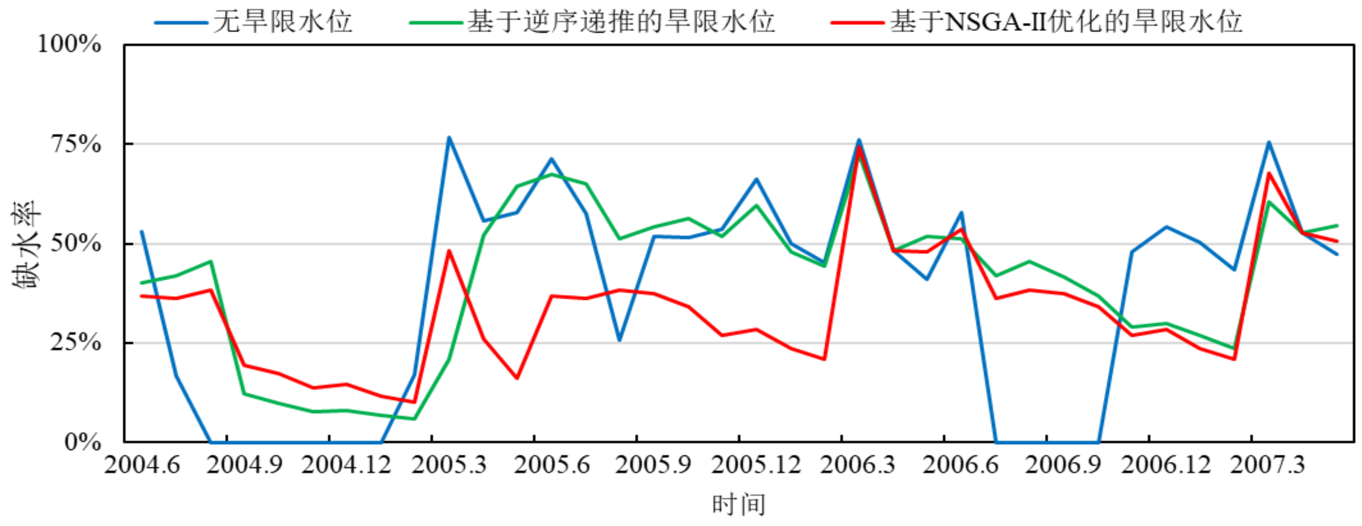
Number of months of severe water shortage for each user and percentage of all months

Users	Threshold of water shortage rate	No-drought-limited water level(number)	Drought-limited water level based on the reverse order recursive algorithm(number)	Drought-limited water level based on optimization of NSGA-II(number)
domestic	30%	81	40	28
Ecology	80%	46	16	14
Upstream industry	50%	126	40	29
Downstream industry	50%	130	34	29
Agriculture	80%	32	14	12
Total water consumption	50%	69	36	26



■ Effect of DLWL - Typical drought years

- **Overall, the average monthly water shortage and the number of months with severe water shortage have significantly decreased with DLWL. Moreover, the optimized level leads to a better drought resistance effect.**
- **with the empirical DLWL, the maximum water shortage rate decreased from 77% to 64% in 2004; in 2006, the maximum water shortage rate decreased from 76% to 60%.**
- **with the optimized DLWL, the maximum water shortage rate further decreased from 64% to 48% in 2004; In 2006, in only 3 months, the water shortage rate was greater than 40%.**



Number of severe water shortage months in the hydrological year 2004-2006

Operation rule	Months with a water shortage rate exceeding 50%
No-drought-limited water level	17
With Empirical DLWL	15
with the optimized DLWL	5

4. Conclusions

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Conclusions

1. In China, drought limited water level index system is proposed for drought warning and reservoir operation.
2. Four major categories of drought-limited water level determination methods were built, solving the problem of applicability of drought-limited water level for different types of rivers, lakes and reservoirs.
3. The reverse order recursion algorithm for DLWL of reservoirs is proposed, with empirical water supply coefficient, this method is easy to use. The optimization method is proposed to avoid the uncertainty in the empirical coefficient, and It can give more reasonable water supply restriction.
4. After setting the drought-limited water level, the drought resistance scheduling effect during drought years can be improved significantly.

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THANKS FOR YOUR ATTENTION