XVIII World Water Congress
第18届世界水资源大会

The main challenges and technical requirements of drought disaster resistance in the Yangtze River Basin

长江流域干旱灾害应对的主要难点及科技需求

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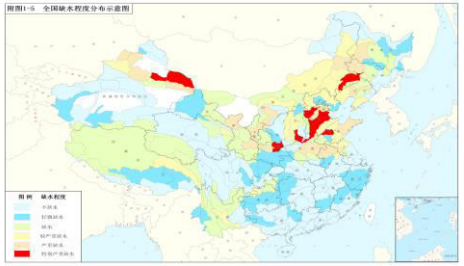
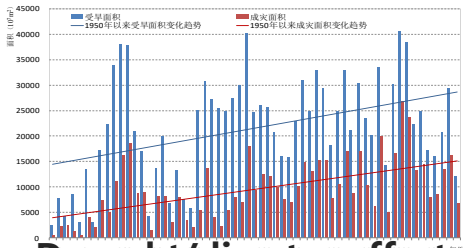
1. Background (背景情况)

- Under the effects of climate change and human activity, extreme meteorological and hydrological events occur more frequently. It showed that climate change would lead to more heavy rainfall and flood disasters as well as more serious droughts in future.

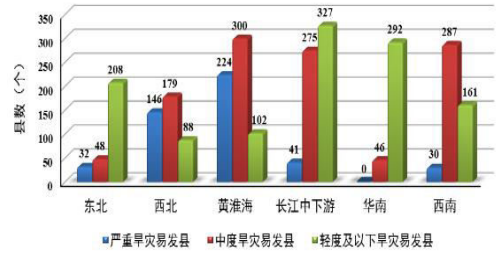
Spatial distribution of precipitation



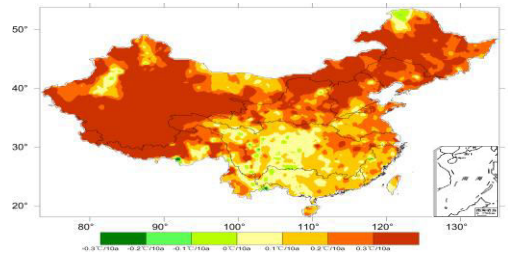
Water shortage level



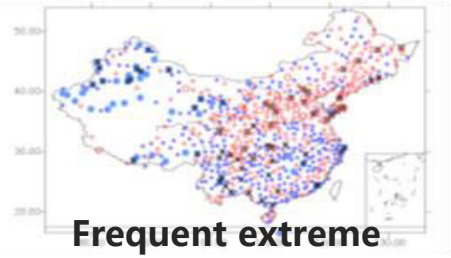
Drought/disaster-affected area change



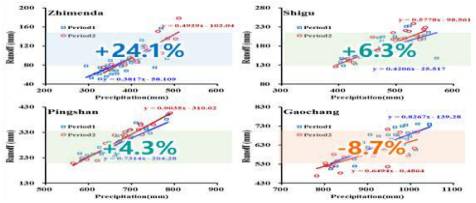
Counties prone to drought



Climate warming



Frequent extreme precipitation



Changes in precipitation-runoff relation

Increase in demand for water resources

气候变化和人类活动影响下，极端气候水文事件更加频繁和严峻。已有研究表明，未来气候变化在带来更多强降雨、洪涝灾害的同时，也会导致许多地区更加严重的干旱

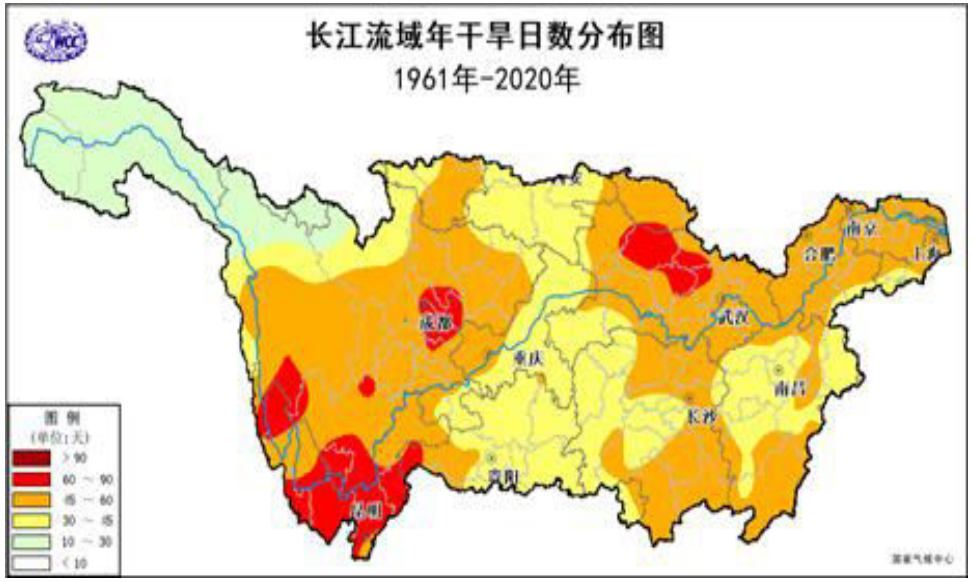
1. Background (背景情况)

- Although the Yangtze River basin is located in humid region, droughts have become more widespread and frequent in recent years, threatening the water, food, energy, shipping and ecology security.

A dry water reservoir
(Fengjie, Chongqing in 2006)

A dry pond
(Shuicheng, Guizhou in 2009)

Villagers are lining up for water
(Yanshan, Yunnan in 2011)



Distribution of dry days in the Yangtze River basin in recent 60 years

A dry tributary of Xiang River
(Hengyang, Hunan in 2013)

A drought-affected farmland
(Qianshan, Anhui in 2019)

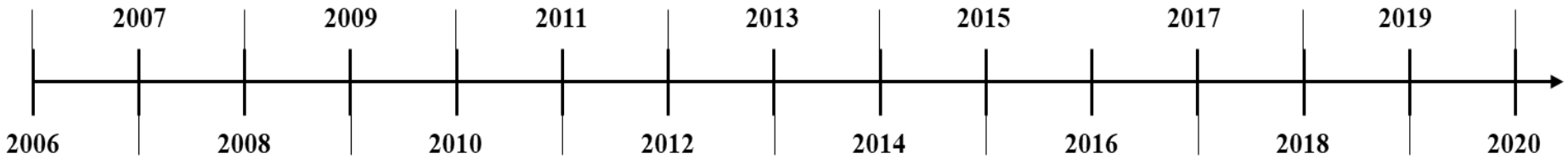
A dry water area in Jinxian Section of Poyang Lake
(Jiangxi in 2022)

长江流域虽然处于湿润半湿润地区，但近些年来干旱呈现出广发、频发的态势，威胁到流域/区域水安全、粮食安全、能源安全、航运安全和生态安全，年均直接受旱损失超过300亿元

1. Background (背景情况)

☐ Especially in the past 20 years, drought events had been hapened almost every year.

Typical drought disaster events in the Yangtze River Basin in the past 20 years



2006：西南地区冬春连旱，同年6月，重庆、四川东部以及贵州东部发生严重的夏伏旱旱情持续时间长、强度大、损失极为严重。

2007：7月下旬，湖南、重庆、江西和湖北等地出现插花旱，农作物受灾严重。

2009：西南5省发生冬春连旱，四川攀西地区连续160多天无降水。同年7月，长江中下游和西南部分地区连续高温少雨，出现秋伏旱。

2011：自2011年冬起，西南地区发生冬春连旱，3月重庆贵州旱情持续发展，作物受灾及饮水困难问题较为严重。1~8月，湖北部分地区发生春夏秋天连旱。

2013：西南地区1~6月出现冬春连旱。四川、云南和贵州等地水利工程蓄水量锐减，3省农作物受旱面积达404.64千公顷，旱情较为严重。

2015：长江中下游地区出现夏伏旱，7月，湖北、湖南和江西等人畜饮水困难问题突出。湖南境内150余座水库干涸。

2019：5-6月，湖北、四川、重庆、贵州等地农作物受干旱影响较为严重。

2007：1月，重庆、四川等地发生冬春旱。5月，太湖蓝藻大范围爆发。8月，江西、湖南等地耕地受旱严重，部分水库、山塘干涸，溪河断流。11月，长江干流湖北段、洞庭湖水位严重下降，江西湖南等地沿江城市取水困难。

2009：江南大部发生秋伏旱，7~9月江河来水严重不足，水利工程蓄水量锐减，湘江、赣江、鄱阳湖和洞庭湖均出现最低水位。湖南、江西农作物受旱严重，沿江地区用水紧张。

2011：1月，长江中下游发生春夏连旱，长江中下游地区降水严重减少，长江干流部分河段出现最低水位，5月，旱情高峰时，湖北洪湖周边饮水困难人口被迫临时动迁。10月，湘赣两江水位严重偏低。

2013：西南地区自2012年入冬后，云南、四川等地降水严重偏少，出现冬春连旱。7月长江中下游出现高温伏旱，湖南、湖北、重庆等8省（市）持续高温少雨，水利工程蓄水偏低1~5成，农作物受灾严重，人畜饮水困难。

2015：1~4月，重庆、四川等地发生春旱。其中四川西部与重庆西部地区作物受旱严重。

2017：长江中下游地区发生高温夏伏旱，湖北、湖南和安徽等地的气温突破极值，部分水库水位下降至死水位。

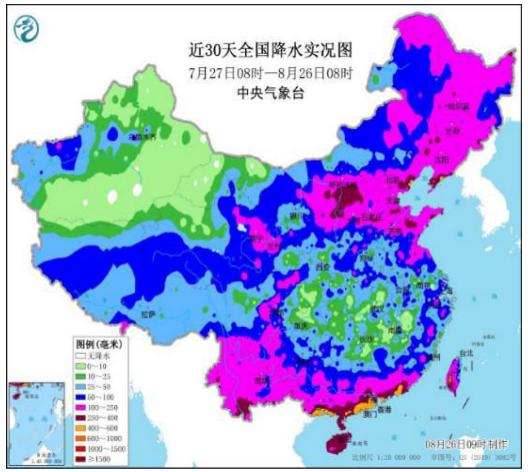
2019：8~12月，长江中下游地区发生夏秋冬连旱，旱情主要集中在湖北、江西、安徽、福建、湖南和重庆6省。

尤其是近20年来，干旱事件呈现频发态势，每1-2年都会发生不同程度的干旱

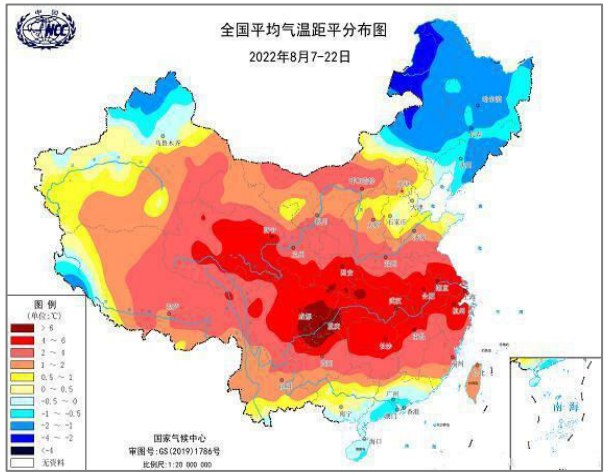
1. Background (背景情况)

- For example in 2022, the precipitation in the Yangtze River basin was the least since 1961. It was 40% less than that in the same period of normal years. In some areas, precipitation was nearly 80% less. Meanwhile, high temperature weather (>37C°) last for more than 30 days, and even more than 40 days in some areas.

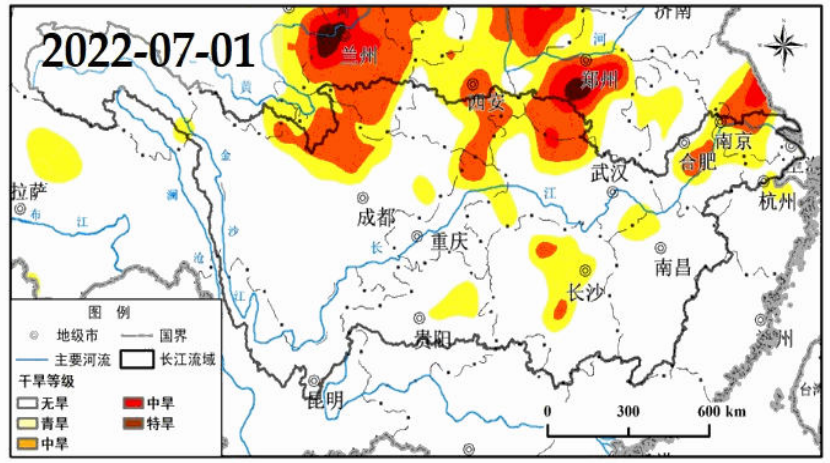
Extreme drought events in 2022



Precipitation From Jul. to Aug.



Temperature in Jul.



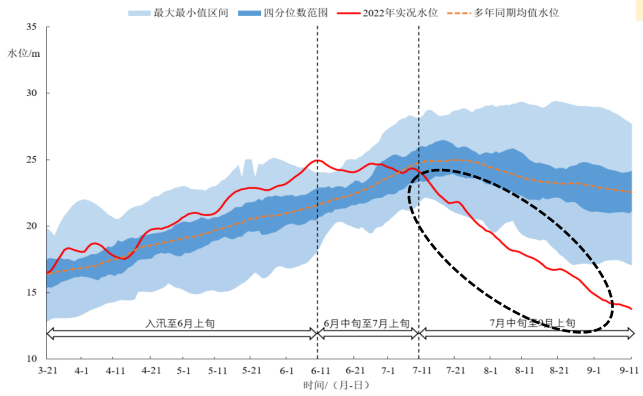
Drought process From Jul. to Aug.

长江流域降水整体较常年同期偏少四成以上，局部地区偏少八成，为1961年以来历史同期最少，高温天气持续时间超过30天，局部地区超过40天

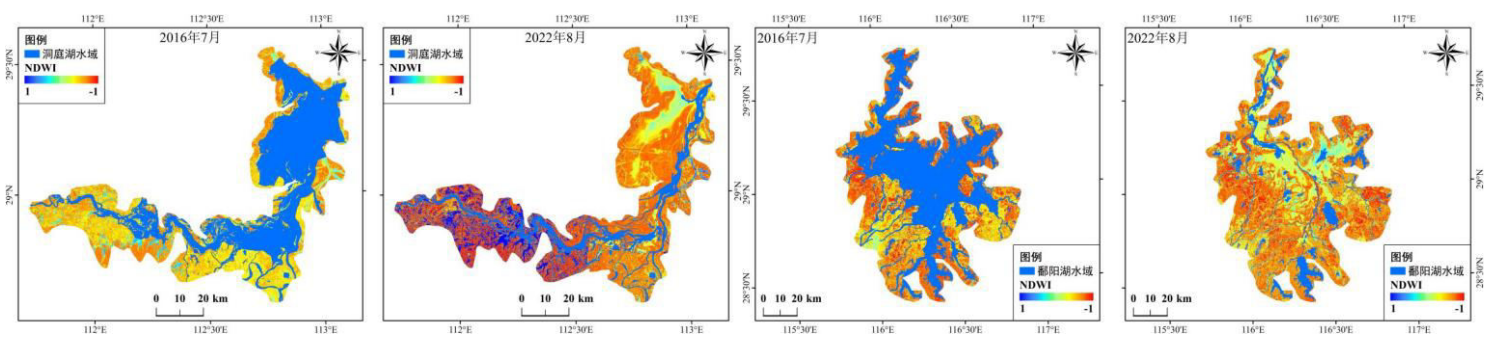
1. Background (背景情况)

- The streamflow of the Yangtze River was 20% to 80% less than that in the same period. The upper and middle reaches had the lowest runoff since 1961. The water level in Hankou Station dropped quickly until it reached to lowest level at the end of August.
- A rare situation known as "drought in flood season" occurred from July to September, as a result the water area of Dongting Lake and Poyang Lake are both reduce 75% (Compared to that in June).

Drought in flood season (2022)



Water level in Hankou Station



Water area in Dongting Lake
Reduce by 74.7%

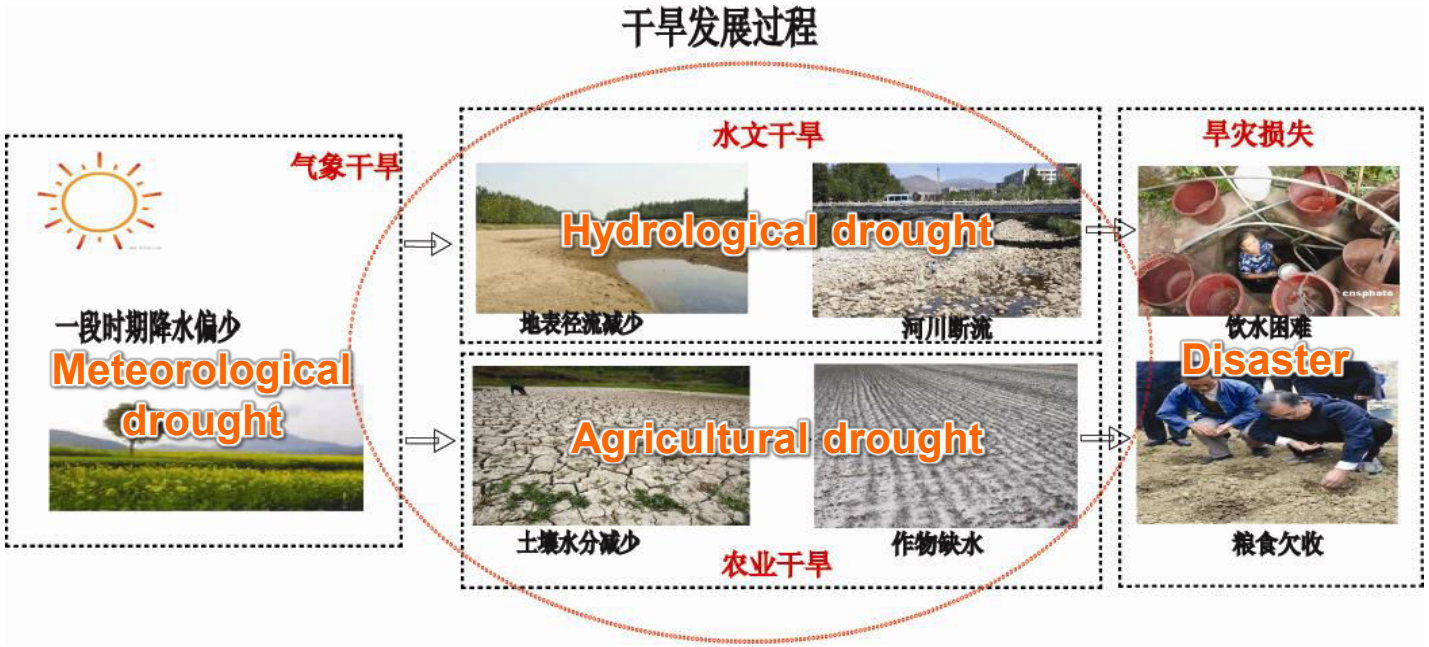
Water area in Poyang Lake
Reduce by 73.9%

Due to the effective drought resistance, there were no major economic and social losses

长江干支流来水量较常年同期偏少二至八成，上中游来水量为1949年以来同期最少；汉口站水位快速下降，8月末汉口水位处于历史同期最低值，洞庭湖和鄱阳湖8月末水面面积较6月份缩小3/4，出现了“汛期反枯”的罕见现象。由于抗旱应对有效，没有出现大的经济社会损失

2. Difficulties of Drought Disaster Resistance in the Yangtze River Basin
(长江流域干旱灾害应对难点)

- The transmission process from meteorological drought to agricultural, hydrological drought or even disaster is complicated. This process influenced by many factors such as precipitation, temperature, runoff, crop types, irrigation, reservoir operation and water intake, etc.



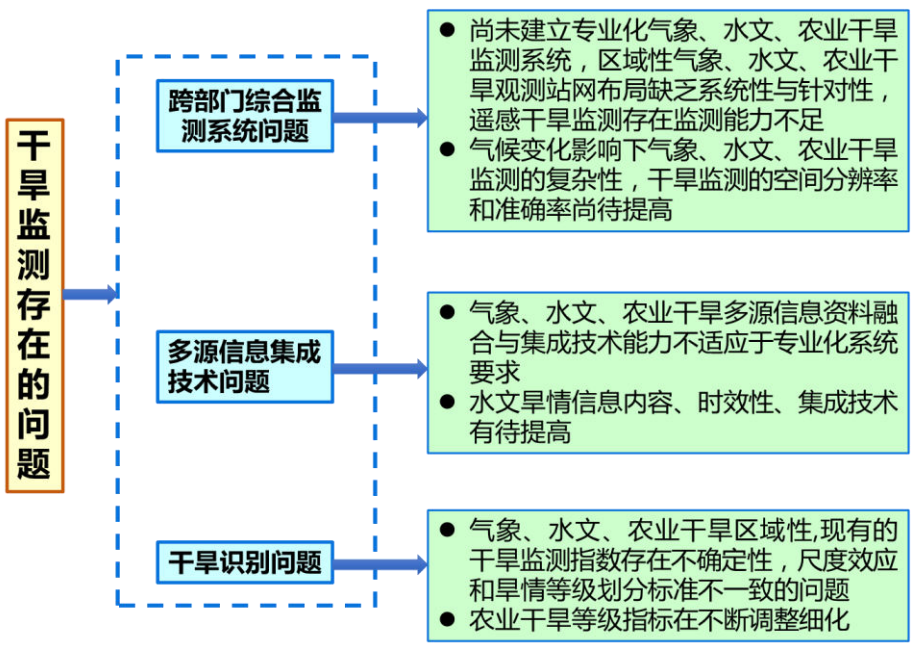
Meteorological drought dose not mean drought disaster.

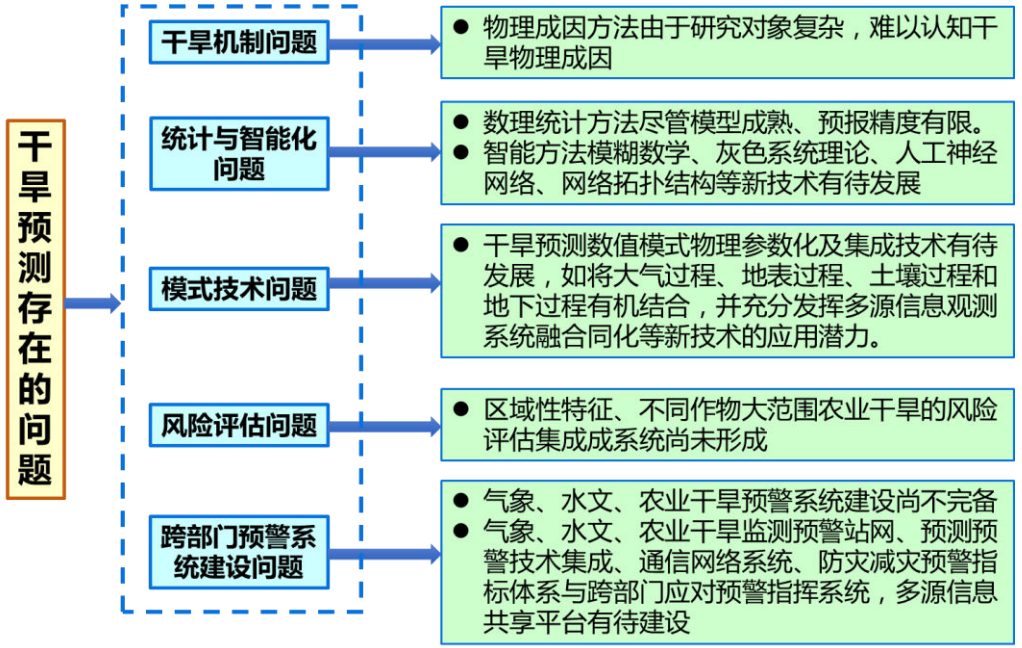
Meteorological drought is only a trigger, but not necessarily causes a disaster.

长江流域位于湿润和半湿润地区，气象干旱发展成农业干旱和水文干旱乃至成灾的过程较为复杂，受到降水和气温等气象条件、农业种植方式和灌溉条件、河流来水、水库蓄水和取水条件等诸多因素的影响，在旱灾应对过程中，需要考虑的影响因子和关键环节繁多。气象干旱≠旱灾，气象干旱只是诱因，但不一定成灾

2. Difficulties of Drought Disaster Resistance in the Yangtze River Basin
(长江流域干旱灾害应对难点)

- Drought is "chronic disease". The propagation process from meteorological drought to disaster may last more than several months or even one year. However, the ability of medium and long term meteorological and hydrological forecast is low, which makes it difficult to predict the development of drought event.

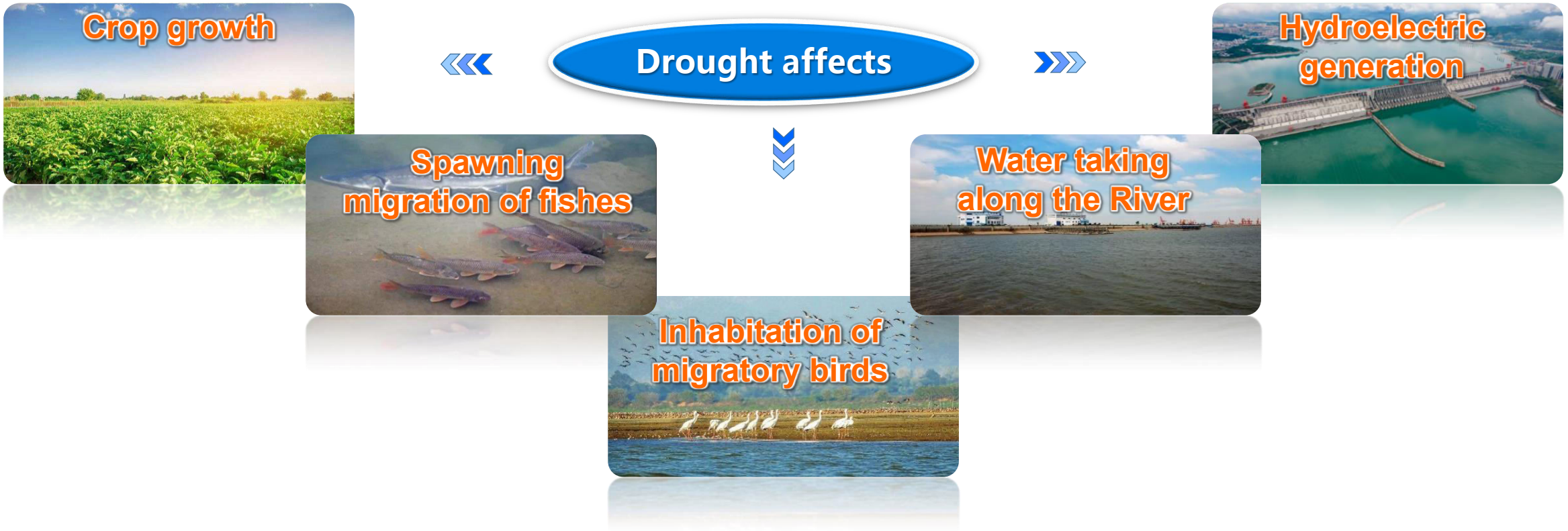




干旱是个“慢性病“，其发展需要一段时间，短则一个月，长则半年，甚至跨年度，目前中长期气候和水文预报精度低，难以准确预测未来发展趋势

2. Difficulties of Drought Disaster Resistance in the Yangtze River Basin
(长江流域干旱灾害应对难点)

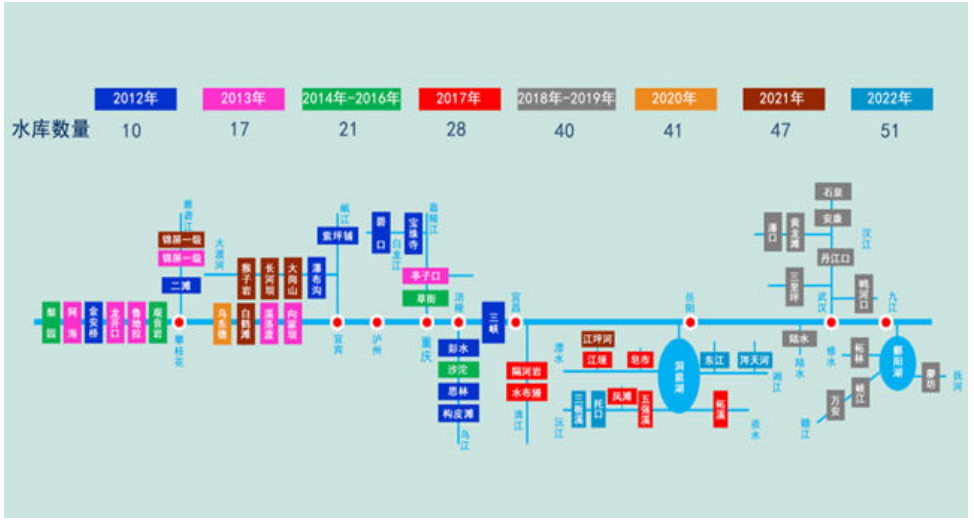
- The drought influences many natrual and social fields, and there is a great difference in drought resistance ability or drought resilience among different regions, so there is great uncertainty about the disaster caused by drought.

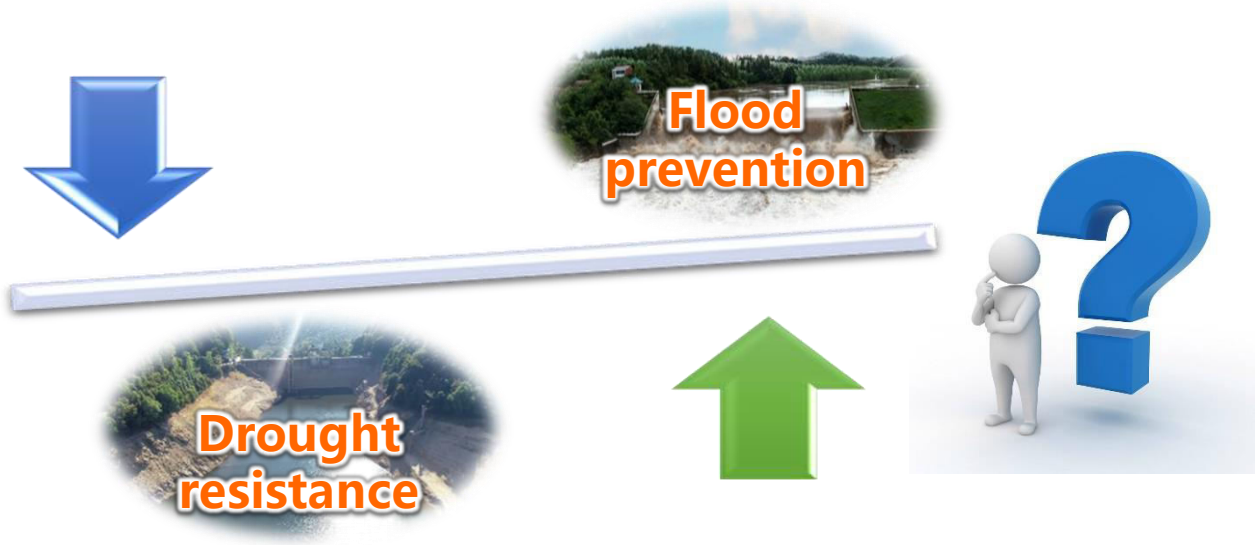


干旱影响涉及范畴广，各地区抗旱能力/旱灾韧性存在较大差异，因旱致灾的不确定性大

2. Difficulties of Drought Disaster Resistance in the Yangtze River Basin
(长江流域干旱灾害应对难点)

- Most of reservoirs the Yangtze River are seasonal reservoirs, which have limited capacity to regulate runoff.
- The relationship between flood control and drought resistance is imbalance. The drought-flood abrupt alternation is a great challenge to the reservoir operation.

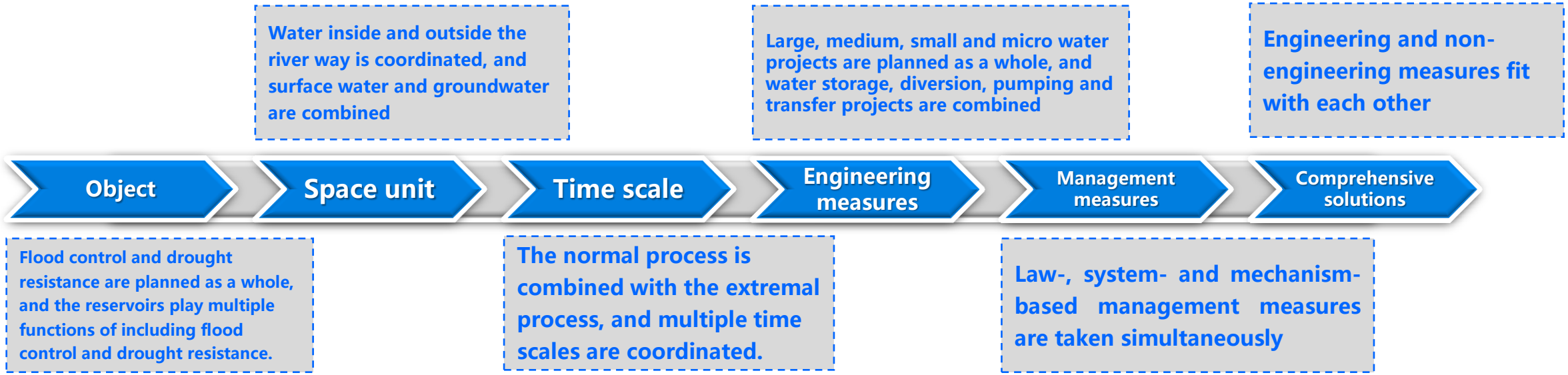




长江干支流大多数水库都是季调度水库，对径流的调节能力有限。防洪与抗旱之间的调度统筹还不够，旱涝/涝旱急转对水利工程运行调度极具挑战。

3. Technical requirements of Drought Disaster Resistance
(长江流域干旱灾害应对科技需求)

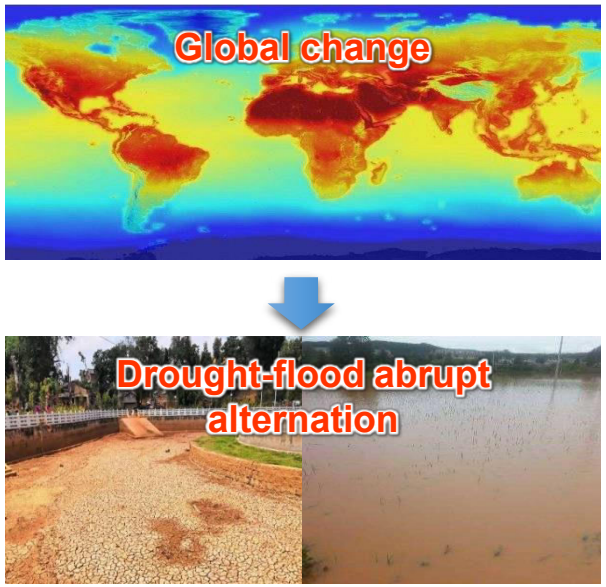
- It is important to enhance the overall prevention of flood and drought disasters according to the water systems management approach. At the same time, it is necessary to strengthen the scientific cognition of drought under climate change. Absolutely, the basic theory, new methods and technologies of integrated flood and drought disaster defense are important.



需要按照新时代的系统治水思路，统筹水旱灾害统筹防御。加强流域水旱灾害整体性统筹防御的科学认知、基础理论，以及新方法和新技术等方面的研究

3. Technical requirements of Drought Disaster Resistance
(长江流域干旱灾害应对科技需求)

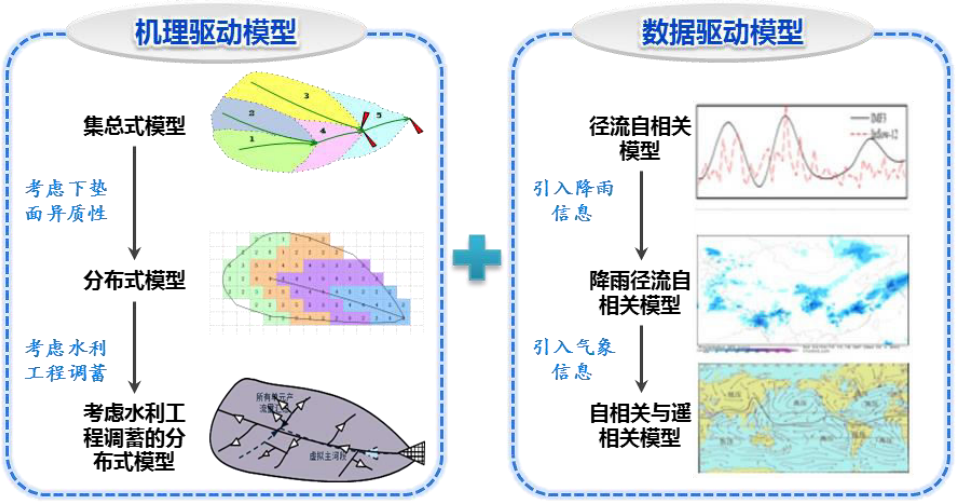
- In comparison to flood control, the study on drought in humid regions is slightly weaker. The theory of flood and drought prevention should be improved. The attention should be paid to understanding the mechanism of drougt process.



相对于防洪而言，针对湿润地区的干旱相关基础研究比较薄弱，应进一步丰富流域/区域水旱灾害统筹防御理论，重点突破气候变化引发的极端气象水文事件、涝旱/旱涝急转的成因机制，以及大范围长历时高温少雨的致灾机理等

3. Technical requirements of Drought Disaster Resistance
(长江流域干旱灾害应对科技需求)

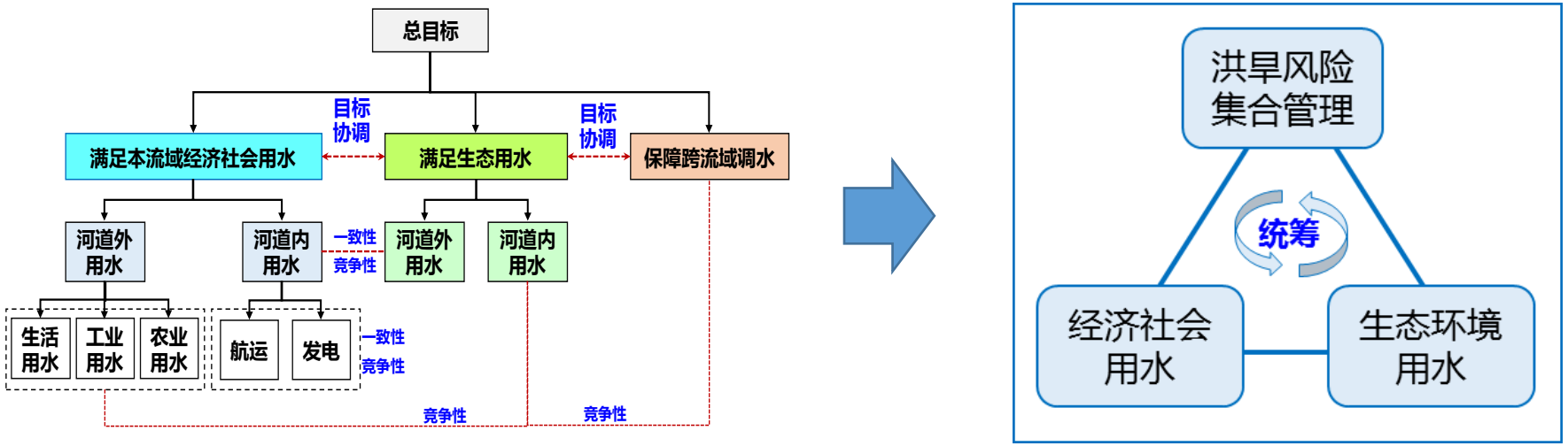
- It is necessary to break through the model methods and innovative technologies of medium and long term meteorological and hydrological forecasting, drought process simulation and drought risk assessment. It is particularly important to develop a decision support platform for drought prevention and emergency management.



需要突破中长期气象水文预报集合旱情模拟推演和旱灾风险评估的模型方法和创新技术，充分利用卫星遥感、大数据、智能感知、数字流域等信息技术，研发集合水情、雨情、工情、农情和民情等多元信息的干旱灾害防御和应急管理决策支持平台技术

3. Technical requirements of Drought Disaster Resistance
(长江流域干旱灾害应对科技需求)

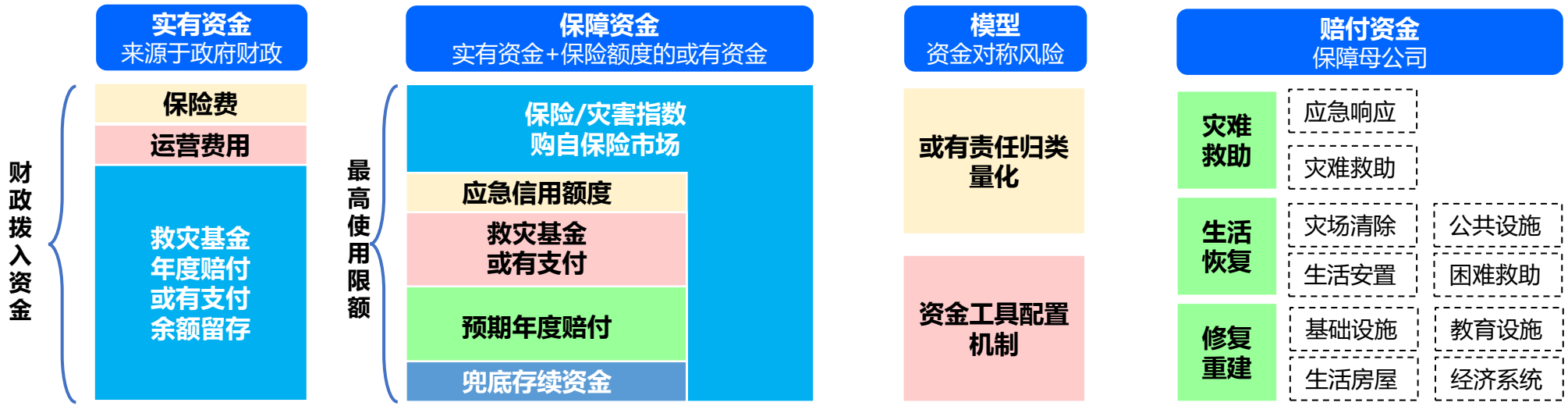
- In view of the characteristics of streamflow change and drought-flood abrupt alternation, it is necessary to study the joint operation of water projects from an overall perspective of flood control and drought resistance. At the same time, the regulation of flood limitted water level should be optimized, so as to improve utilization potential of flood resources.



针对长江流域径流特点及其丰枯变化，尤其旱涝/涝旱急转频发地区，从防洪和抗旱统筹角度，来研究水利工程的联合调控，并优化水库汛限水位运行方式，发挥水库防洪与抗旱多重效益，提高雨洪资源化利用潜力

3. Technical requirements of Drought Disaster Resistance
(长江流域干旱灾害应对科技需求)

- It is necessary to improve the study of drought adaptation based on the modern natural disaster theory. We need to integrate disaster resistance into economic and social development planning. It is necessary to carry out the non-engineering measures of drought resistance, and promote the transition from passive drought resistance to active defense.

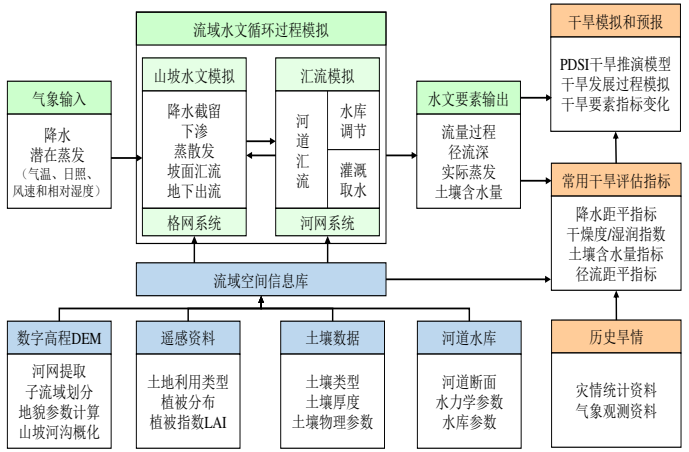


干旱是自然现象，但是否发展成为旱灾，则与我们的抗旱能力和应对行为密切有关。需要以现代自然灾害系统理论为指导，深化干旱适应性研究，创建将防灾减灾融入经济社会布局的理论方法，加强灾害金融和巨灾指数保险等研究，从而提高抵御灾害风险的经济社会系统韧性，促进被动抗旱减灾向主动防御适应转变

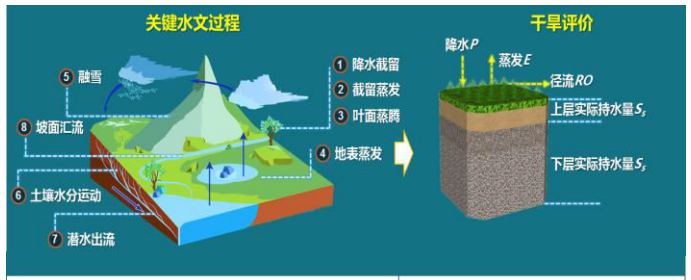
4. Research achievements (目前已开展的相关工作)

- We propose a comprehensive drought assessment and forecast model method. This set of methods describe the drought process by continuously calculating the cumulative effects of precipitation, evaporation, soil water deficit and duration.

Model framework



Equations for key processes



$$S_v = C_v \times S_{max} \times \left(1 - e^{-\frac{P_{am}}{S_{max}}}\right) \qquad E_{canopy}(t) = \begin{cases} K_c K_c E_p, & S_c(t) \geq K_c K_c E_p \Delta t \\ S_c(t)/\Delta t, & S_c(t) < K_c K_c E_p \Delta t \end{cases}$$

$$E_p(t,j) = K_c K_c E_p f_1(Z_j) f_2(\theta_j) \frac{LAI(t)}{LAI_0} \qquad E_{ssplant}(t) = \begin{cases} (1-K_v)E_p, & S_s(t) \geq E_p(1-K_v)\Delta t \\ S_s(t)/\Delta t, & S_s(t) < E_p(1-K_v)\Delta t \end{cases}$$

$$M(t) = M_f(T(t) - T_b)\Delta t$$

干旱指标：$x_i = 0.867 x_{i-1} + z_i / 42.792$

水分距平指数：$z_i = k' \cdot d_i$

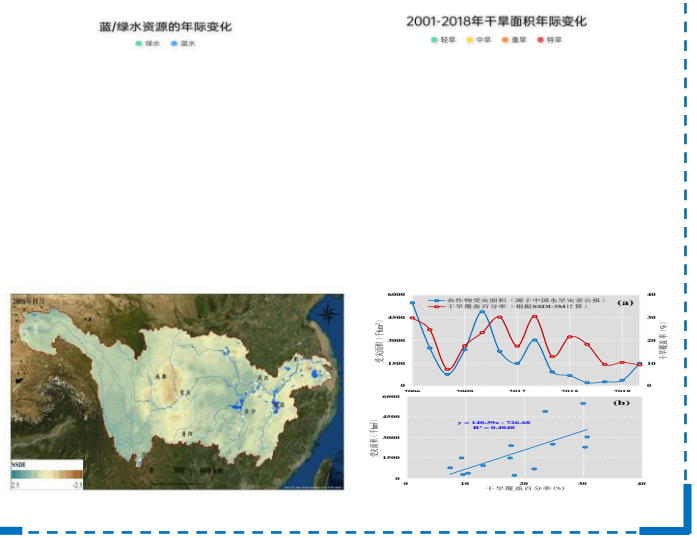
修正后权重因子：$\bar{K} = -694.8 / \left(\sum d\right)$

$$K' = 1.812 \ln\left(\frac{PE + \bar{R} + \bar{RO}}{(P + LD)}\right) + 6.173$$

水分距平值：$\hat{d}_i = P_i - \hat{P}_i$

气候适宜降水量：$\hat{P}_i = E\hat{T}_i + \hat{R}_i + \hat{RO}_i - \hat{L}_i$

Model application

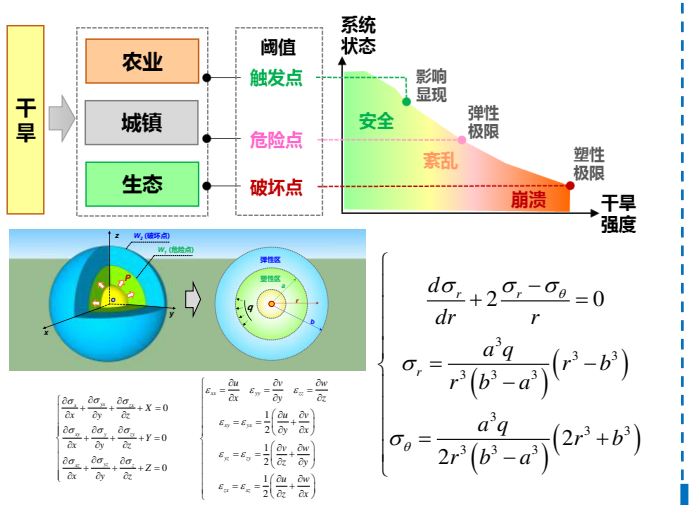


提出旱情的综合评估和预报模型方法，该方法通过连续演算降水蒸发、土壤水分亏缺和持续时间对干旱程度的累积影响，描述干旱的发生、发展和结束全过程，可对旱情发生发展的动态过程进行多指标的综合评估和高时空精度的推演预测

4. Research achievements (目前已开展的相关工作)

- The propagation process from drought to disaster in terms of different risk exposures were revealed. We also established equations to describe the relationship between drought intensity and loss. And according to the above equations, the drought disaster risk maps for the Yangtze River basin were carried out.

Relationship between intensity and loss

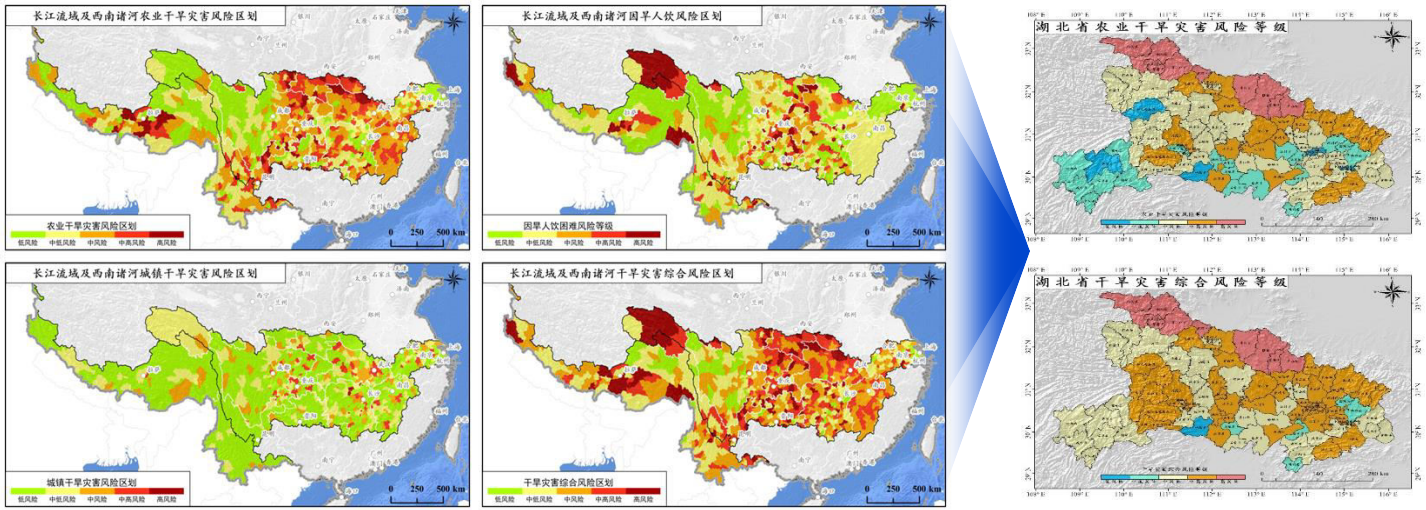


$$\frac{d\sigma_r}{dr}+2\frac{\sigma_r-\sigma_\theta}{r}=0$$

$$\sigma_r=\frac{a^3q}{r^3\left(b^3-a^3\right)}\left(r^3-b^3\right)$$

$$\sigma_\theta=\frac{a^3q}{2r^3\left(b^3-a^3\right)}\left(2r^3+b^3\right)$$

Drought risk division

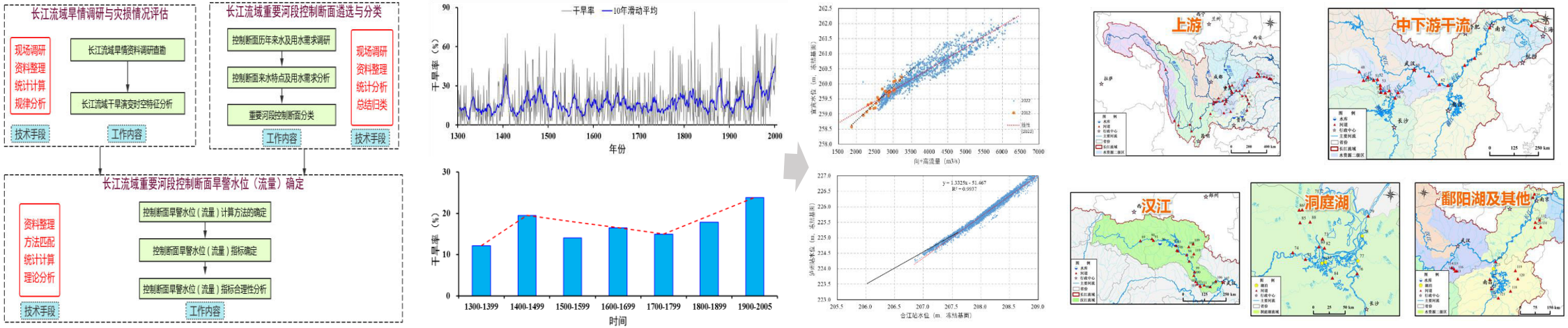


揭示了湿润半湿润地区不同承灾体的因旱致灾模式，建立了干旱强度和旱灾损失之间的本构方程，绘制了能够体现长江流域气候特征和地域空间差异性的旱灾风险区划图

4. Research achievements (目前已开展的相关工作)

- We analyzed the temporal and spatial distribution characteristics of drought intensity, duration, influence area and frequency. In addition, the calculation method of drought warning water level was put forward. According to this method, drought warning water level index system for 135 important sections was established.
- This achievement improved the drought warning ability and played an important role in the early drought warning and emergency management in 2022 .

Drought warning water level index system

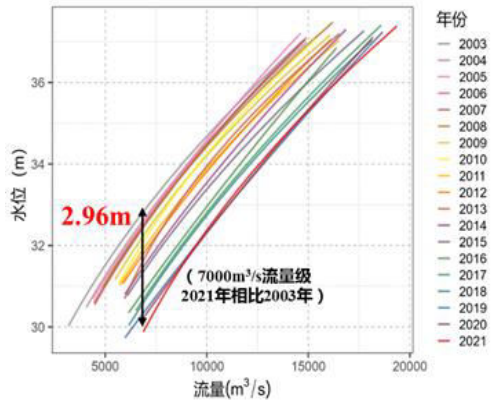


解析了长江流域干旱强度、历时、影响范围和频度等方面的时空分布特征，提出了面向多类型控制断面的旱警水位计算方法，首次建立了由135个重要控制断面组成的长江干支流主要河段旱警水位指标体系，完善了长江流域江河湖库旱情预警机制，在长江流域2022年供水安全预警与应急补水调度中应用并发挥了重要作用

4. Research achievements (目前已开展的相关工作)

- We revealed spatio-temporal correlation between reservoir operation and hydrological situation in the middle and lower reaches under the influence of drought. For drought emergency, the capacity and effective range of reservoirs were further carried out.

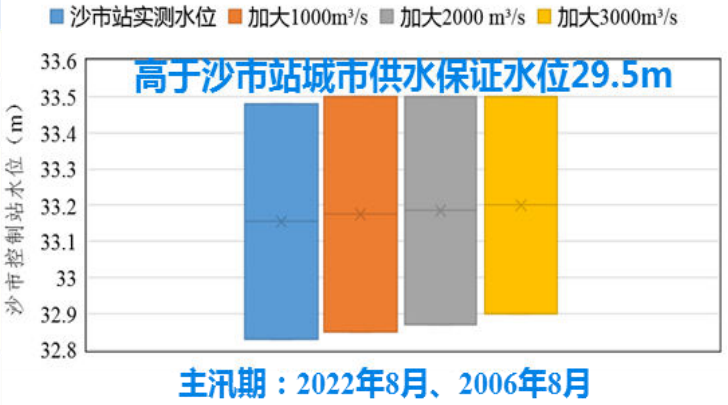
Evaluation of emergency drought resistance capacity of reservoir group in the basin



三峡水库运行后沙市断面低水位条件下的水位流量关系

Water level fluctuation at each station in the lower reaches of the Three Gorges Reservoir after water replenishment

宜昌流量级（m³/s）	水库补水方式	水位变幅（m） 沙市	城陵矶	汉口	九江	大通
≤6000	加大500m³/s	0.08~0.13	0.03~0.08	0.02~0.03	0~0.02	0 ~0.01
	加大1000m³/s	0.30~0.36	0.11~0.14	0.04~0.06	0~0.05	0.01~0.02
	加大2000m³/s	0.71~0.76	0.21~0.27	0.09~0.10	0.02~0.09	0.02~0.03
8000左右	加大1000m³/s	0.02~0.22	0.01~0.06	0.01~0.05	0~0.02	0~0.01
	加大2000m³/s	0.02~0.47	0.01~0.08	0.01~0.05	0~0.04	0~0.02
	加大3000m³/s	0.05~0.77	0.03~0.10	0.01~0.08	0.01~0.06	0.01~0.05



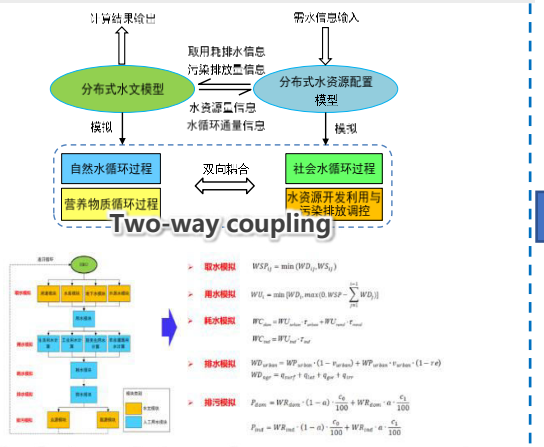
主汛期：2022年8月、2006年8月

解析了长江流域水库群水文要素特征及其跨时空关联机制，揭示了干旱影响下长江流域水库群运行与中下游水文情势的映射关系，量化了水库群应急抗旱补水能力及有效作用范围，三峡水库枯水期多年平均可补水量为100.70~215.71亿m³、2022年汛期反枯时段可补水量为2.70亿m³ ~74.49亿m³，补水影响范围主要为荆江和武汉河段

4. Research achievements (目前已开展的相关工作)

- A distributed water resources optimal allocation model in dry season has been established. The multiple water sources cooperative supply and its allocation in different departments were carried out.

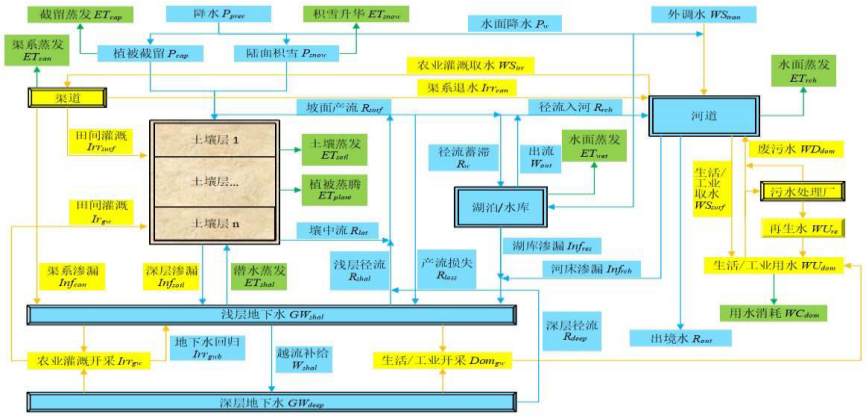
Simulation of water cycle based on physical mechanism



Two-way coupling

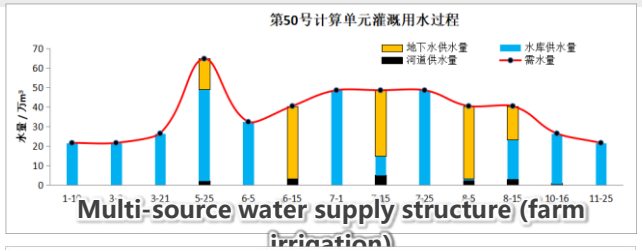
Calculation of "supply - use - consumption - discharge" process cohesion

Analysis of the whole transformation process of natural-social water resources

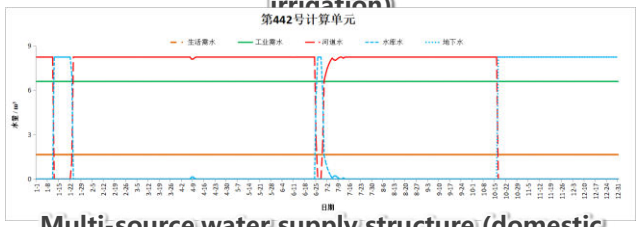


Whole-basin water resources cycle and transformation

Water resources allocation results



Multi-source water supply structure (farm irrigation)



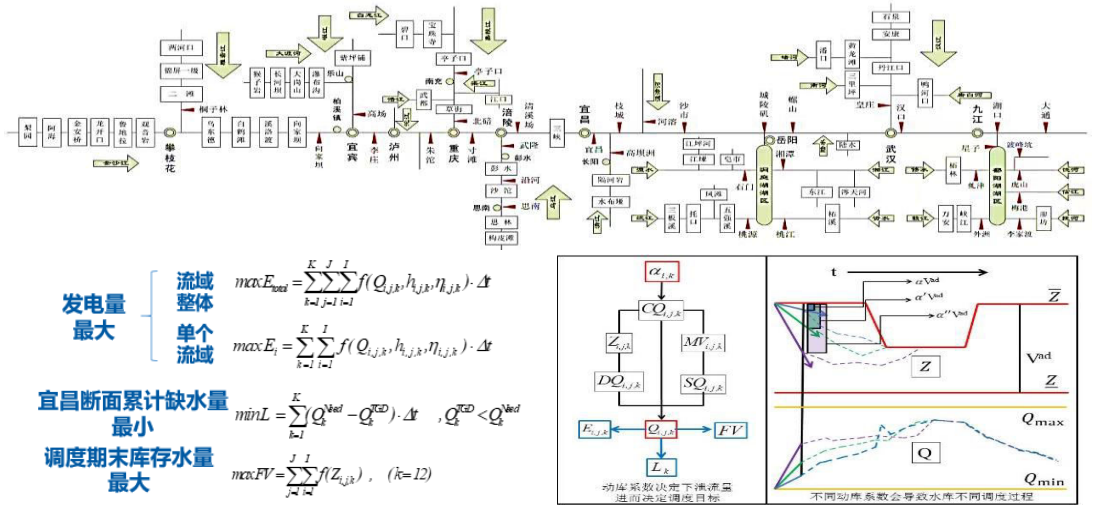
Multi-source water supply structure (domestic and industrial use)

构建了面向旱期多源互济供水的分布式水资源优化配置模型，实现了多水源协同供水及其在多行业的优化配置。长江流域用水总量模拟误差从3.78%降至2.48%，地表水供水量模拟误差从2.44%降至1.01%，地下水供水量模拟误差从8.41%降至5.42%

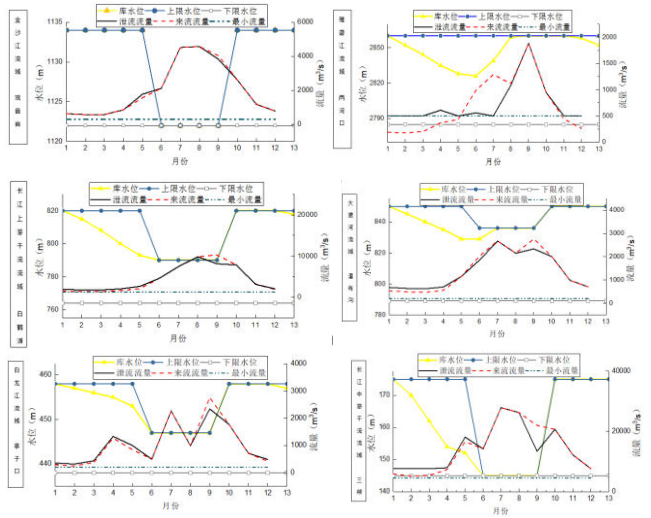
4. Research achievements (目前已开展的相关工作)

- An adaptive optimization method for joint operation of reservoirs under drought conditions was also put forward. These methods and approaches provided a technical support for coping with drought conditions and ensuring water demand in the basin.

Formulation of multi-source water supply criteria and modeling of water supply dispatching for reservoir group



Water supply dispatching scheme

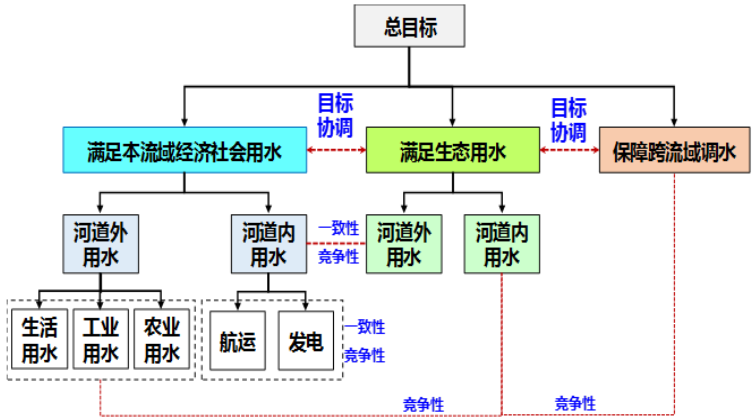


建立了河湖库渠多源供水调度模型，提出了干旱条件下流域水库群联合调度的适应性优化方法，为应对流域旱情、保障用水需求提供了技术支撑

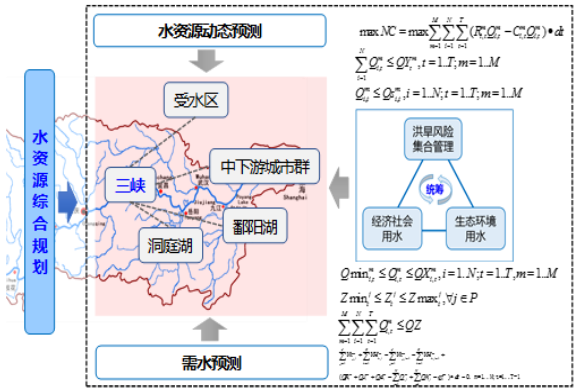
4. Research achievements (目前已开展的相关工作)

- The water supply approaches and emergency plans of reservoirs in the Yangtze River basin under the influence of drought were established, which significantly reduced the water shortage and drought disaster risk in the middle and lower reaches.

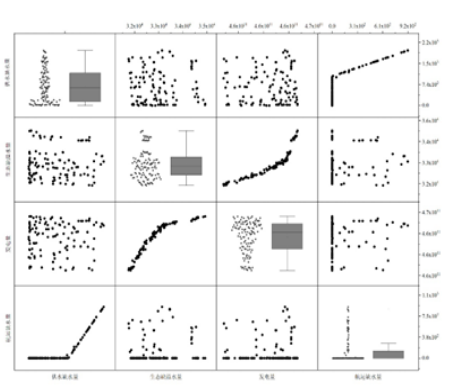
water supply approaches and emergency plans of reservoirs in the Yangtze River basin under the influence of drought



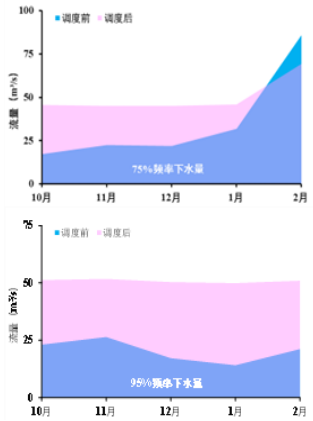
多目标需求及竞争关系



考虑洪水资源化的配置方案



四维矩阵投影图



枯水期调度结果

建立了干旱影响下长江流域水库群供水调度模式与精细化应急补水调度方案，显著提高了下游干流主要控制断面和重要引调水工程用水安全保障水平，显著降低了中下游缺水差额与小流量成灾风险。

5. Suggestions (建议)

- It is suggested to strengthen the study on the theory, method and technology, for overall prevention of flood and drought disasters, and develop the overall prevention planning for flood and drought disasters

- It is suggested to optimize the operation mode of reservoirs in flood season, and implement the flexible regulation of reservoir flood control water level

- It is suggested to improve the non-engineering measures of drought prevention, including policies and regulations, economic measures, financial insurance, etc., and enhance the climate change adaptability and resilience


Thanks !