Dynamical optimal water resources allocation under a changing total water use control index

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FALL MEETING

Introduction

To promote water use efficiency, and safeguard sustainable socioeconomic development , China's State Council explicitly implemented the Strictest Water Resources Management System (SWRMS), which established "Three Red Lines" as a core element. As an important component of the "Red line" for controlling total water use, the total water use control index (TWUCI) is the maximum amount of water that can be used for living, production, and off-stream water demand by all water users, after considering changes in water resources and utilization.

However, the current TWUCI is static year-round, so it cannot adapt to dynamic inflows and deviations between water plans and actualization . To this end, an innovative methodology called the "forecast-decision-implementation-renewal" (FDIR), was proposed to carry out real-time TWUCI determination.

Model

Objective: minimize the basin water shortage in the remaining period:

$$\min \quad F=\sum_{t=tc}^{T}\sum_{i=1}^{N}\sum_{j=1}^{M}\left[\alpha_{ij}\left(D_{t,i,j}-S_{t,i,j}\right)\right]$$

Constraints: water balance constraints for operation zones, the reservoir water balance equation, water level, reservoir discharge flow, water demand, ecological water demand, non-negativity constraints, and the total water use control index. As a new constraint, the total water use control index constraint is expressed as:

$$WF_{tc,i}=W_{tc,i}-\sum_{t=1}^{tc-1}\sum_{j=1}^{M}Y_{t,i,j}$$

$$\sum_{t=tc}^{T}\sum_{j=1}^{M}S_{t,i,j}\le WF_{tc,i} \qquad tc=2,\dots,T-1$$

Methods

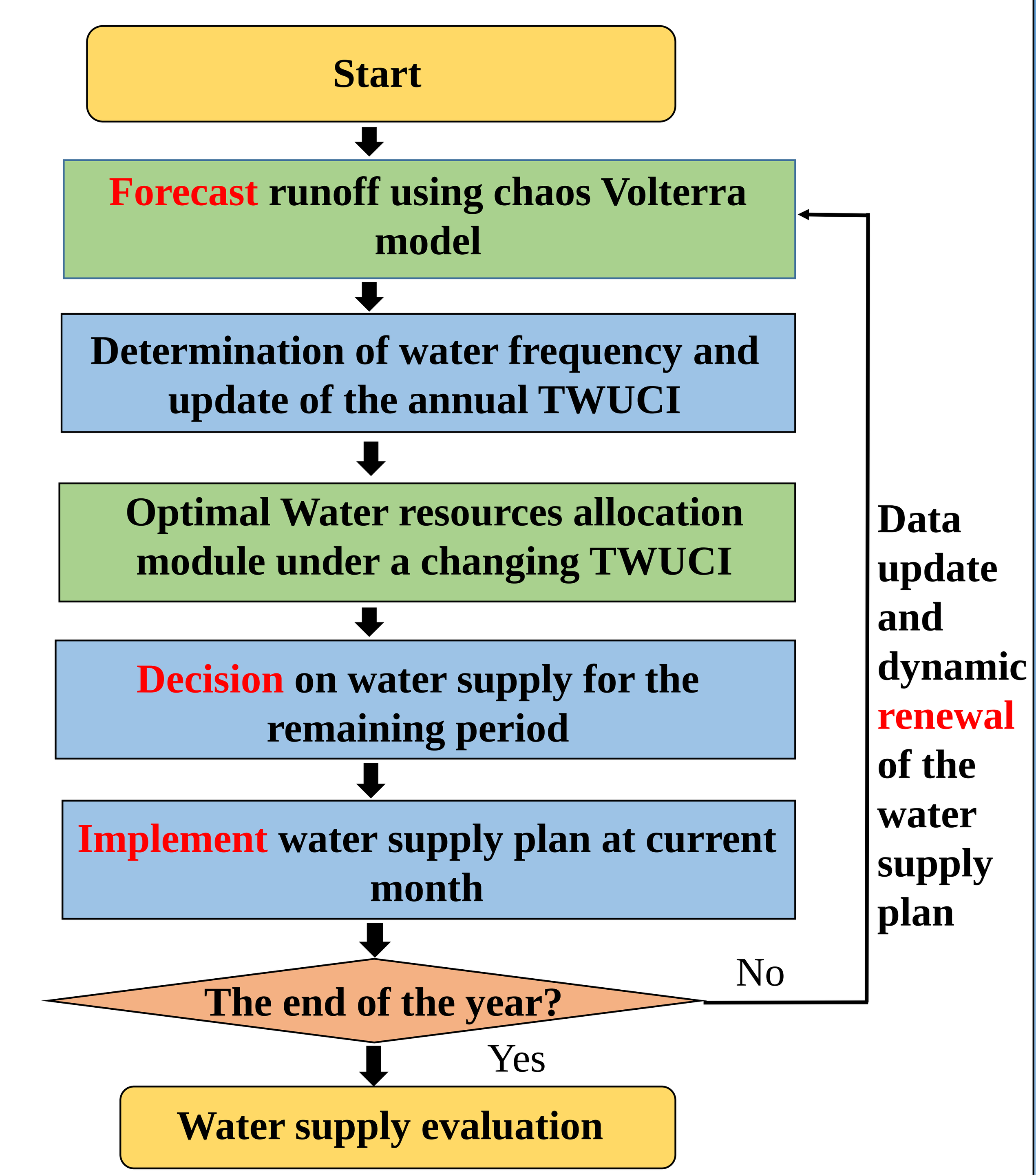

Fig.1 Dynamical optimal water allocation process for total water use control

Study area and data

a). Study area

Fuhe River Basin (FRB) is located in the east of Jiangxi Province, China, with a catchment area of 16493km². The study area was divided into 12 operational zones according to the intersections of the watershed and administrative county regions. Six control sections were selected to represent ecological water demand in the river and the environmental requirements of these areas (Fig.2).

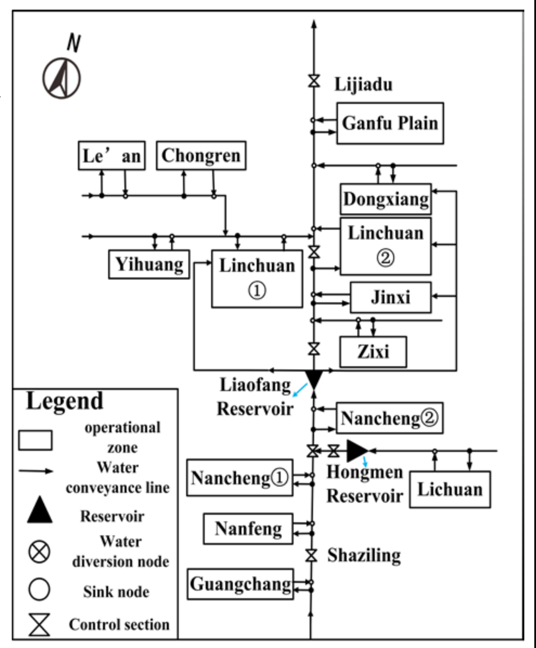

Fig.2 Node diagram of water resources system of Fuhe River Basin

b).Data

i) Monthly regional inflow data in the FRB at water frequencies of 50%, 75%, and 95%, as well as a monthly natural runoff series for five hydrological stations from 1964-1987 (collected from Jiangxi Water Conservancy and Hydropower Research Institute);

ii) Water demand data for each zone in 2020 (collected from the statistical yearbook as well as a research report on water distribution in the FRB);

iii) Total water use control index for each zone (derived from the "three red lines" of the SWRMS in 2020 issued by the Fuzhou Water Conservancy Bureau).

Table 1 The Nash-Sutcliffe efficiency of runoff prediction in the FRB

Zone	Nash-Sutcliffe efficiency	Zone	Nash-Sutcliffe efficiency
Nanfeng	0.80	Guangchang	0.61
Nancheng	0.87	Linchuan	0.63
Lichuan	0.80	Zixi	0.67
Le'an	0.79	Jinxi	0.64
Chongren	0.79	Dongxiang	0.64
Yihuang	0.75	Ganfu Plain	0.84

Table 2 The water shortage rate for the FRB in 2020

Zone	Scheme #1		Scheme #2	
	Ideal index/ 10^8m^3	Shortage ratio/ %	Initial index /10^8m^3	Shortage ratio /%
Guangchang	1.68	7.8	1.50	11.6
Nanfeng	**2.71**	**1.1**	**2.42**	**26.4**
Nancheng	2.11	8.7	4.04	9.0
Lichuan	1.69	0	1.69	14.7
Le'an	1.06	7.5	0.79	31.2
Chongren	1.82	13.3	1.82	13.3
Yihuang	1.46	12.8	1.46	12.8
Linchuan	**6.32**	**5.8**	**12.58**	**-23.3**
Zixi	0.23	8.4	0.27	8.4
Jinxi	1.66	15.0	1.99	15.0
Dongxiang	2.38	4.3	1.77	11.7
Ganfu plain	12.58	3.5	15.10	5.1

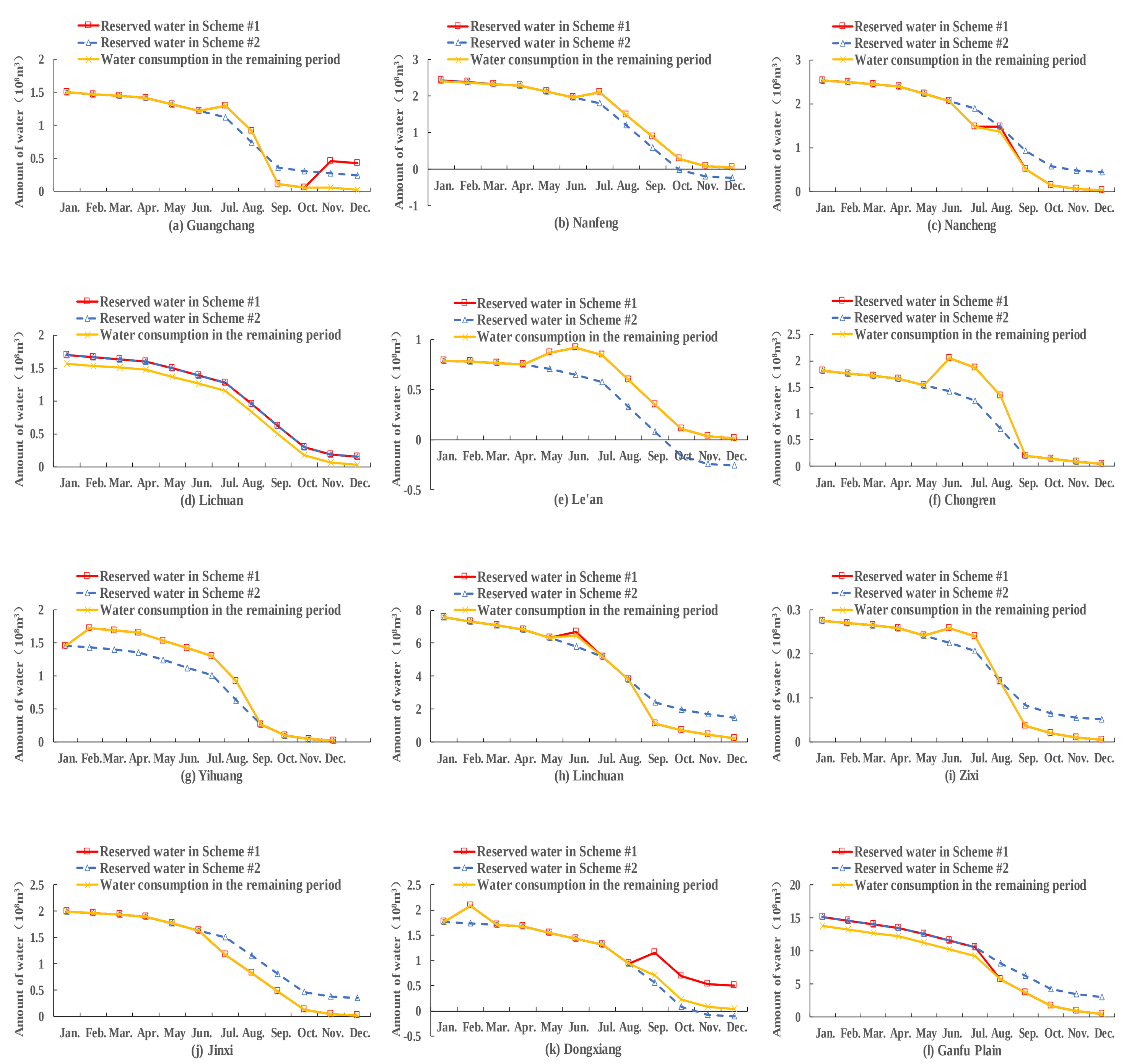

Fig.3 Dynamic process of TWUCI for remaining period in each operational zone

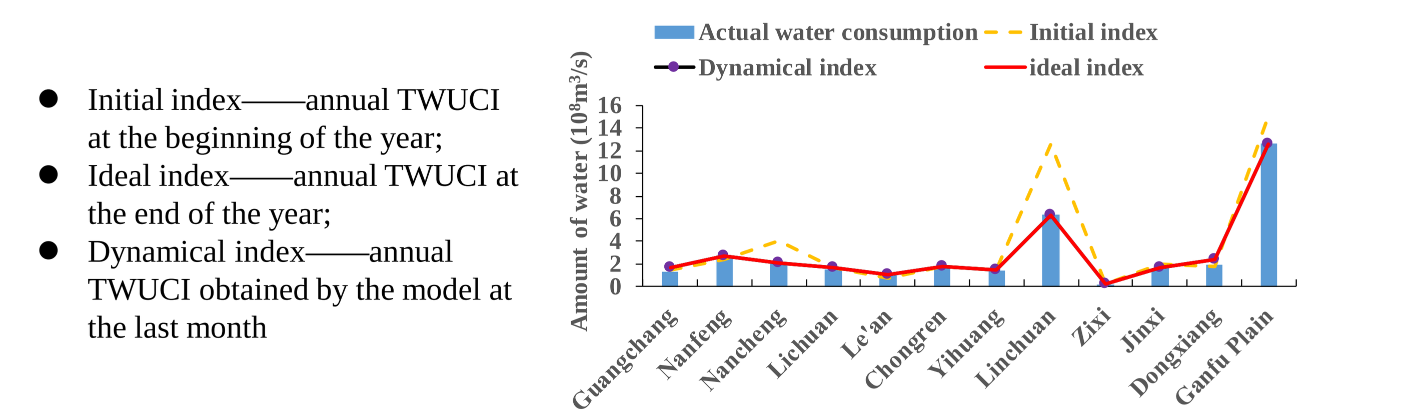

Fig.4 The changes of initial index, dynamic index, ideal index and actual water consumption

Results

a). Inflow forecast analysis

The calibrated model was used to forecast inflow from January to December, 1979. The result (see Table 1) showed that the Nash-Sutcliffe Efficiency for most regions was greater than 0.75, which met the forecast requirements.

b). Analysis of TWUCI in the remaining period

(i) water consumption of each zone in the remaining period in scheme#1 was always controlled within the TWUCI in the remaining period, while water consumption at most of the zones in scheme#2 was higher than the TWUCI in the remaining period (Fig.3); (ii) the TWUCI in the remaining period in scheme#1 was adjusted more effectively and efficiently according to the different water supply conditions compared with that in scheme#2. Here, scheme#1 represented water supply plan under dynamical TWUCI in the remaining period, scheme#2 represented the water supply plan under initial index.

c). Annual total water consumption control

A comparison of the ideal index, initial index, dynamic index, and actual water consumption is shown in Fig.4. After implementing dynamic total water use control, the dynamic indices basically agreed with the ideal indices, and the annual water supply for each zone was within the ideal index control ranges. This showed that the dynamical annual TWUCI could flexibly adapt to the inflow scenario. Under dynamic operating decisions, the water shortage ratio in the water-use area declined by 3.8%~25.3% when the inflow scenario(IS) changed from wet to dry, while the actual water supply was reduced to the TWUCI when a dry IS became wet (see Table 2).

Conclusion

The FDIR method provided a new way to dynamically manage total water consumption in the river basin. To ensure that the water supply was controlled within the TWUCI, a wetter (or drier) IS in the subsequent period resulted in a lower (or higher) dynamical TWUCI than the initial index. In this way, water supply was limited (or augmented) under different IS to better respond to water demand.

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