Evaluation the ecological water demand of Dongting Lake based on ecological hydrology during the storage period

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Abstract. This paper is aimed at evaluating the ecological water demand of Dongting Lake in the middle reach of Yangtze River. Since Dongting Lake has evolved into a lake area connected by three waterways: Eastern Dongting Lake, Southern Dongting Lake and Western Dongting Lake, the ecological water level and ecological water demand of different lake areas must be obtained separately. In the Eastern Dongting Lake, we choose Lujiao station as the water level representative station, and choose Yingtian and Yangliutan station as the water level representative station in Southern Dongting Lake, and choose Nanzui and Xiaohezui station as the water level representative station in Western Dongting Lake. The natural water level data is used to obtain the ecological water level in different lake areas of Dongting Lake based on the ecological hydrology method, and then the ecological water demand is obtained through the lake water level-volume relationship curve. The ten-day average minimum ecological water demand of Dongting Lake from September to October is 6.042, 5.294, 4.095, 3.548, 3.139, 2.864 billion m$^3$. The determination of the minimum ecological water demand of Dongting Lake provides a scientific basis for defining the safety status of the lake ecosystem.

1. Introduction
The minimum ecological water demand (MEWD) means the water that must be consumed to maintain the balance and normal development of the river or lake ecosystem, and to ensure the normal function of the wetland system[1-2]. If the water volume is less than the minimum ecological water demand, the ecosystem balance will be directly affected, the ecosystem will gradually degenerate or even disappear[3]. In view of the research on ecological water demand, the research mainly focused on the minimum ecological water demand of rivers. In the 1940s, the problem of fishery reduction caused the attention of the US water resources protection department, focusing on the river flow for fishes. The effects of reproductive growth, and then the minimum flow of rivers needed to maintain the normal growth and growth of fish[4-5]. This is the first concept of river ecological water demand [6-8], but the definition is not very clear. Click[9] clarified the definition of river ecological water demand, a certain amount and quality of water must be required to maintain the balance of the ecosystem. In the same period, Baird systematically analyzed the relationship between plant growth and hydrological processes in ecosystems, and emphasized the important role of flow factors in biodiversity conservation again[10]. It is the decisive factor for the formation, development, disappearance and regeneration of lake wetlands, and promotes the research of ecological water demand in the international academic community. One of the most popular topics is the river ecological water
demand. For example, Buzan determined the minimum ecological water demand of the Galveston Bay based on the correlation between oyster production in and freshwater inflow and salinity\cite{11}. Sun et al defined the ecological water demand of the estuary according to the ecological health needs of the estuary\cite{12}, but few research focus on the ecological water demand of the lake wetland.

The water level of the lake mainly depends on the dynamic balance of the inflow and outflow, and the water level of the closed lake is mainly determined by the processes of rainfall, evaporation, and transpiration. In addition, the ecological water demand of lakes will evolve along with the evolution of Lake Basin structure and lake runoff. However, the current research focuses on the ecological storage capacity of lakes in a specific period.

2. Method for evaluating ecological water demand

Ecological water demand is one of the hot issues in current ecological and hydrological research. The minimum ecological water demand of lakes is the amount of water needed to maintain the basic function of lake ecosystems, and the reduction of ecological water demand will directly affect the dynamic balance of lake ecosystems and the normal function of their functions. The minimum ecological water demand of lakes consists of the minimum inflow ecological water demand, the minimum ecological water demand in lake area and the minimum outflow ecological water demand in the lake, see Figure 1.

![Figure 1. Evaluation model of lake ecological water demand](image)

The ecological inflow water requirement into the lake refers to the amount of water that must flow into the lake to meet the minimum ecological water level of the lake and meet the minimum ecological water demand of the downstream river, including surface inflow, underground inflow, and precipitation. The minimum ecological water demand in the lake area is the amount of water that needs to be consumed to maintain the lake’s basic function of the ecosystem. Specifically, it is the amount of water volume that must be stored to maintain the minimum ecological water level of the lake. The minimum outflow ecological water requirement for the lake is to meet the ecological water demand of the downstream. The ecological outflow water demand for the lake includes surface flow, underground flow, evaporation, leakage, and human water use.

According to the law of ecological tolerance, each ecological factor has a range of adaptation, called ecological amplitude. Therefore, the ecological water demand of the lake area, which is one of the main ecological factors should be within a reasonable range. The upper limit is the maximum ecological water demand of the lake, and the lower limit is the minimum ecological water demand of the lake. When the water quantity is within the appropriate range can ensure that aquatic plants and animals have optimal growth conditions to maintain the dynamic balance of the lake system. The water level corresponding to the minimum ecological water demand of the flowing type lake is the lowest ecological water level.

To calculate the ecological water demand in the lake, first we can calculate the ecological water level of the lake, and then obtain the ecological water demand to maintain the lake itself according to the lake water level-volume relationship curve. The commonly calculation methods used for the ecological water level includes statistics method according the natural water level data, lake
morphological analysis, minimum space requirements for biology, water quality index impact method, comprehensive index method.

2.1 Statistical method according to natural water level data
In the natural status, although the lake water level changes, the disturbance to the ecosystem is very intense. However, in the long-term ecological evolution of the lakes, the ecosystem has adapted to such disturbances. The natural low-water level disturbance to the ecosystem is within the elasticity of the ecosystem and does not affect the stability of the ecosystem. However, in the case of strong human disturbance or extreme weather, such as the use of lake water sources in the special dry season or in the dry season, the lake water level may be lower than the minimum water level, or in the event of a major flood, the lake water level is higher than the maximum water level. This change is sudden in time and is not encountered in the long-term evolution of the ecosystem. Therefore, $3\sigma$ principle can be used to screen out the water level in the very dry year and the lowest water level in the remaining years as the lowest ecological water level $H_1$.

2.2 Lake morphological analysis method
The natural water level data statistical method requires long-term water level data. Under the condition of lack of water level data, the lake's lowest ecological water level can be obtained by lake morphology analysis. Lake volume is used as an indicator of Lake Hydrology, while the lake area is used as an indicator of lake function. As the lake area decreases, so does the lake depth. On the relationship curve, the change rate of lake volume has a maximum value. At this maximum, the reduction of lake function will increase significantly for each unit of water level. Above this value, the Lake Hydrology and terrain subsystem functions will be seriously degraded, so the maximum water level is the lowest ecological water level, and the relationship between Lake water level and water surface area is as follows:

$$A = f(H)$$

(1)

Where, $A$ is the lake area; $H$ is the lake water level.

The lowest ecological water level of a lake is expressed as follows:

$$\frac{\partial^2 A}{\partial H^2} = 0$$

(2)

Solve solving formula (2) we can get the minimum ecological water level $H_2$.

2.3 Minimum space requirements for biology
The main aquatic organisms growing in the lake have a living space, such as the upper water body suitable for the living depth of about 1.5m, and the crucian and carp are suitable for living in the lower water body with a water depth of about 1.0m. Therefore, when calculating the minimum ecological water level according to the appropriate water depth of the representative organism. If the lake is also equipped with functions such as shipping and tourism, these factors should be considered when calculating the lowest ecological water level, and various factors should be considered. For the water level requirements, the final result is taken as the maximum value of each indicator.

$$H_1 = H_b + h_t$$

(3)

Where, $H_b$ is the lake bottom elevation; $h_t$ is the minimum water depth required for consideration of important aquatic organisms or other factors for the time period (determined according to measured data or empirical methods).

2.4 Functional method
Water resources are both a natural resource and the most basic and important element of the ecological environment. For lakes, water resources mainly include three functions: environmental function,
ecological function and production function. The lake water storage capacity and water resources are closely related. The calculation method of lake minimum ecological water level based on functional method is as follows:

$$H_4 = \sum_{i=1}^{n} \beta_i h_i / n$$  \hspace{1cm} (4)

Where $H_4$ is the water level corresponding to the minimum ecological water demand of the lake; $\beta_i$ is the $i$th water resource function coefficient of the lake; $h_i$ is the water level corresponding to the minimum ecological water quantity required to meet the first water resource function of the lake; $n$ is the number of resource functions.

2.5 Comprehensive index method

The lowest ecological water level calculated by the above four methods only considers a single factor, and the lowest ecological water level is usually the result of many factors working together. Therefore, the minimum ecological water level can be determined according to the above four methods, and then carefully compare and consult experts, give the weight of each indicator, and get the comprehensive minimum ecological water level.

$$H_{\min,t} = \sum_{i=1}^{4} \lambda_i H_i$$  \hspace{1cm} (5)

In the formula, $H_{\min,t}$ is the minimum ecological water level of a variety of lakes; respectively, $\lambda_1$, $\lambda_2$, $\lambda_3$, $\lambda_4$ are the proportions of various factors, and $\sum \lambda_i = 1$.

In this paper, based on historical data, we use the natural water level data statistical method to find the lowest ecological water level of lakes in each period, and then the minimum ecological water demand in the lake differentiation period is obtained through the water level-lake capacity curve.

3. Minimum ecological water demand of Dongting Lake

There are obvious periodic hydrological changes in Dongting Lake. The flood season of the Yangtze River is from July to September every year, while the main flood season is from July to August. The Dongting Lake flood season is from April to September every year. During this period, ecological water demand is not a constraint factor for the ecosystem. Considering the impact of reservoir storage on Dongting Lake, the ecological water demand of Dongting Lake is mainly concentrated in the reservoir storage period and dry season, that is, from September to March of the following year. This study focuses on the water storage period in the reservoirs of the middle reaches of the Yangtze River. Therefore, this paper only discusses the minimum ecological water demand of the Dongting Lake from September to October.

Dongting Lake has evolved into a group of waterways connected to the Eastern Dongting Lake, the Southern Dongting Lake and the Western Dongting Lake. It is distributed in an east-west direction and the water level distribution has obvious spatial heterogeneity. Select Lujiao station as the representative station of Eastern Dongting Lake, select Yangliutan and Yingtian Stations as the representative station of Southern Dongting Lake, and choose Nanzui and Xiaohezui stations as the representative of Western Dongting Lake (Figure 2). The Chenglingji hydrological station is located at the intersection with Dongting Lake and the Yangtze River, water level reflects the effect of the Yangtze River on the lake's emptying or jacking.
In the analysis of water level changes in different lake areas, the average water level of Yangliutan and Yingtian station is used as the water level of Southern Dongting Lake, the average water level at Nanzui and Xiaohezui station is on behalf of the water level of Western Dongting Lake. According to the data at five representative sites of 1953-1985 and 1988-2002, 3σ principle was used to screen out the extremely dry years (1963, 1966, 1971, and 1972) and the flood years (1983, 1998). The lowest, suitable and highest ecological water level in each lake area of Dongting Lake is obtained and shown in Figure 3.

According to the topographic data of Dongting Lake, the ArcGIS spatial analysis module is used for spatial interpolation. By constructing triangular irregular network (TIN), the calculation model is close to the bottom of the lake. The area and volume calculations are performed on the TIN, The lake water level-volume curve of eastern, southern and western Dongting Lake are obtained, see Figure 4.
According to the water level-lake volume relationship of each lake area, the minimum ecological water demand in the lake area at different time points is obtained, see Table 1.

| Time          | Eastern Dongting Lake (*10^8 m³) | Southern Dongting Lake (*10^8 m³) | Western Dongting Lake (*10^8 m³) | Total (*10^8 m³) |
|---------------|----------------------------------|-----------------------------------|----------------------------------|------------------|
| Early September | 27.83                            | 19.61                             | 12.98                            | 60.42            |
| Middle September | 21.46                           | 18.97                             | 12.51                            | 52.94            |
| Late September | 16.34                            | 15.79                             | 8.82                             | 40.95            |
| Early October  | 13.04                            | 14.33                             | 8.11                             | 35.48            |
| Middle October | 10.76                            | 13.20                             | 7.43                             | 31.39            |
| Late October   | 9.29                             | 12.50                             | 6.85                             | 28.64            |

4. Conclusion

According to the lake ecological health theory, the calculation method of the ecological water demand of Dongting Lake is expounded. Based on the historical observation data of long series, the natural water level data statistical method is used to estimate the lowest, suitable, and highest water demand of Dongting Lake from September to October. The determination of the minimum ecological water demand of Dongting Lake provides a scientific basis for defining the safety status of the lake ecosystem, and also the research results could provide necessary preparation for subsequent optimization and regulation research.

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