The "Lake-Canal-Irrigation District" System in Gaoyou Ancient Irrigation Project

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Abstract: In the practice of water control in the past dynasties in China, plain systemic thought runs through it. In Gaoyou, Jiangsu Province, the Li Canal connects Gaoyou Lake and Gaoyou Irrigation District through hydraulic facilities such as gates and dams on the east and west embankments. It realizes the deployment of water between "Lake-Canal-Irrigation District" system and takes into account irrigation and water transport. "Lake-Canal-Irrigation District" system is an open and complex system, from water storage, water transfer, water transportation, water distribution to irrigation, it is an organic whole coordinated operation, achieving dynamic balance. The "Lake-Canal-Irrigation District" system is connected, which promotes regional biodiversity and interprets the concept of sustainable development of "the harmony between man and nature". The "Lake-Canal-Irrigation District" system solves the imbalance in the spatial and temporal distribution of water resources and improves the utilization efficiency of water resources. The systematic ancient water control projects have been enduring for a long time. Although they have evolved and developed, the basic layout structure and the principles of organization have been implemented throughout.

1. Introduction
The practice of water control in the past dynasties in China is marked by systematic thinking and methods. The natural basin of water itself presents a net-like form, which is more obvious in the large-scale space. The construction of water conservancy projects makes the main body of the water network system not only contain natural rivers, lakes, swamps, and wetlands, but also involve artificially excavated canals, channels, and reservoirs[1]. These objectively caused a fundamental change in the natural distribution and connection pattern of rivers and lakes, and the natural state of the distribution of water resources has also undergone tremendous changes. The result not only affects the regional water resources allocation and guarantee capacity, but also affects the stability of the ecological environment system and the development of the social economic system [2].

In 486 BC, Wu Kingdom built Hangou. The development and evolution of this artificial canal lasted for nearly 1800 years. Not only connects the five major water systems of the Hai River, the Yellow River, the Huai River, the Yangtze River and the Qiantang River in the north-south direction, but also connects the Gaoyou Lake, Li Canal and Gaoyou Irrigation Area from east to west through hydraulic facilities such as gates, Holes, and dams in the middle part of Gaoyou, Jiangsu Province. This canal realizes the on-demand deployment of water resources between "Lake-Canal-Irrigation District" system, taking into account both irrigation and water transportation. It is a model of the ingenious use of river and lake water systems, rational control of rivers and lakes, and water system
connection projects in ancient China. Which is a successful practice of system theory in ancient irrigation projects.

Figure 1. The style of "Lake-Canal-Irrigation District" system in Gaoyou

2. "Lake-Canal-Irrigation District" Water Resources Allocation System

2.1. The Origin of the "Lake-Canal-Irrigation District" System’s Development

During the Spring and Autumn Period, Fuchai, king of the Wu Kingdom dug Hangou. In the Sui and Tang Dynasties, the construction of weirs and ponds eased the instability of the lake and river water volume, and water transportation and irrigation benefited at the same time. After the Song Dynasty, the Yellow River captured the Huai River, and the Huai River invaded southward, forming the Gaoyou Lake after the integration of many lakes. According to "Gaoyou Zhouzhi" records, Gaoyou Lake evolved from dozens of natural lakes of varying sizes, and ranks the sixth largest freshwater lake in China. Gaoyou Lake draws water from the lake for economic transportation and irrigation, and becomes the center of Gaoyou's production and life.

According to historical records, Li Jifu, the prime minister of the Tang Dynasty, presided over the construction of Pingjin Weir, which was an important ancient weir in the Li Canal section and was built to regulate the water level of the canal. His "prevention of inadequacy and more than leakage" became the guiding ideology for the construction of Gaoyou's water conservancy system for more than a thousand years. Before the Ming Dynasty, the canal was transported by numerous interconnected lakes. Since the second year of Hongzhi in the Ming Dynasty, the two embankments of the Li Canal were built and perfected successively, realizing the separation of the canal and the lake. After the Ming and Qing Dynasties, a complete irrigation deployment system was gradually formed, that is, through the sluices, water gates, and water tunnels of the embankment, the water was stored between the lakes, rivers and fields to realize water storage, water transfer, and water distribution, and finally achieve irrigation.

The Gaoyou Lake and the Li Canal Sluices adjust their water levels through sluice holes and other water conservancy facilities, while the Li Canal irrigates Yundong farmland through the sluice holes, turning floods into water conservancy.

2.2. Historical Hydraulic Facilities in the "Lake-Canal-Irrigation District" System

By the beginning of the 20th century, nine gates and nine holes and Guihai Dam had been built on both sides of the canal in Gaoyou, forming a relatively complete irrigation and drainage facility. There are 9 gates and 9 holes on both sides of the canal in the territory. Among them, there are 6 gates and 9 holes located in east dam: Ziying Gate, Jieshou Smallgate, Tou Gate, Nanguanbaer Gate (also named Nanguan Gate), Cheluobaer Gate (also named Cheluo Gate), Heyao Gate, Puji Hole, Kanhua Hole, Qingfeng Hole, Yongfeng Hole, Shaociagou Hole, Tonghuaqiao Hole, Nanshuiguan Hole, Pipa Hole, Lipu Hole. There are 3 gates located in east dam: Lu'an Gate, Qing'an Gate, Lifesaving Port Gate.
Table 1. Statistics of some gates and holes along the canal

| Culvert name | location          | Construction time                                      | Dimensions of main parts (m) | Length | Aperture |
|--------------|-------------------|-------------------------------------------------------|-------------------------------|--------|----------|
| Cheluo Gate  | South Cheluo Town | The fifth year of Qianlong in Qing Dynasty (1740)     |                               | 36.79  | 4.18     |
| Balisong Hole| South Middle Dam  | Ming Jiajing three years (1524)                       |                               | 30.70  | 0.70     |
| Nanguan Gate | Wuli Dam          | Third Year of Jiaqing in Ming Dynasty (1656)          |                               | 37.19  | 3.39     |
| Pipa Hole    | Gaoyou South Gate | Fifty-sixth Year of Kangxi in Qing Dynasty (1717)     |                               | 46.50  | 0.58     |
| Nanshuiguana Hole | Gaoyou South Gate | The fourth year of the Northern Song Dynasty Kaibao (971) |                               | 51.20  | 0.70     |
| Jieshou Small Gate | South Jieshou Town | Tenth Year of Shunzhi in Qing Dynasty (1656) |                               | 22.25  | 1.80     |
| Ziying Gate  | North Jieshou Town| Twenty-fourth year of Wanli, Ming Dynasty (1596)      |                               | 13.50  | 3.59     |

In addition, in the central part of the territory in the thirty-fourth year of King Zhou Jing (486 BC), the main north-south water system, dominated by Hangou, has formed. In the seventh year of Emperor Wen's Kailhuang period (587), the second Shanyangdu water system with a north-south direction was formed in the east. Since the end of the Ming Dynasty, three main water systems have gradually formed within the territory, namely: the Zhunhe River in the west, including Xiangyang River, Tianling River and Gaoyou Lake; the Lixia River in the east, including Sanyang River, Yunyan River, Beichengzi River, Nanchengzi River, Luyang Lake, etc. After a long period of natural evolution and artificial excavation, such as dredging, straightening, and diversion, the current east-west main river has been formed in the Gaoyou Irrigation District, and a horizontal and vertical network with north-south rivers and a criss-crossing river network has formed.

Figure 2. the whole project of the irrigation system
2.3. Systematic Analysis of "Lake-Canal-Irrigation District" Water Resources Allocation

(1) "Lake-Canal-Irrigation District" is an open Complex System

The Gaoyou section of the canal used to travel by the lake for a long time, and gradually realized channelization after the Ming Dynasty. Gaoyou Lake and the Li Canal formed two relatively independent bodies of water. Between the lake and the river is the west embankment of the Li Canal, and in the subsequent construction, it was proposed to "install culverts and fill each other". For example, the existing life-saving sluices that are still in use have two main functions: introducing water from Gaoyou Lake into the canal to ensure the smooth flow of water transportation; and leading the canal water into Gaoyou Lake to avoid the danger of bank burst caused by excessive water level in the Li Canal.

Between the river and the field, the river and the city is the east embankment of the Li Canal. By the beginning of the 20th century, 6 gates and 9 holes had been built on the Chudong Dam, forming a connection between the Li Canal and the river system east of Yanyun. The canal water is discharged through the Dongdi sluice hole to the vertical and horizontal network of rivers in the Lixiahe area; through the north and south water gates of the ancient city of Gaoyou, the river is introduced into the city in a vertical and horizontal direction. It not only regulates the navigable water level of the Li Canal when the floods are rising, but also provides water sources for farmland irrigation and urban water use.

The boundaries of various water bodies such as rivers, lakes, farmland, ditches, wetlands, etc. are not completely closed, but are open complex systems. The connection between water resources forms a network, which complicates the system. Rivers, lakes, farmland, wetlands, groundwater, surface water, and environment are the nodes of the water system network. The formation of the connection between these nodes is a long-term and natural process. Through the construction of interconnection facilities such as drainage and irrigation tunnels and gates, the connection between multiple nodes was artificially increased, and the water network structure was significantly changed.

Water is a basic element in a complex system. It changes when the variables of the system are different, such as climate, hydrology and water demand. The structure of the system is diverse, and each water use subsystem has complex behaviors. Because of the subjective active factor of the system-human beings' adjustment, control and utilization for this systematic and connected water body, the complexity of the management of has also increased significantly.

(2) The Integrity and Comprehensiveness of the "Lake-Canal-Irrigation District" System

![Figure 3. The "Lake-Canal-Irrigation District" System Diagram](image)
The "Lake-Canal-Irrigation District" system is a perfect organic whole. The Gaoyou Lake-Li Canal-Gaoyou Irrigation District takes "lake", "river" and "field" as the three carriers of water resources; takes "gate", "hole", "guan" and "dam" as the four channels of water resources; and takes "river" and "ditch" as the irrigation water distribution terminal, completes water storage, water transfer, water transportation, water distribution and water reduction, forming an overall coordinated operation system.

The "Lake-Canal-Irrigation District" system has comprehensive functions such as water resource allocation, drought and flood prevention, and water quality improvement. Each main function has multiple sub-functions. For example, the water resource allocation function can realize multiple functions such as water transportation, agricultural irrigation and domestic water supply; the flood and drought disaster prevention function also has multiple functions such as flood discharge, drought resistance and emergency water supply; water quality improvement also includes functions such as water quality improvement, ecological restoration and landscape maintenance.

Comprehensive consideration and balance of many factors such as climate change, water transportation capacity, planting area, farming methods, population and there interrelationships etc., is related to water resources carrying capacity, and plays a key role in the smooth operation of the "Lake-Canal-Irrigation District" system. In the meantime, it also meets the core requirements of system theory. From this perspective, the "Lake-Canal-Irrigation District" systematic length deployment thought is ahead of its time.

(3) The Dynamic Balance of the "Lake-Canal-Irrigation District" System

The operation process of the "Lake-Canal-Irrigation District" system is dynamic. The first is because the system is a composite system composed of many subsystems such as rivers, lakes, fields, ecology, environment, and society. The internal subsystems continue to develop and change under the interaction and action of each other. Secondly, key elements, such as climate, hydrology or water demand, are changing, which makes the system complex and unpredictable.

Dynamic balance is an important characteristic of a typical system. In the "Lake-Canal-Irrigation District" system, the ancients took "preventing insufficiency and surplus leakage" as the fundamental concept, integrating reality, grasping the objective conditions and operating rules of the water resource allocation system, and formulating sophisticated management methods for the opening and closing of gates. In the 22nd year of Emperor Qianlong of the Qing Dynasty (AD 1757), the "Shui Ze" was set up at the imperial wharf on the west dike of the Li Canal, which was the earliest water level station in the Huai River Basin. The opening and closing time of the Yanyun sluice tunnel is determined through continuous water level observation, and a system is formed within a certain period of time. Reasonable opening and closing of tunnel gates enables the scientific deployment of water volume among lakes, rivers and fields. In the meantime, Gaoyou Lake becomes a water tank for regulating the water volume of the Li Canal, and the Li Canal not only ensures the safety of water transportation, but also becomes the main irrigation water canal in the Lixia River area. In this way, two major dynamic balances are realized: adjusting the water level balance of drought and flood; taking into account the functional balance of water transportation and irrigation.

The scientific river-lake-field water system connection project has successfully adjusted and changed the connection status of the natural water system, forming a river, lake-field water network with smooth drainage, proper storage and drainage, rich and dry regulation, multi-source complementation, adjustable and controllable functions. It is a successful application of systems theory in ancient irrigation projects.

(4) Sustainable Development of the "Lake-Canal-Irrigation District" System

“The unique features of a local environment always give special characteristics to its inhabitants”. The unique natural conditions of the river basin form a special ecosystem and unusual humanistic characteristics. Maintaining the water and soil balance in the river basin is an important condition for sustainable development. The water system in the "Lake-Canal-Irrigation District" is connected to maintain the integrity of the wetland ecosystem. The connectivity of the water system will affect the water quality of the water function zone. The better the connectivity of the water system, the stronger
the self-purification and pollution-holding capacity of the water flow. Aquatic biodiversity also needs to be realized through water system connectivity. Without water system connectivity, aquatic biodiversity will be greatly affected\[3\].

"Lake-Canal-Irrigation District" system in Gaoyou is a perfect wetland agricultural system. It not only has natural beauty, but also has abundant shallow wetlands, which provides a unique ecological environment for the growth, habitat and reproduction of various fish, birds and aquatic plants. There are currently more than 500 species of wild animals and plants, including 40 families and 194 species of birds. The wetland agricultural system has a long history in Gaoyou. The compound ecology of "rice and duck farming" is economical and efficient. It interprets the traditional farming concept of "the harmony between man and nature" and has important enlightenment for the development of modern ecological agriculture.

The theory of sustainable development is the theoretical basis for the evolution of society, ecology, and water resources systems. In the "Lake-Canal-Irrigation District" system, water is a factor that acts as a bridge in the entire system, and the great systematic governance and utilization also shows the level of local social and economic development.

3. Conclusion
In ancient China, people used system theory ideas and methods to guide the construction of water conservancy projects, and there are many successful cases in the practice of water control and water use, such as Dujiangyan Project. After studying the general method of modern system theory, it is found that: the planning and design of the ancient Dujiangyan project system is in full compliance with the basic principles of modern system science. It not only scientifically determined the optimal setting values for the two state variables of the water demand and water quality of the cultivated land in Chengdu Plain according to its basic goals, but also made it have a certain degree of adaptability by using topography and features\[4\].

"Lake-Canal-Irrigation District" system in Gaoyou solves the imbalance in the spatial and temporal distribution of water resources, makes overall arrangements and improves water use efficiency. The systematic ancient water control projects have been enduring for a long time. Although they have evolved and developed, the basic layout structure and the principles of organization have been implemented throughout. As an ancient complex system project, the simple system thought of the ancients flashed. The scientific level and creation of its planning, design and construction are not inferior to those measured by today’s systematic methods\[5\].

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