清華大學 Tsinghua University

XVIII World Water Congress
International Water Resources Association(IWRA)
Beijing, China | September 11-15, 2023

ET/EC/ES Coupling and Application to "Basing four aspects on water resources"

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9/12/2023

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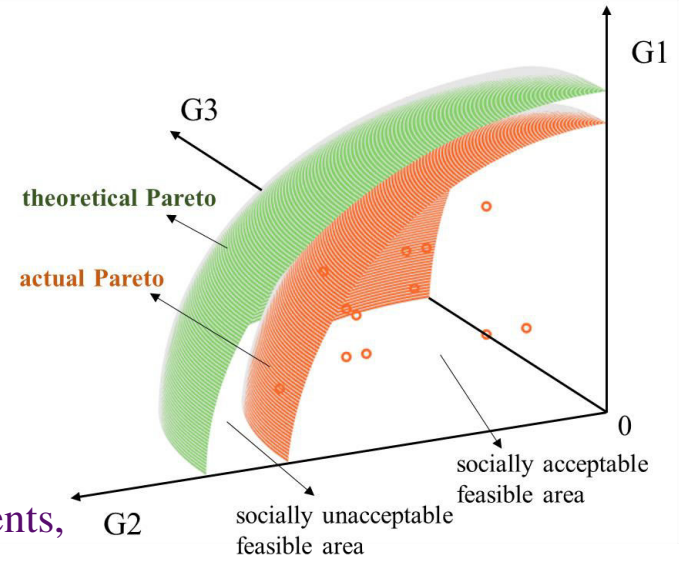
Mismatching in different plans

- Water resources and economic development plans are commonly independently (Dalcin&Fernandes Marques, 2020), population development plans, economic development plans, pollution control plans, eco-environmental modification plans and water resource allocation plans lack effective coordination, which leads to conflicts and hinders the balance of trade-offs among social, economic, environmental, and ecological considerations.

File	Issuing department
Population development planning	Development and Reform Commission
Land and space development planning	Natural Resources Bureau
Industrial development planning	Bureau of Industry and Information Technology
Description of data related to water right control indicators	Water conservancy bureau
Prevention and control of water pollution	Bureau of Ecology and Environment
…	…



Water management in China

Water-related plans and regulations

Different sectors, different departments, different plans related to water.

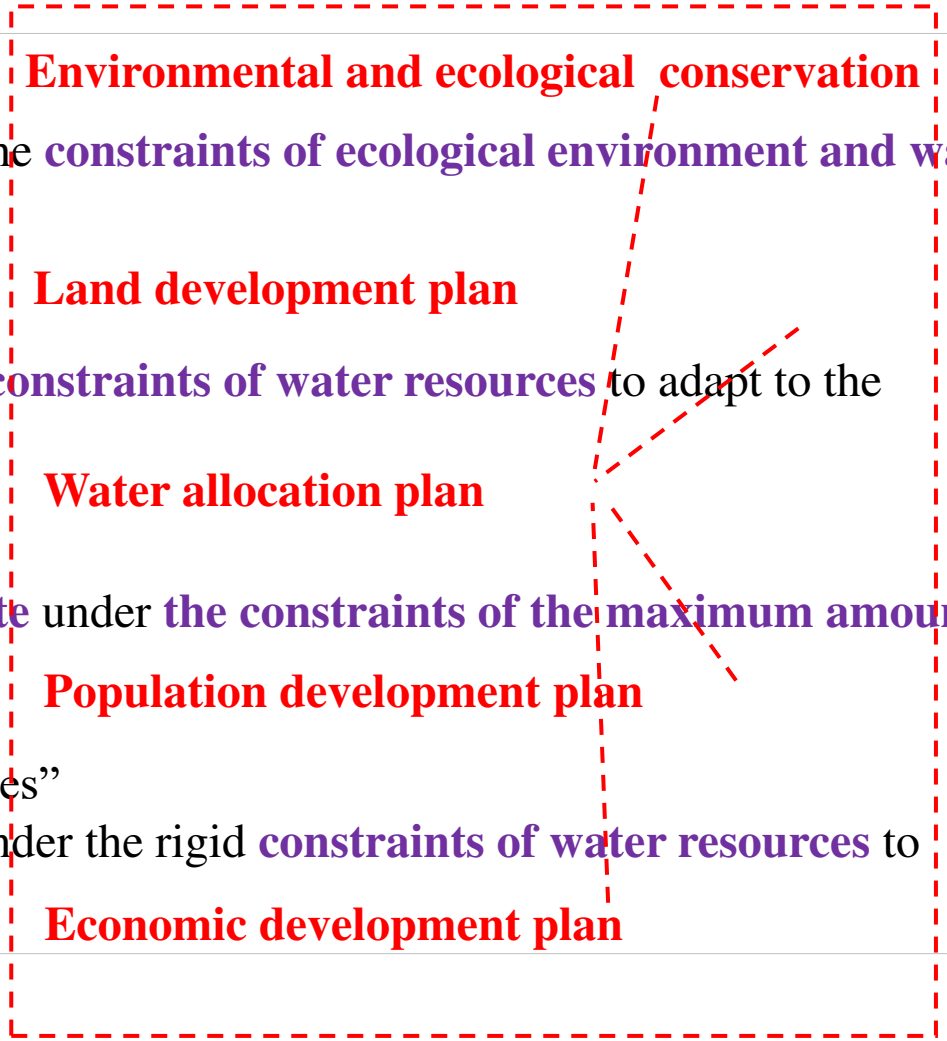
Basing four aspects on water resources

- "Determine the city based on water resources":
Control the **urban development boundaries** under the **constraints of ecological environment and water resources** to avoid the disordered expansion of urban

- "Determine the land based on water resources"
Control **the land use (basic farmland…)** under **the constraints of water resources** to adapt to the conditions of water resources

- "Determine the people based on water resources"
Determine **the population size and urbanization rate** under **the constraints of the maximum amount of urban water resources** in each stage

- "Determine the production based on water resources"
Adjust the regional **industrial scale and structure** under the rigid **constraints of water resources** to achieve sustainable and green development



Gaps to bridge

Few researches consider all these issues in a holistic way and associate water resource allocation plan with other water-related plans

- The comprehensive research and analysis is relatively limited, and the research model physical and equation machine are insufficient. It is difficult to describe the interaction and restriction among the components and subsystems of the complex large system composed of "water and human". Therefore, it is necessary to develop a model with perfect physical mechanism

Integrated model

Constraints

Constraints are fuzzy and mismatching

- Water consumption target / Total pollution control / Regulations related to water environment and ecology …

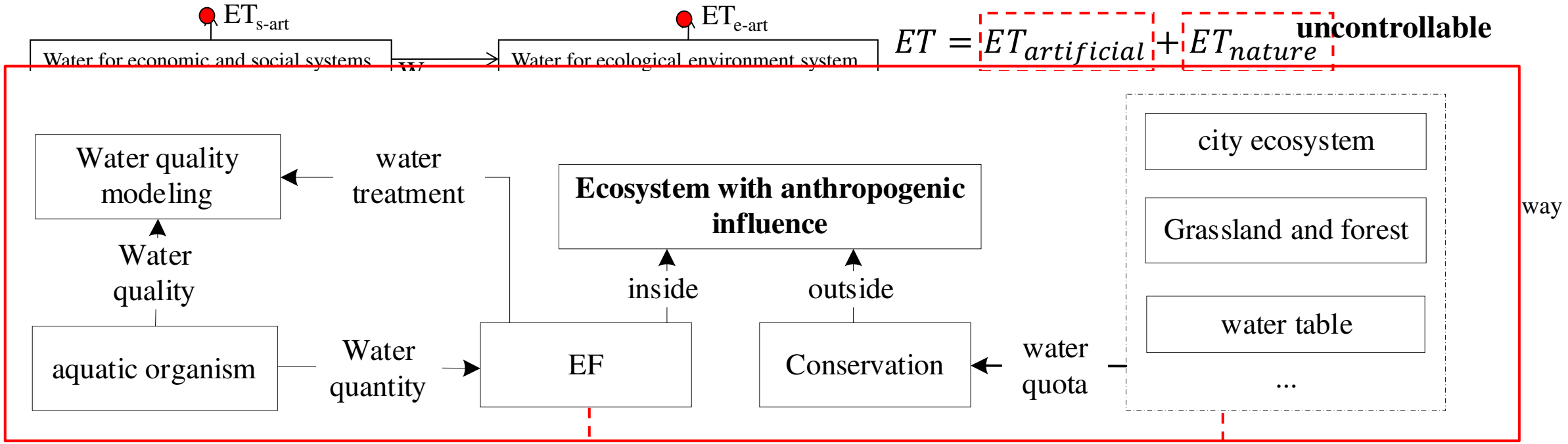
Coupled constraints

Water management department

the constraints of water resources / water environmental capacity / ecological requirements

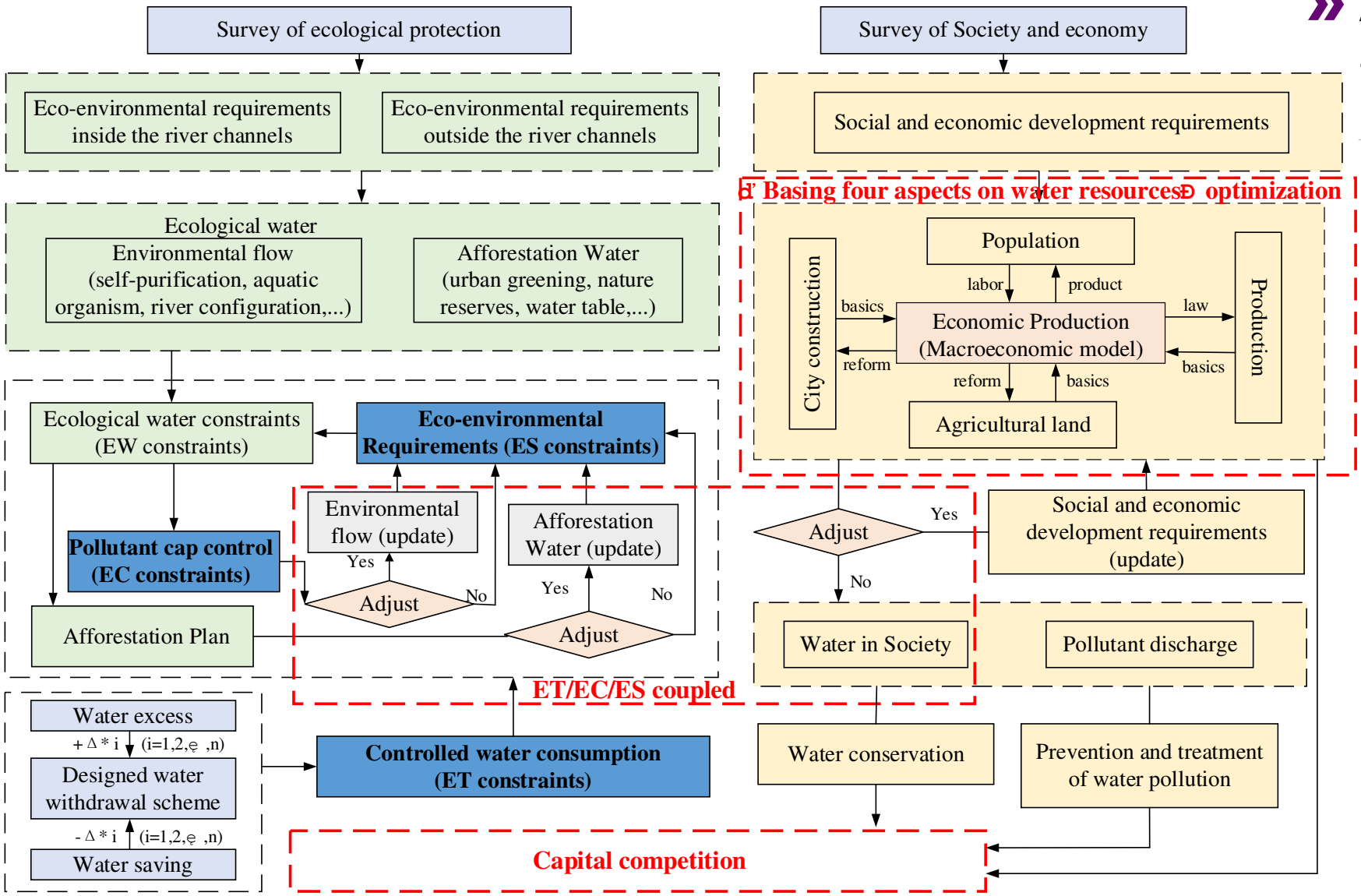
ET

- ET: water consumption in societal and ecological systems in the basins, which takes into account solar energy processes, as well as mechanical, chemical energy processes.



ES

- ES here indicates environmental flow inside river and ecological protection outside river as it is so difficult to quantify the value of ES in uniform monetary terms or through other means that the value of ecological services being a direct management target is unscientific.



Allocate water resources among society and ecosystem based on coupled ET/EC/ES

- Search feasible ET

$$(-\Delta \cdot n + DW, -\Delta \cdot (n-1) + DW, ..., DW, ..., \Delta \cdot (n-1) + DW, \Delta \cdot n + DW) \quad \Delta \geq 0$$

- Optimize water allocation under ET constraints to search possible EC/ES values / search ET under fixed EC/ES preference

$$J = \max\{O_1(x,\omega_1), O_2(x,\omega_2), O_3(x,\omega_3), O_4(x,\omega_4)\}_{(0,1)}$$

$$s.t. \quad f_{bt}(ET, EC, ES), \ x \in R^n, \ \omega_i \in \Omega$$

- Get ET/EC/ES target under best fit strategy

$$f_{bt}(ET, EC, ES)$$

Search feasible ET

Set search area as follows:

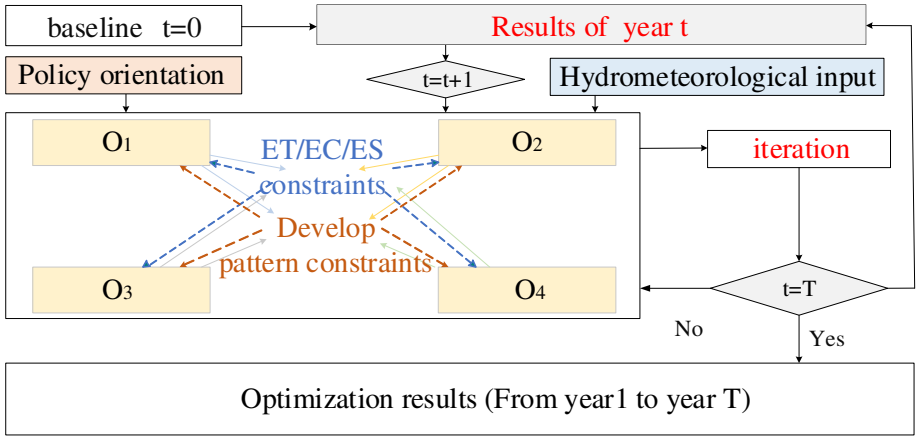
$$(-\Delta\cdot n+DW,-\Delta\cdot(n-1)+DW,...,DW,...,\Delta\cdot(n-1)+DW,\Delta\cdot n+DW)\quad \Delta\geq 0$$

Based on potential water saving (etc. industrial restructuring, technical progress, unconventional water…), and minimum requirement of water capacity and ecosystem protection (fixed):

$$(-\Delta\cdot n+DW,-\Delta\cdot(n-1)+DW,...,-\Delta\cdot m+DW)\quad \Delta\geq 0$$ **Infeasible**

$$(-\Delta\cdot(m-1)+DW,-\Delta\cdot(m-2)+DW,...,DW,...,\Delta\cdot(n-1)+DW,\Delta\cdot n+DW)\quad \Delta\geq 0$$ **Feasible**

Optimize water allocation under ET constraints to search possible EC/ES values



Population size

$$\max\ O_1=\sum_{t=1}^{T}(Npop^t)$$

Construction land

$$\max\ O_2=\sum_{t=1}^{T}(Ld_{city}^t)$$

Ecological area equivalent

$$\max\ O_3=\sum_{t=1}^{T}\sum_{l=1}^{L}CE_l\cdot Ld_l^t$$

Net economic benefit

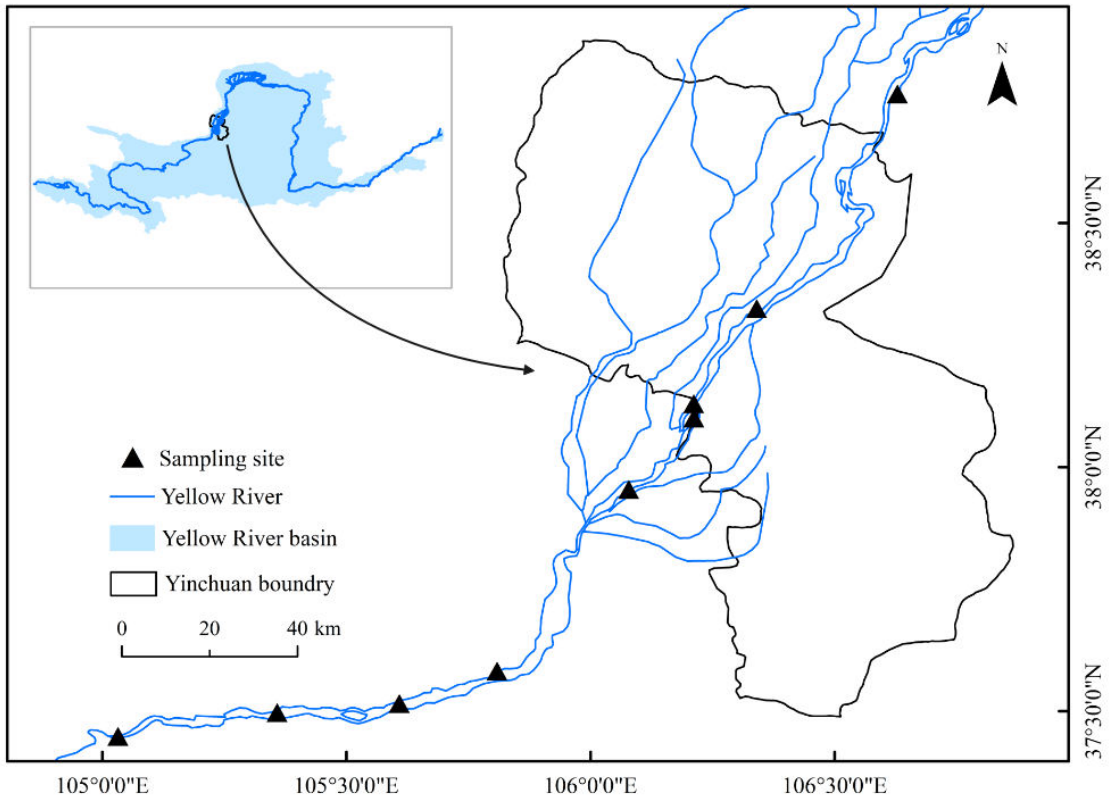
$$\max\ O_4=\sum_{t=1}^{T}(GDP^t-\sum_{j=1}^{N}(Investsavewater_j^t+Investrepo_j^t))$$

Get ET/EC/ES target under best fit strategy

Search from $P_0=(ET_0,EC_0,ES_0)$ to $P_{0b}=(ET_0,EC_b,ES_b)$ $s.t.\ \|P_{0b}\|_2\geq\|P_{0i}\|_2\ (i=1,2,...,n)$

✓ Water consumption constraint ✓ Water environment capacity constraint(Total pollutant control) ✓ Ecosystem protection constraint

Study area

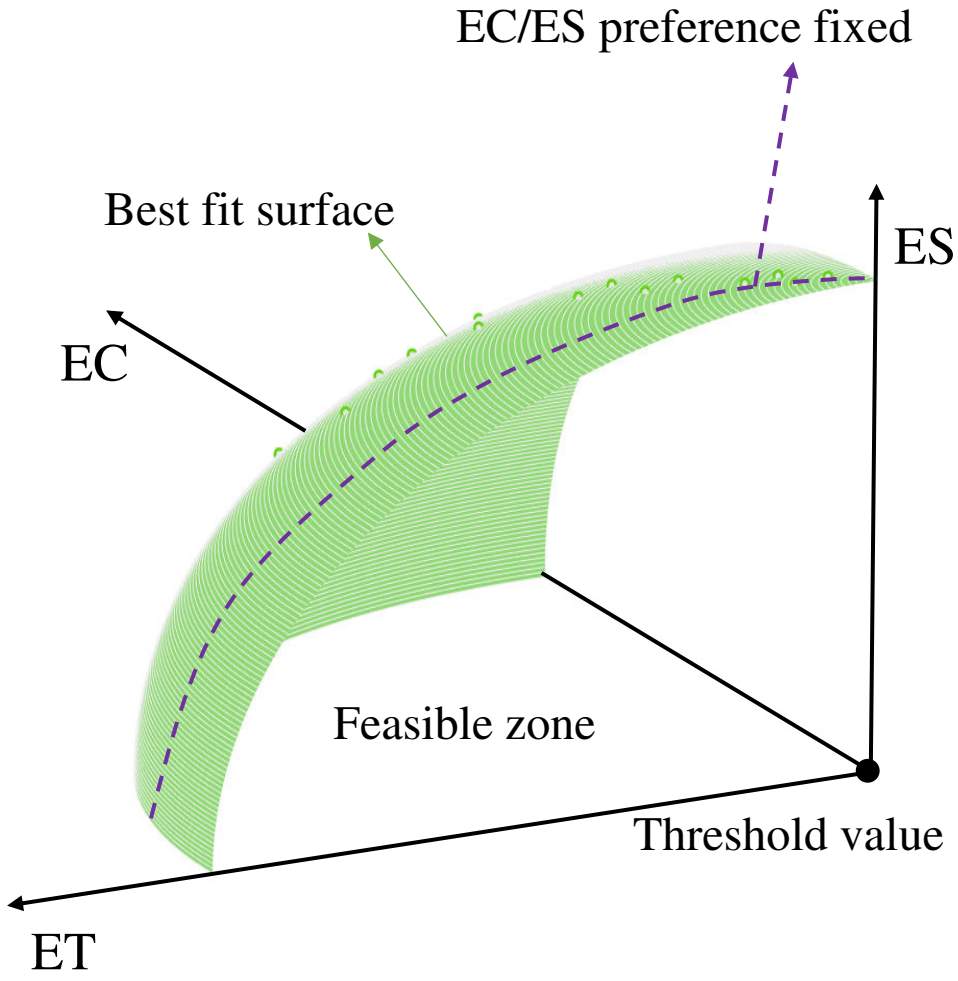


Yinchuan City located in the upper reaches of the Yellow River

- Yinchuan City (YC) is located in the upper reaches of the Yellow River, with an area of 8225.38 km^2 (excluding Ningdong energy base).
- Data sources: all the data in this study were obtained from:

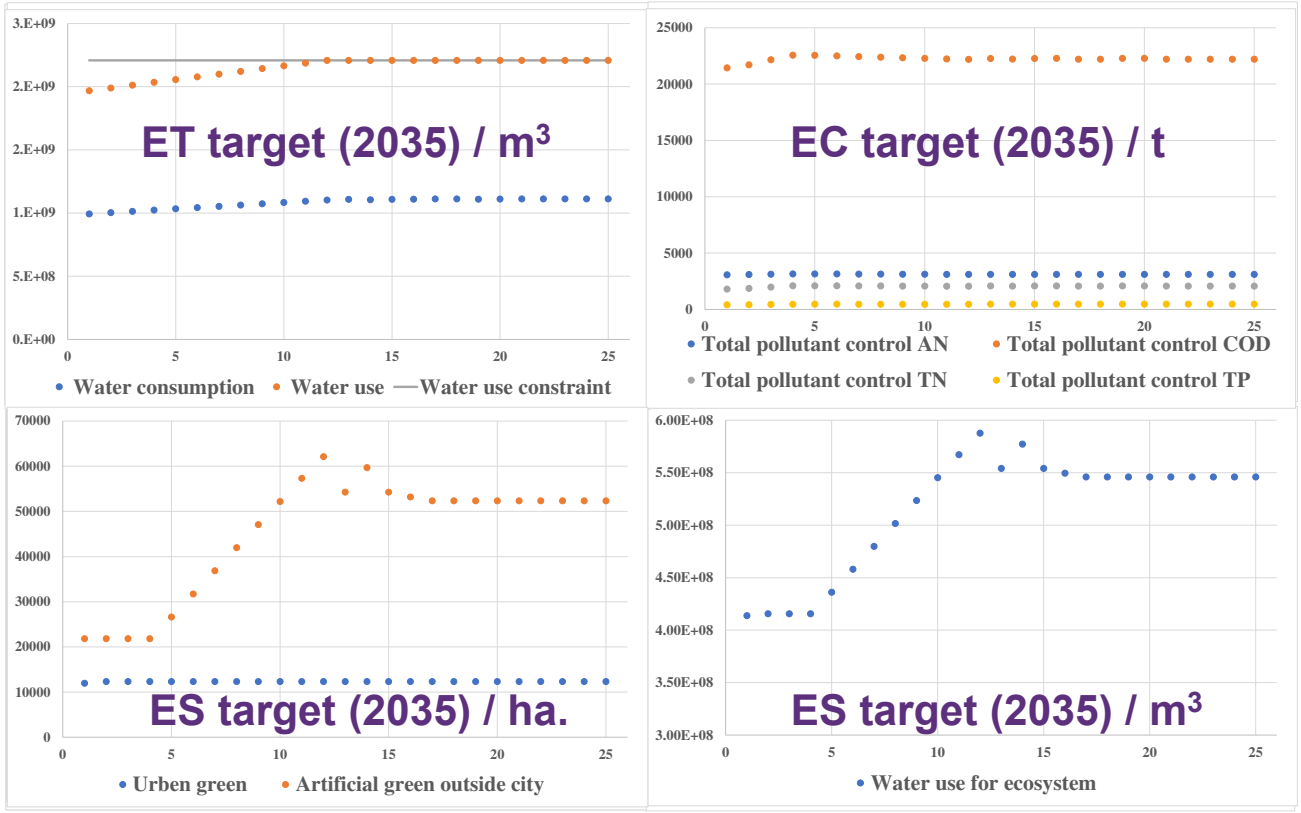
1. Water Resources Bulletin of Yinchuan
2. Statistical Yearbook of Yinchuan
3. Yinchuan Development and Reform Commission
4. Yinchuan Water Affairs Bureau
5. Water Conservancy Research Institute of Ningxia
6. Yinchuan Industry and Information Technology Bureau
7. Yinchuan rural Agriculture Bureau
8. Yinchuan Natural Resources Bureau
9. Yinchuan Ecological Environment Bureau
10. Yinchuan Municipal Statistics Bureau
11. Yinchuan Science and Technology Bureau

Typical scheme

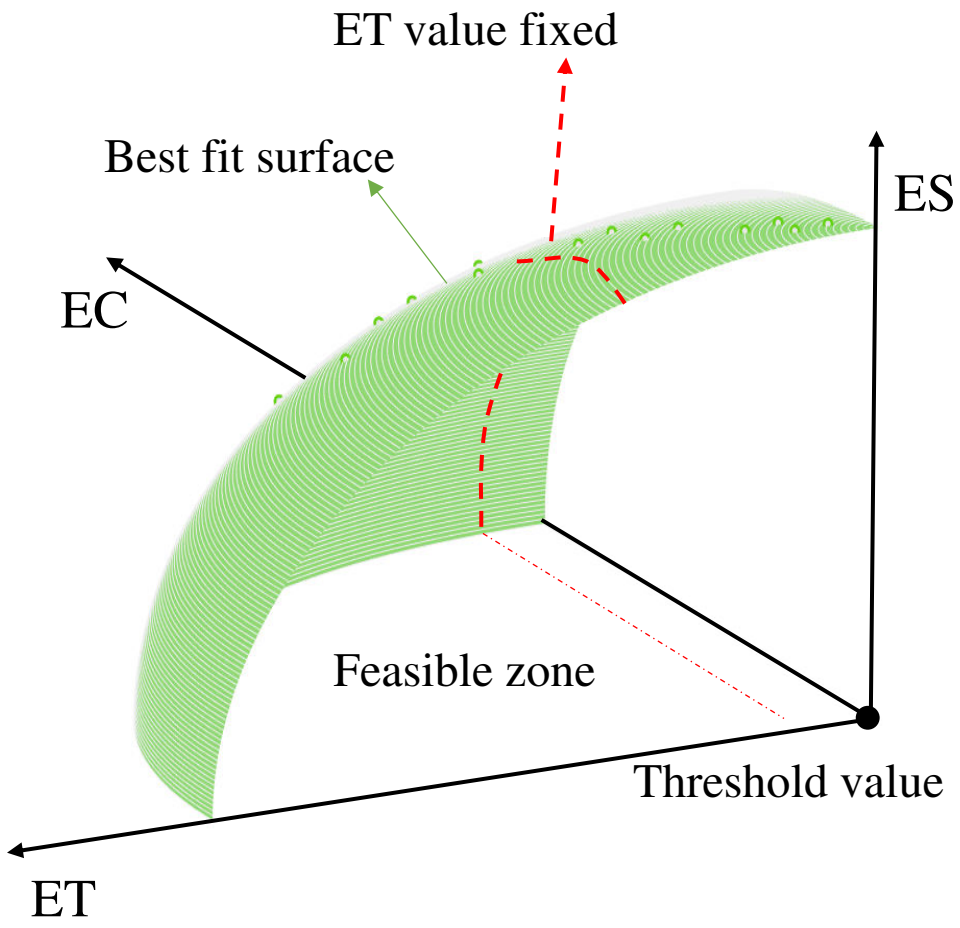


- EC/ES preference fixed
  - Search range (8.33×10^8 : 0.1×10^8 :12.33×10^8)
  - Feasible range (9.93×10^8 : 0.1×10^8 :12.33×10^8)

Scheme	O_1 weight (W1)	O_2 weight (W2)	O_3 weight (W3)	O_4 weight (W4)
fixed	0.25	0.25	0.25	0.25

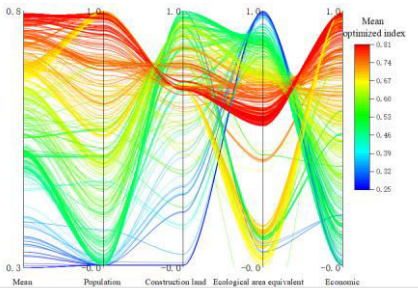


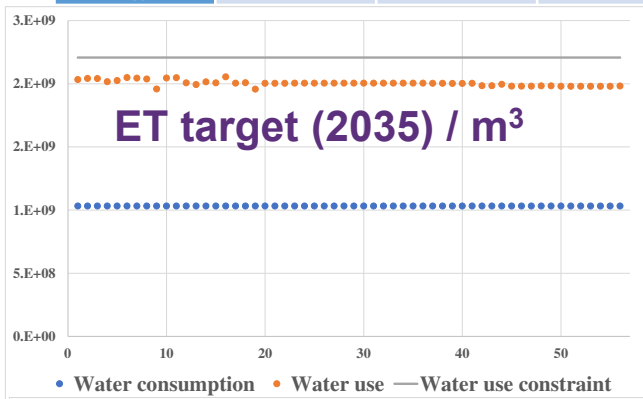
Results

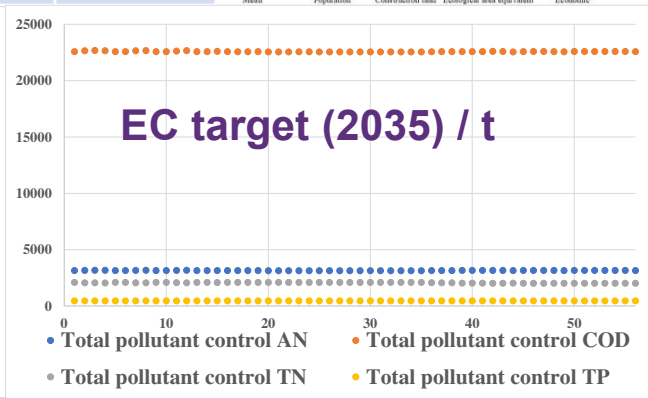


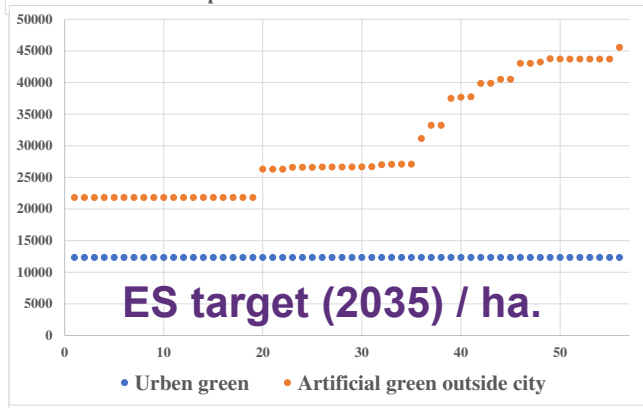
ET value fixed=$10.33\times10^8 m^3$

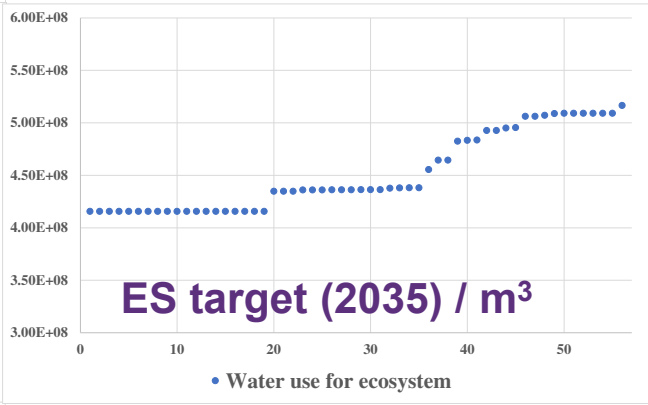
Scheme	O_1 weight (W1)	O_2 weight (W2)	O_3 weight (W3)	O_4 weight (W4)
1	1	Δ	Δ	Δ
2	0.9	0.1	Δ	Δ
3	0.9	Δ	0.1	Δ
4	0.9	Δ	Δ	0.1
…	…	…	…	…
283	0.1	Δ	Δ	0.9
284	Δ	0.1	Δ	0.9
285	Δ	Δ	0.1	0.9
286	Δ	Δ	Δ	1



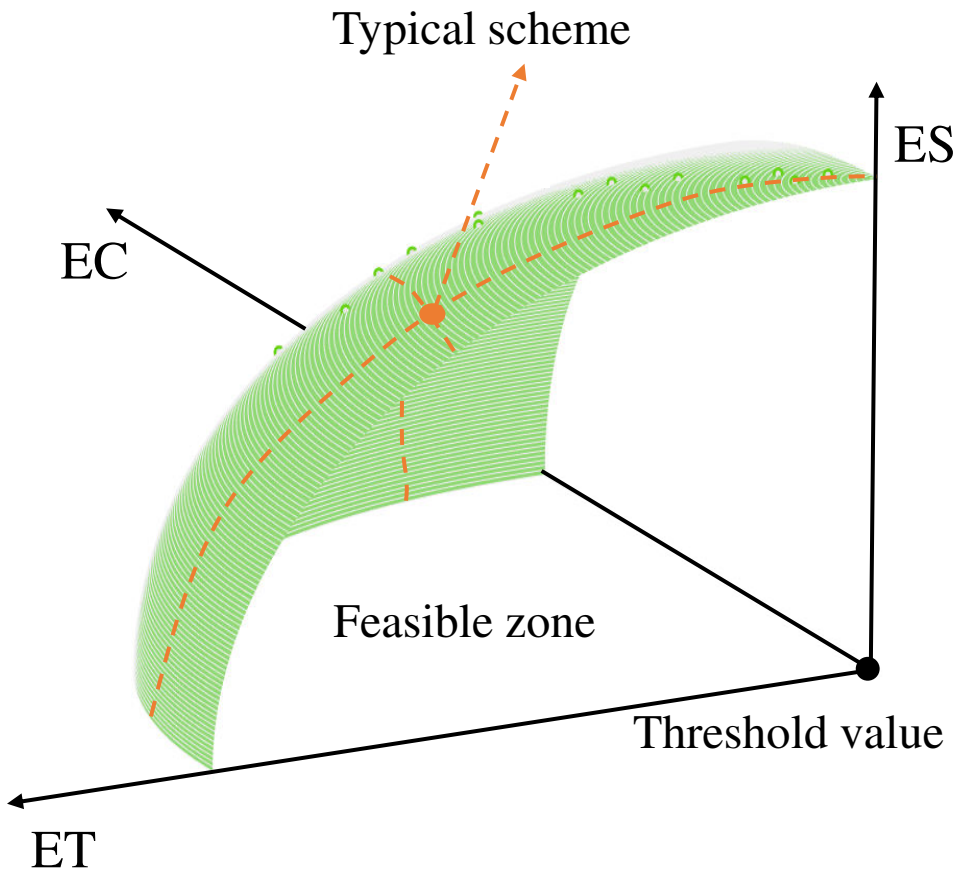




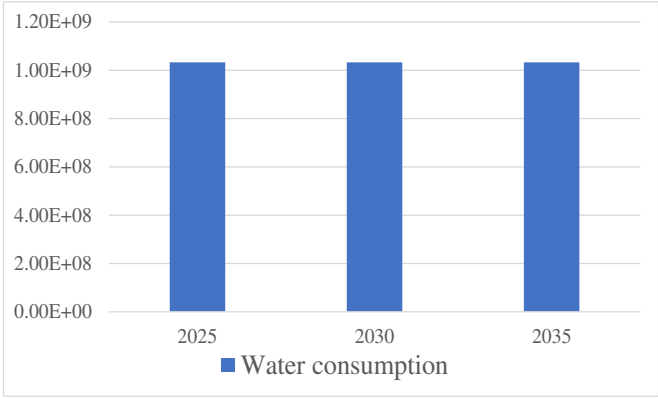




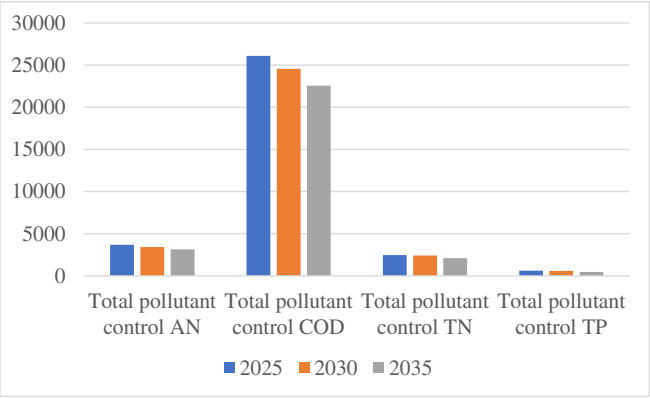
Results



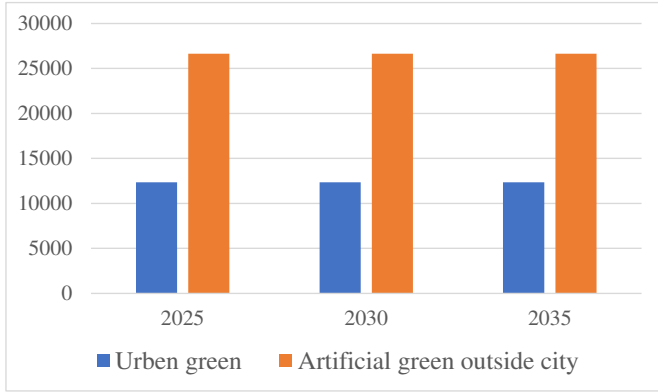
- ET fixed (10.33×10^8 m^3)
- EC/ES preference fixed (0.25,0.25,0.25,0.25)



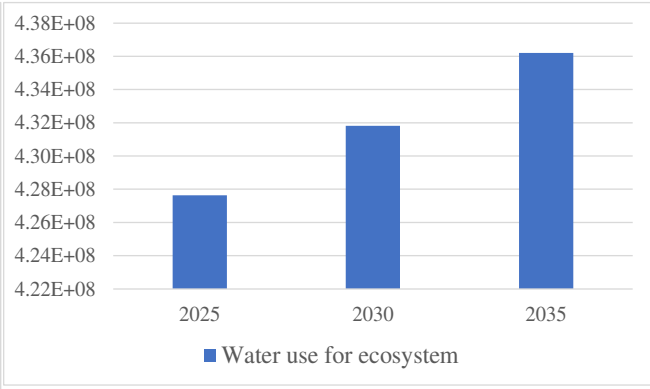
ET target (2025-2030-2035) / m^3



EC target (2025-2030-2035) / t

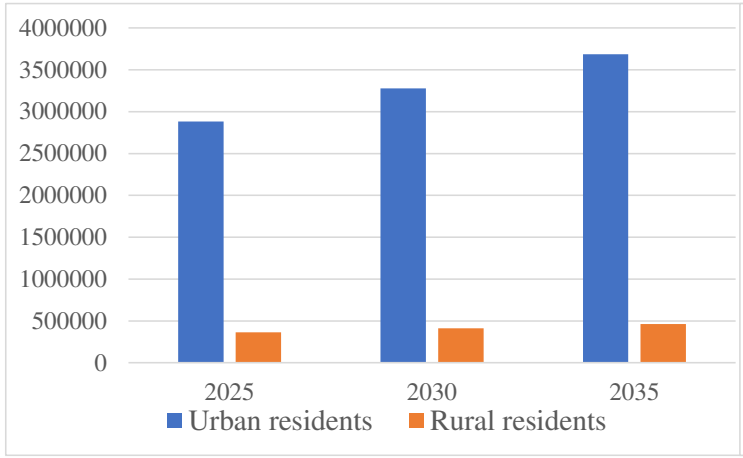


ES target (2025-2030-2035) / ha.



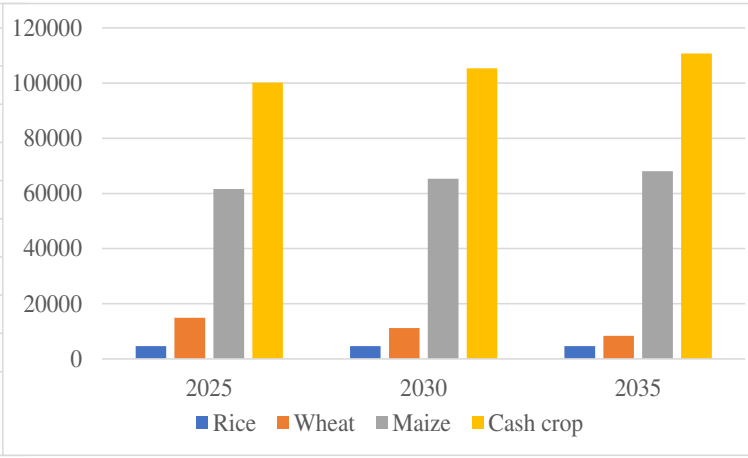
ES target (2025-2030-2035) / m^3

Results

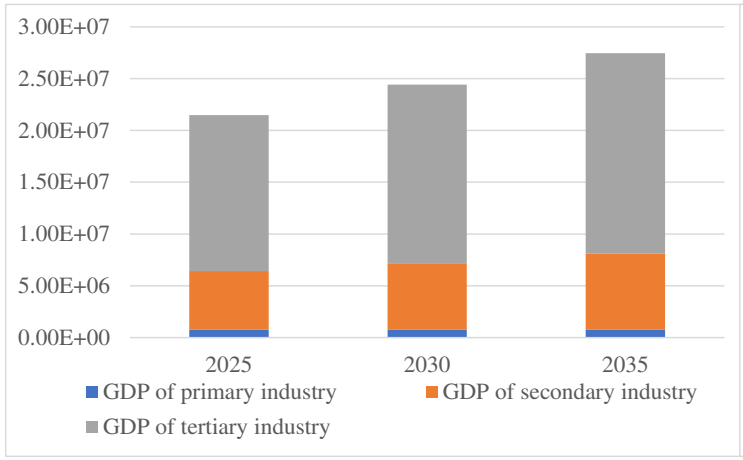


Population

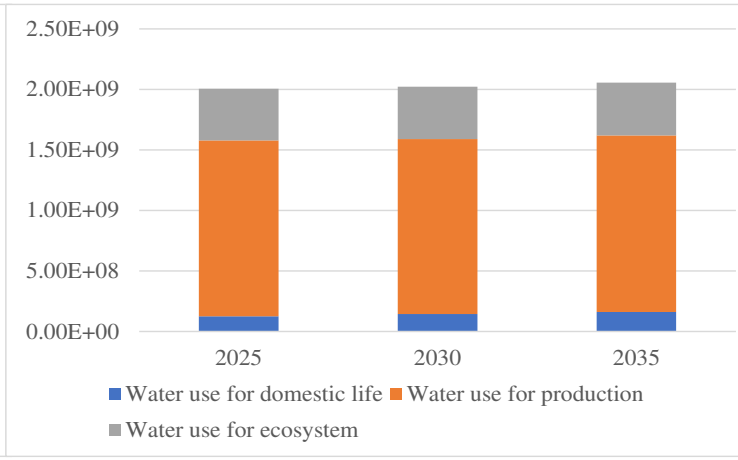
Land use in urban city / ha.



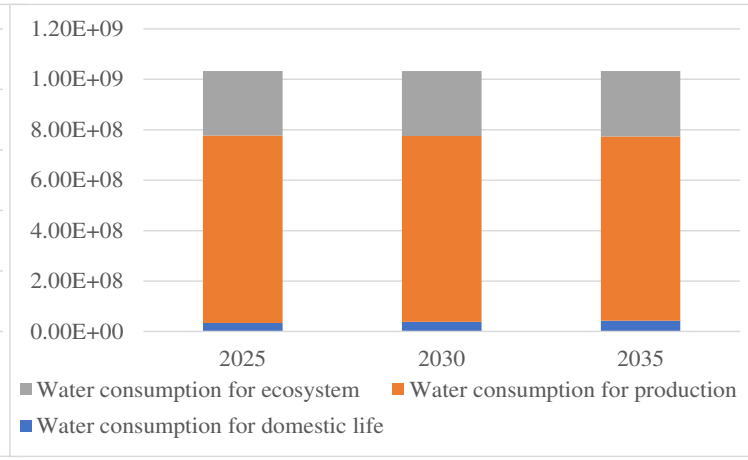
Land use in agriculture / ha.



Gross Domestic Product / 10^8 yuan



Water use / m^3



Water consumption / m^3

Limitations

Leontief metric unchanged

- Leontief matrix is from the input-output table which could represent the structure of economic production. In China, the input-output table will be published in year xxx2 or year xxx7. There will be uncertainties if we use the same input-output structure in the next 15 years' forecast and optimization. However, some boundary conditions remain constant to allow us to examine internal dynamics (as opposed to responses to external forces) (Elshafei et.al, 2016), the static input-output table could help us analyze the internal relationships between subsystems.

Results mainly dependent on the society

- To coordinate the water-related plans mentioned above, the preference of the public and government is one of the most important basis to determine the results.
- In our practical work, we invited managers from different departments and try to balance all the issues.

Yinchuan Municipal Development and Reform Commission	Yinchuan Municipal Water Bureau	Water Conservancy Research Institute of Ningxia Hui Autonomous Region
Yinchuan Bureau of Industry and Information Technology	Yinchuan rural Agriculture Bureau	Yinchuan Natural Resources Bureau
Yinchuan Ecological Environment Bureau	Yinchuan Municipal Bureau of Statistics	Yinchuan Science and Technology Bureau

Conclusion

A Framework to couple ET/EC/ES target management and “Basing four aspects on water resources”

- We proposed a framework to couple ET/EC/ES target management and “Basing four aspects on water resources”. The framework could analyze the correlation pattern of social and economic development and environmental ecology under resource constraints, and contribute to the coordinated development of society and nature under resource constraints.

Apply the Framework in Yinchuan City in China to allocate water resources in 2021-2035

- We applied the framework in Yinchuan and determine the objectives and control requirements of people, city, land, property and ecological construction under different best fit ET/EC/ES targets. From the typical scheme, the results can effectively improve the ability of water security for the economic and social development and ecological protection of Yinchuan City.

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Thanks for attention!

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