Water resources allocation in Erhai irrigated district considering catchment water-cycle health

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Abstract. In order to realize the healthy circulation of Erhai Basin water system, this paper constructs the Mike basin simulation model of Erhai Basin water resource system through the concept of water resource comprehensive allocation. Which is based on the principle of Erhai Lake water ecological environment protection and follows the principle of ecological priority, sanitary water into the lake, double control of total amount and consumption, and water conservation and emission reduction. The results show that the agriculture irrigated area of Erhai Basin should be gradually reduced to 472000 mu, and 48200 mu of wetland ecological pool should be increased, which is used as the collection area of basin landscape and irrigation return water. After adjusting the crop planting pattern according to the depth of water saving in Erhai irrigation area, the goal of controlling the agricultural water consumption to be no more than 201 million cubic metre and the total water consumption to be less than 366 million cubic metre should be achieved. The effect of reclaimed water irrigation on water saving and emission reduction is considerable. The application of reclaimed water irrigation can reduce the amount of clean water used in paddy growth period by 46.4%, and the amount of nitrogen fertilizer applied by 30.2%. The replacement rate of garlic reclaimed water can reach 100%. After the comprehensive allocation of water resources, it can supply 501 million cubic metre of ecological water in the river channels and 359 million cubic metre of water out of the river channels. Through the comprehensive utilization project of farmland drainage water and the construction of ecological regulation and storage belt, all irrigation drainage water should be reused and zero discharge can be realized. TN and TP emissions in irrigated area will be reduced by 39.3% and 46.3% respectively. Compared with the current situation, Erhai Lake water inflow and cleanly water inflow increased by 65 million cubic metre and 134 million cubic metre respectively. The annual average water level of the lake will be 0.15m higher than the current situation.

1. Foreword
Basin is a complex system with hierarchical structure and integral function, synergistically formatted and at the level of applied science. Human activities should be paid attention to realize the comprehensive management of water resources, other natural and social resources [1]. The study...
focused on three process mechanisms of basin water system physics, biogeochemistry and humanity linked by water cycle and the coupling and comprehensive regulation of its multiple links maintain the healthy water cycle at base scale and support the sustainable development of social economy. Climate change contributes to the emission of pollutants from human activities and economic development, and the adaptive countermeasures should be targeted and operable[2]. The "natural – artificial" dual evolution of the basin water cycle is the essential cause of water problems and water crisis in recent 30 years. The basis of scientific regulation of water resources is the cognition of the internal mechanism and law of water cycle and water resources evolution in the basin under the interference of high intensity human activities, and to build a comprehensive simulation platform for the dual water cycle and its associated process in the basin to simulate the future evolution trend of water resources, water ecology and water environment [3]. In the basin and irrigation area scale, the water resource allocation mainly adopts the software platforms based on rules such as MIKE BASIN, SWAT and WAS, etc.[4~6], as well as water resources simulation applied for lake areas after simulation integration of the water yield of surface water and groundwater models and the lakes [7].

As an important part of the land hydrosphere, lakes have the functions of regulating river runoff, improving ecological environment, providing water source, irrigating farmland, shipping, breeding aquatic animals and plants, maintaining biodiversity and tourism, etc. Under the long time scale of interdecadal, the population increase, urban expansion and economic development have led to lake shrinkage and inflow river cut-off. Water resource shortage, deterioration of water environment, fragility of water ecology and other problems are widespread. Climate warming has led to the rise of lake water temperature and acceleration of the biochemical process of the lake, and made water quality management more important in the hydrological change environment [8,9]. The lake area of Erhai Lake was 252 km² when the water level was 1,966m, and the lake volume was 2.959 billion m³. After entering the 21st century, due to the over standard of TN or TP, the water quality of Erhai Lake has been reduced from class II to class III. The water quality has a strong fluctuation. The TN, TP and COD in the water still maintain a high level, and the CODMn is increasing year by year. The pollution load from agricultural source into the lake is higher than that of industry and life. The impact of the first industry on the water quality of Erhai Lake is much higher than that of the second and third industries. The rapid development of animal husbandry and crop planting is the inducement [10]. The key to control the outbreak of blue-green algae in Erhai Lake is the input of nutrient salts, the reasonable regulation of lakewater level, the improvement of water transparency and the restoration of aquatic plants [11]. On the other hand, Erhai Lake basin is the birthplace of national civilization in the border areas of Nanzhao and Dali ancient countries. There are 18 townships (towns and subdistrict offices), 167 village committees and 33 communities in Eryuan County of Dali City, with a total population of 923,000, 796,000 mu of cultivated land, and 510,000 mu of farmland irrigation region in dam areas of Eryuan, Dengchuan, Dali, Xiaguans and Fengyi, etc. Agricultural water accounts for 68.6% of the total water consumption of the whole society. The contradiction between the social and economic development and the protection of Erhai Lake-Cangshan water ecological landscape is increasingly prominent. It is very urgent to achieve the goal of Erhai Lake protection through the water conservation and water utilization structure adjustment in the irrigation area, and by means of promoting the agricultural economic development of Erhai Lake area with the efficient utilization and unified allocation of water resources in the basin.

2. Material and methods

2.1. Adopted data and documents

(1) The observation data of monthly (daily) average temperature, maximum (minimum) temperature, relative humidity, sunshine hours, wind speed and precipitation, etc. of five county meteorological stations in Dali, Eryuan, Binchuan, Jianchuan and Weishan in and around Erhai Lake basin of Dali prefecture from 1950s to 2017; monthly (daily) runoff and sediment data of four hydrological stations including Liancheng, Tianshengqiao, Yangzhuangping and Dahuizhuang on the tributaries of Jinsha
River, Honghe River and Lancang River in the region; and observation data of monthly (daily) water level, outflow and evaporation of six lakes and reservoirs in Erhai Lake, Cibi Lake and Haixihai Lake, etc. from 1950s to 2017

(2) Social and Economic Development Statistical Yearbooks, agricultural water conservancy statistical annual reports, urban construction and tap water statistics and other basic data of Dali prefecture and Dali, Eryuan, Binchuan and other cities and counties since 1949. National economic development planning, as well as development planning of cities, industries, agriculture, land use, water conservancy and other industries of Yunnan Province, Dali prefecture, Dali, Eryuan, Binchuan and other cities and counties.

2.2. Simulation method of water resources allocation in irrigation area

On the basis of 11 irrigation sections obtained from irrigation subarea, 57 allocation calculation units are further divided into five levels of water resources subarea. Based on the ArcGIS platform, the regional water resources system network is generalized, the simulation model of water resources system based on inter-industry water fairness rules is established, and the international mainstream water resources allocation management tool MIKE BASIN is adopted, and the parameter calibration, node water balance test, main reservoir regulation rules, water supply capacity constraints, water resource allocation scheme simulation, output finishing and other steps are approved. Through "three supply and demand balances", the results of unified allocation of living, production and ecological water in each level year in Erhai Lake basin and surrounding areas are obtained [6].

3. Overall technical route of healthy water cycle in Erhai Lake basin

Based on the investigation and evaluation of the river and lake water system and water resources system in Erhai Lake basin, we should follow the basic principles of "ecological priority, clear water entering the lake, double control of total amount and consumption, and water conservation and emission reduction", take the protection of lake water ecological environment and agricultural water conservation and emission reduction as the main task, strictly control the total water consumption, water efficiency and pollution discharge in the basin, and take the restrictions of no increase of irrigation area, no increase of irrigation water consumption and no increase of agricultural non-point source(irrigation waste water) of farmland as the rigid conditions; optimize the planting structure of crops in the irrigation area, control the planting area of large water and fertilizer crops, vigorously promote the construction of water conservation and emission reduction projects, and realize the "less water consumption, high utilization and low emission" of irrigation. On the basis of the integral framework of the dual water cycle theory of the basin, integrate the overall thinking of the basin system governance and the "seven actions" plan of Erhai Lake protection and governance, and realize the healthy water cycle of Erhai Lake basin through the unified allocation of water resources in the irrigation area, as shown in Figure 1. The main technical routes are as follows:

①Determine the receiving water source of the inflow river, and carry out the comprehensive treatment of the river channel of Erhai Lake from the aspects of establishing the basin management mechanism, constructing a complete flood control system, building a clear water channel, increasing the amount of clear water entering the lake, reducing the total amount of pollutants entering the lake, etc. [12].

②The Qingshui corridor takes the built reservoir or streams on the inflow river of Erhai Lake as the water supply source, and uses Erhai Lake, Cibihu reservoir, Haixi reservoir and Sanchahe reservoirs as the core to increase the overall planning, quality and circulation of water resources and realize the optimal allocation and joint operation of water resources. The ecological water supply of Miju River and other clear water corridor should be guaranteed through the water system connection and the reservoir ecological operation in combination with the domestic sewage interception project of markets and towns along the river and the rural area.

③On the premise that the total irrigation area of the irrigation area does not expand, combined with the elevation of each irrigation section, soil and water resource conditions, adjust the planting structure
of crops, strictly limit the planting area of garlic, vegetables and potatoes, based on ensuring the self-sufficiency of basic rations and regional grains in rural areas, properly control grain crops such as rice and wheat, and vigorously develop economic crops such as flue-cured tobacco, tea and fruit with low water consumption and high output[13]. According to the analysis, the bulk crop planting proportion of rice will be decreased from current 50.6% to 36.9% in 2035, that of corn will be decreased from 26.1% to 8.3%, and that of broad bean will be decreased from 25.8% to 14.3%, and multiple cropping indexes of spring and autumn rotation will reach 195%.

4. The urban sewage intercepting channel receives the treated urban domestic sewage and initial urban rainwater, which are directly discharged out of Erhai Lake basin through the main sewage intercepting main pipe around the lake to supplement part of the ecological water in the downstream course of the Xi'er River.

5. Increase the comprehensive utilization of urban reclaimed water and farmland irrigation waste water, combine with Erhai Lake wastewater interception project and wetland construction planning of Dali City, collect farmland waste water and urban reclaimed water into wetland and purification pond dispersedly, which can be reused for agricultural irrigation through the comprehensive utilization project of irrigation area after staying in the wetland and purification ponds for 3-5 days for purification, thereby reducing the clean water intake and sewage discharge, achieving water conservation and emission reduction, and reducing the pollution load into the lake.

Wang Hao et al. believed that in order to alleviate the water and soil resource dislocation and water resource contradiction in the north aggravating by the transportation of grain from north to south in China, we should focus on improving the utilization of rainwater by suitable water planting, strengthening engineering water conservation and agronomic water conservation, improving the utilization of irrigation water and increasing the utilization of unconventional water and strengthening management, etc., so as to build a modern irrigation agriculture with water conservation and high efficiency [14,15]. Erhai Lake irrigation area is an area with concentrated and contiguous cultivated land, flat and fertile land and good irrigation conditions in the basin. Its elevation is mostly 1,966~2,200m, and Fengyupian is 2,100-2,300m. Among the current irrigation area, there are 389,000mu of paddy field, 98,000mu of dry land, 7,000 mu of irrigated land and 17,000 mu of garden land. By 2035, the national reserve forest construction project of China plans to add 50,000mu of afforestation on mountain in the east of Erhai Lake. Dali city and town and industrial park will occupy 38,000mu of cultivated land. Through land resource balance, the appropriate design farmland in irrigation area will be 452,600mu, and the afforestation on the mountain in irrigation area will be 50,000mu. In Erhai Lake irrigation area, 343,000 mu of efficient water conservation irrigation will be developed, including 86,000mu of garlic with micro sprinkler irrigation, 50,000mu of olive with drip irrigation, 47,000mu of vegetables with efficient water-saving irrigation, 70,000mu of flue-cured tobacco and corns, 110,000mu of other economic fruits.
4. Water resources allocation in irrigation area based on basin healthy water cycle

4.1. Ecological water allocation in irrigation area

According to the survey, in Erhai Lake irrigation area, in the two counties and cities of Eryuan and Dali, combining the cleaning of small basins and rural non-point source control, etc, on both sides of the river downstream of some villages, or low-lying waterlogged areas have been transformed into wide shallow ponds. In some cases, surface flow wetlands have been built to introduce wastewater discharged after treatment by sewage treatment plants of markets and towns to these surface flow wetlands for purification and degrading nitrogen and phosphorus pollution concentration, and the tail water then flows into inflow river to Erhai Lake. According to the water environment protection management and tourism landscape demand of Erhai Lake basin, 21 wetland reservoirs were built, including Cibi Lake, Fengyu River, Xihu Lake, Donghu Lake and Longkan. The wetland area is 18,600mu, the water depth is about 1.2m, and the volume is 11.02 million m³; and by 2035, 16 wetland reservoirs are planned to be increased, with a total area of 25,500mu and the increased volume of 24.11 million m³. On this basis, combined with the layout of irrigation and drainage works, topography and hydrogeological conditions of the irrigation area, it is proposed to build 17 new wetlands and ecological ponds, with an area of 5,790mu, water depth of 1.50m and volume of 4.97 million m³. The ratio of irrigation area to wetland area in newly built wetland and ecological pond is between 13:1 and 28.5:1, and the volume of wetland and ecological pond is basically the same as that of the first day's rainfall.

The plants in the wetland ecological pool mainly include the wet plants and the ecological landscape trees. The wet plants include reed, water bamboo, shallot, cattail, calamus, canna, water bamboo, water lily and arrowhead, and the ecological landscape trees include trees and shrubs. The Penman—Monteith formula recommended by Food and Agricultural Organization of the United Nations (FAO) is adopted to calculate the evapotranspiration of the reference crops. The growth period and intercropping characteristics of the typical plants, as well as the regional hydrological and meteorological factors are considered. The crop coefficient is modified to obtain the actual...
evapotranspiration of the typical plants. Then the water consumption quota of the main typical plants in the wetland is calculated by the water balance method, and coordinates with Water Quota (DB53/T168-2019) of Yunnan Province [16]. The average annual water consumption per mu of wetland will be 1,455.3mm, including 752.7mm of effective rainfall, and 705.6mm water will need to be replenished; under the scenario of P=75%, the water consumption will be 1,415.7mm, 685.7mm of effective rainfall will be utilized, and 718.9mm water will need to be replenished. In 2035, the total area of wetland and ecological pond in Erhai Lake irrigation area will be 48,200mu, and the annual average water demand will be 22.67 million m$^3$. In addition to effective rainfall utilization, 15.96 million m$^3$ of reclaimed water and farmland return water will be allocated in the markets and towns, and 6.71 million m$^3$ of clean water will be replenished in some periods.

Table 1. Achievements of planned irrigation area in Erhai watershed (unit: Mu)

| Serial number | Irrigation unit     | Current year |          |          |          |
|---------------|---------------------|--------------|----------|----------|----------|
|               |                     | Effective irrigation area | Guaranteed irrigation area | Effective irrigated area of farmland | Reserve forest irrigated area | Wetland and etange area |
| 1             | Sangying            | 152492       | 106414   | 140446   | 11030    |
| 2             | Fengyu              | 52109        | 26054    | 50069    | 9421     |
| 3             | You Suo             | 67993        | 46665    | 64953    |          |
| 4             | Da Songping         | 3375         | 0        | 3375     |          |
| 5             | Shangguan           | 29508        | 12210    | 25897    | 11912    |
| 6             | Xizhou              | 82242        | 46942    | 76313    | 6480     |
| 7             | Xiaguan             | 61131        | 40557    | 43518    | 5715     |
| 8             | Fengyi              | 39319        | 19660    | 27188    | 1154     |
| 9             | Wase                | 12942        | 8079     | 12131    | 332      |
| 10            | Haidong             | 9150         | 4370     | 8680     | 390      |
| 11            | Haidong greening    | ---          | ---      | ---      | 50000    |
|               | Total               | 510260       | 310951   | 452569   | 50000    |

(2) Guarantee of basic ecological water utilization in irrigation area

According to the actual situation of Erhai Lake irrigation area, combined with the technical regulations such as the Guidelines for Assessment of Water-Draw and Utilization in Construction Projects of Water Resource and Hydropower (SL 525-2011) and the Feasibility Study Report of Water Diversion Project in Central Yunnan, all water conservancy projects shall give priority to the discharge of river ecological basic flow, completely eradicate the occurrence of river cut-off, and indirectly guarantee the realization of the red line of pollution control in the water function area of Erhai Lake basin. Under normal circumstances, in 2035, the ecological discharge standard will be 10% of the average annual natural runoff in the dry season, and in flood season, it will be based on 30% discharge river ecology of annual average natural runoff. On the west bank of Erhai Lake, 51,400 mu of arable land will be irrigated by the 18 streams of Cangshan, and the rural domestic water supply of Dali, Yinqiao, Wanqiao, Xizhou, Shangguan, etc. is also mostly drawn from the 18 streams of Cangshan. More than 40 water intakes have been built at present. Due to the unreasonable utilization of upstream domestic and production water, the 18 streams are often cut off, which has a serious impact on the water ecological environment. In the design level year, water resources will be allocated and optimized as a whole. After water purification from Erhai Lake through Dali urban and rural water supply project, rural domestic water supply for villages and towns on the west bank of Erhai Lake will be solved in a unified way. Reclaimed water from markets and towns, farmland waste water and Erhai Lake carrying water will be utilized to guarantee irrigation water supply on the west bank of Erhai Lake. That is to say, the river runoff of the 18 streams of Cangshan will be discharged into the lake as ecological water
consumption. The discharge standard of river ecological flow in Erhai Lake irrigation area is shown in Table 2.

Table 2. Downstream ecological flow of key water conservancy sections in Erhai Lake irrigation area

| Serial number | Irrigation unit   | Number of controlled sections | Controlled runoff area (km²) | Total runoff in section (million m³) | Minimum ecological discharge (million m³) |
|---------------|-------------------|-------------------------------|-----------------------------|--------------------------------------|----------------------------------------|
| 1             | Sangying          | 11                            | 955.8                       | 422.89                               | 84.63                                  |
| 2             | Fengyu            | 3                             | 23.2                        | 15.47                                | 3.16                                   |
| 3             | You Suo           | 4                             | 223.2                       | 501.42                               | 100.42                                 |
| 4             | Da Songping       | 0                             | 0                           | 0                                    | 0                                      |
| 5             | Shangguan         | 1                             | 6.2                         | 2.18                                 | 0.44                                   |
| 6             | Xizhou            | 7                             | 145.9                       | 120.95                               | 120.95                                 |
| 7             | Xiaguan           | 11                            | 70.8                        | 52.50                                | 52.50                                  |
| 8             | Fengyi            | 3                             | 67.8                        | 34.95                                | 7.01                                   |
| 9             | Wase              | 0                             | 0                           | 0                                    | 0                                      |
| 10            | Haidong           | 2                             | 17.6                        | 6.03                                 | 1.20                                   |
| 11            | Haidong greening  |                               |                             |                                      |                                        |
| 12            | Xier river (erh export) | 1                        | 2565                        | 1171.10                              | 198.52                                 |

(3) Comprehensive utilization project planning of farmland waste water in irrigation area

Aiming at water conservation and production increasing, Erhai Lake irrigation area has carried out technical transformation to speed up the development of various water conservation irrigation projects; and by combining the reduction of channel water transmission loss with the reduction of field irrigation loss, the current annual irrigation waste water discharged into Erhai Lake irrigation district is 49 million m³, and the domestic sewage is 23 million m³. In the future, Erhai Lake irrigation area will, on the one hand, build agricultural water conservation and high efficient irrigation projects to reduce irrigation waste water; on the other hand, through the construction of water resources comprehensive utilization projects such as regulation and storage belt, wetland, ecological pond and waste water comprehensive utilization project, the agricultural waste water and the treated domestic sewage will be collected into the ecological ponds. After the agricultural waste water stays in the ecological pond and is purified, it will be supplied to the downstream irrigation area through engineering measures, and the agricultural waste water will be consumed in the field as much as possible, so as to realize water conservation and emission reduction, greatly reduce the agricultural irrigation waste water and domestic sewage discharged into Erhai Lake, and improve the water quality of the inflow river. In 2035 of level year, the average annual waste water of domestic, industrial and agricultural irrigation will be 135.06 million m³, among them, 17.94 million m³ will be allocated to enter the wetland and ecological pond, 50.96 million m³ of domestic and industrial tail water of Xiaguan section of Fengyi will be discharged to the Xi'er river downstream of Erhai Lake, and 44.46 million m³ of agricultural irrigation will be comprehensively recycled. After the completion and operation of the irrigation area and the sewage interception project around the lake, 83.9% of the domestic sewage and agricultural irrigation drainage can be recycled or discharged, and the urban reclaimed water and farmland waste water entering Erhai Lake can be reduced by 69.2 million m³ compared with the current situation.

The comprehensive utilization project of farmland waste water in irrigation area consists of wetlands and ecological ponds, comprehensive utilization pump station and comprehensive utilization lines. Wetlands and ecological pondsshall make best use of the constructed wetland and the newly built wetland as per "13th Five Year Plan" for Water Environment Protection and Management in Erhai Lake Basin. For the planning and construction of newly built regulation and storage wetland by
Haixi comprehensive utilization project of water cycle in Haixi area that cannot meet the demands, new wetlands and ecological ponds are planned at the end of drainage ditch and low-lying area of each irrigation area (unit irrigation area) to collect the agricultural waste water and rural domestic waste water of the irrigation area. After the agricultural waste water and rural domestic waste water stay and purify in the wetland and ecological pond, the comprehensive utilization pumping station and water transmission pipeline shall be set up, and the treated waste water shall be inverted to the nearby irrigation channel for agricultural irrigation. The planned new irrigation area waste water comprehensive utilization project will be equipped with 38 water transmission lines with a total length of 92.6km, design flow of 0.01~1.75m³/s, and comprehensive utilization of waste water of 44.46 million m³. There will be 30 supporting pump stations with 5-93m carrying water lift, 2.2-560kW installed capacity and 2541kW total installed capacity.

In addition, in the process of the farmland waste water flowing in irrigation area, for the purpose that the pollutants in the water can be absorbed by the ditch protection block stones, sedimentation in the ecological ponds and growth and absorption of aquatic plants as far as possible, so as to achieve the purpose of pollutant degradation and concentration attenuation. It is necessary to carry out ecological design for drainage ditch type, soil slope or block stone slope protection and soil ditch bottom. For dry land, 1d rainstorm shall be discharged from the crops flooded for 1d to the field surface without ponding, and the design drainage modulus is 0.160–0.565m³/s/km²; and for paddy field, 3d rainstorm shall be used from 3d flooding to flooding tolerance depth, and the designed drainage modulus is 0.144–0.343 m³/s/km². The total drainage area of the irrigation area is 172.61km², 20 existing drainage ditches will be renovated, with a renovation length of 65.12km; and 9 new drainage ditches are planned, with a slope of 1:1, bottom slope of 0.0005, flow rate of 0.30-0.75m³/s, and new built length of 22.35km.

4.2. Allocation of domestic and production water in irrigation area
(1) Water demand analysis under the strictest water resource management

The current annual total water consumption of Erhai Lake basin is 379 million m³, including 58 million m³of urban and rural life, 79 million m³for industry and 24,200 m³for agricultural irrigation, accounting for 15.3%, 20.8% and 63.8% of the total water consumption respectively. At present, the per capita water consumption is 411 m³/person, the GDP water consumption of 10000 yuan is 100 m³/10000 yuan, the industrial added value water consumption of 10000 yuan is 63 m³/10000 yuan, the farmland irrigation quota is 476 m³/mu, and the irrigation water utilization coefficient is 0.53-0.60. By the level year of 2035, according to the requirements of Erhai Lake protection and management, to strengthen the spatial management and control of Erhai Lake basin and to promote the green transformation and development, the development focus of political, economic and cultural center of Dali prefecture will be adjusted to Weishan new area outside the Erhai Lake basin, therefore, in terms of population, only natural growth rate should be considered. In 2035, the total population will be 1.025 million, and the urbanization rate will be 76.4%; the industrial growth rate will be 5.0%, in 2035, the industrial added value will be 37.569 billion yuan; and the scale of livestock in the basin will remain unchanged, and the irrigation area will be 452,600mu.

The controlled total water consumption of Erhai Lake basin is 427 million m³in the planning period. Under the conventional water conservation plan, it is predicted that in 2035, the water demand out of the river course will be 424 million m³. Although the water use efficiency of domestic, industrial and agricultural meets the requirements of the Total Water Use Control Index Scheme of Yunnan Province (YSZY No. (2016)24), the water consumption shall also be within the total water consumption control. However, the total water consumption has increased by 45 million m³compared with the current situation, which is inconsistent with the protection and management requirements of Erhai Lake. It is necessary to implement deep water conservation, so that the gross quota of domestic water consumption will be 5.3% lower than the conventional water conservation; the industrial water consumption will not be greater than the current water consumption, and the water quota of 10000 yuan added value will be 22% lower than the conventional water conservation; the rice irrigation
mode will be changed from the conventional flooding mode to the intermittent water conservation mode, the area of drip irrigation, sprinkler irrigation and other efficient water conservation irrigation will be increased to 266,000 mu, the water utilization coefficient of conventional irrigation will be further increased to 0.70, and the gross quota of agricultural comprehensive irrigation will be decreased by 13% compared with conventional water conservation irrigation. Under the deep water conservation mode, the water demand outside the river course of Erhai Lake basin in 2035 will be 366 million m$^3$, 57 million m$^3$ less than the conventional water conservation mode and lower than the current situation, as shown in Table 3.

Table 3. Prediction of water demand in 2035 in Erhai Lake basin (water unit: 100 million m$^3$)

| Solution scenario       | Urban and rural domestic | Industry | Agricultural irrigation | Total water demand outside the river |
|-------------------------|--------------------------|----------|-------------------------|-------------------------------------|
|                         | Gross quota (L/person. day) | water demand (L/person. day) | Coefficient of efficient water conservation and utilization | Gross quota (m$^3$/mu) | Water demand (100 million m$^3$) |
| Commonly water usage    | 245                       | 0.92     | 27                      | 0.66                                | 0.85                        | 450 | 2.31 | 4.24 |
| The deeply saving water | 232                       | 0.87     | 21                      | 0.7                                 | 0.85                        | 392 | 2.01 | 3.66 |

(2) Water resource allocation model and scheme setting

On the ArcGIS platform of geographic information system, the river network model is established according to the detailed river network, water supply facilities, spatial distribution of water utilization objects and hydraulic connection, etc. of Erhai Lake basin. In 2035, the total number of water resource allocation model nodes will reach 458, including 24 lakes and reservoirs, 3 water diversion from outer basins, 41 water drawing and lifting in lakes, 59 ecological flow in rivers and lakes, 17 ecological wetland reservoirs and ponds, 62 domestic and production water, 51 irrigation and urban waste water, and 201 other nodes.

In the current year, "introducing Erhai Lake water into Binchuan" project, according to the 73 million m$^3$ of annual water diversion approved by Dali prefecture, conducts monthly adjustment of crop irrigation needs in Binchuan dam area; monthly adjustment of crop irrigation needs in Binchuan dam area; after the expansion of Haishao reservoir and the completion of the water diversion project in Central Yunnan in 2035, the water supply of the project of "introducing Erhai Lake water into Binchuan" will be restored to the original preliminary design of 50 million m$^3$, besides, only the waste water from Erhai Lake is introduced. After the expansion of Haishao reservoir, the agricultural water supply process changes as the regulation and storage of "introducing Erhai Lake water into Binchuan", which will reduce the water supply pressure of Erhai Lake, so as to protect and control Erhai Lake. The cascade hydropower stations of the Xi'er River can only rely on abandoned water of Erhai Lake for power generation, and the regulation of Erhai Lake does not guarantee the power generation water consumption of the Xi'er River hydropower station alone. The water diversion project in Central Yunnan distributes 1.00 m$^3$/s of water to Dali City, with an annual water supply of 29 million m$^3$. When the water supply is stopped for maintenance in November, it needs to be supplemented by local water sources.

The model is verified by the current year, and the rationality of simulation results such as flow process of control nodes (such as hydrological station), water supply process of engineering nodes and water utilization process of user nodes is analyzed. According to the specific situation of each scenario plan in different level years, 8 aspects including water conservation planning, agricultural planting structure adjustment, new backbone water storage project, new small-scale water conservancy, urban
renewable water utilization, agricultural irrigation backwater utilization, urban and rural overall water supply, and water diversion in outer river basin, are adjusted to participate in the scheme combination. The logical relationship between water supply and consumption between water source project and users is adjusted, and the start and end time of simulation and time step (usually January) for scheme simulation is set. According to the objective function of different scenarios, the simulation results of corresponding parameters are derived. The model parameters are adjusted repeatedly, the simulation results are compared and selected synthetically, and the recommended scheme of water resource allocation is obtained.

(3) Analysis of water resources allocation achievements

In the current year of Erhai Lake basin, instream water-use is 367 million m$^3$ and offstream water supply is 469 million m$^3$ (379 million m$^3$ in Erhai Lake basin, and 90 million m$^3$ is transferred out to Binchuan and Xiangyun through the project of "introducing Erhai Lake water into Binchuan"). In 2035, 510 million m$^3$ of water will be provided for instream water-use, 335 million m$^3$ of water will be provided for offstream water supply (286 million m$^3$ in Erhai Lake basin, and 49 million m$^3$ of water will be transferred to Binchuan), and 129 million m$^3$ of water will be provided from Erhai Lake pumping station. Through the optimal allocation of water resources in the irrigation area of the healthy water circulation of the basin, the offstream water supply of the Erhai Lake basin will be reduced by 134 million m$^3$ compared with the current situation, the water intake from Erhai Lake for production activities will be reduced by 34 million m$^3$, and the ecological water consumption in the water course will be increased by 134 million m$^3$ compared with the current situation, as shown in Table 4 and table 5. In 2035, the total water consumption of offstream of Erhai Lake irrigation area will be 359 million m$^3$, which will be decreased by 20 million m$^3$ compared with the current year, and the water consumption for agricultural irrigation will be decreased by 48 million m$^3$ compared with the current year.

Table 4. Water resource allocation of different water sources in Erhai Lake basin (unit: 100 million m$^3$)

| Target year | Administrative area | Offstream water supply | Water allocation in the river |
|-------------|---------------------|------------------------|-----------------------------|
|             |                     | Offstream water Total  | Local clean water 0.00      | Reclaimed water 0.00 | Water intake 0.00 | Water quantity transferred 0.00 |            |
| 2016        | Eryuan              | 1.52                   | 1.52                        | 1.52                  | 0.00            | 0.00                        | 3.20        |
|             | Dali                | 2.27                   | 2.27                        | 2.27                  | 0.00            | 0.00                        | 0.47        |
| Total       |                     | 3.79                   | 3.79                        | 3.79                  | 0.00            | 0.00                        | 3.67        |
| 2035        | Eryuan              | 1.44                   | 1.37                        | 1.17                  | 0.20            | 0.00                        | 3.55        |
|             | Dali                | 2.23                   | 2.22                        | 1.69                  | 0.24            | 0.29                        | 1.46        |
| Total       |                     | 3.66                   | 3.59                        | 2.86                  | 0.44            | 0.29                        | 5.01        |
Table 5. Water resource allocation of different water users in Erhai Lake basin (unit: 100 million m³)

| Target year | Administrative area | Water consumption of different water users (100 million m³) | Proportion of water consumption allocated by different water users |
|-------------|---------------------|-----------------------------------------------------------|---------------------------------------------------------------|
|             | Urban domestic      | Industry | Rural domestic | Agriculture | Total | Urban domestic | Industry | Rural domestic | Agriculture |
| 2016        | Eryuan              | 0.06     | 0.07          | 0.06        | 1.33  | 1.52          | 3.8%     | 4.4%          | 3.8%        | 88.0%      |
|             | Dali                | 0.40     | 0.72          | 0.07        | 1.09  | 2.28          | 17.5%    | 31.8%         | 3.0%        | 47.7%      |
|             | Total               | 0.46     | 0.79          | 0.13        | 2.42  | 3.79          | 12.0%    | 20.8%         | 3.3%        | 63.8%      |
| 2035        | Eryuan              | 0.13     | 0.08          | 0.07        | 1.11  | 1.38          | 9.1%     | 5.5%          | 4.7%        | 80.6%      |
|             | Dali                | 0.62     | 0.71          | 0.06        | 0.83  | 2.22          | 27.8%    | 32.2%         | 2.6%        | 37.4%      |
|             | Total               | 0.74     | 0.79          | 0.12        | 1.94  | 3.59          | 20.6%    | 21.9%         | 3.4%        | 54.0%      |

After irrigation with reclaimed water is adopted, 82.5% of clean water intake in field growth period will be reduced and 46.4% in growin period will be reduced in Dali and Eryuan. Due to the limited nitrogen content in reclaimed water, the fertilizer source of rice mainly depends on chemical fertilizer, the nitrogen fertilizer brought in by reclaimed water plays a supplementary role, and the nitrogen fertilizer application amount of rice irrigated by reclaimed water will be reduced by 30.2% on average. The water for garlic irrigation can all be satisfied by reclaimed water, and the replacement rate of reclaimed water is 100%. When the TN concentration of reclaimed water is 15mg/L, the amount of fertilizer that the reclaimed water can bring to the garlic is limited, and the demand of garlic for fertilizer is large. The percentage of fertilizer application reduced by reclaimed water irrigation is only 10.66%. It is suggested that TN treatment process should be simplified and TN concentration of reclaimed water should be increased.

4.3. Analysis of water resources balance of Erhai Lake

In current year, the annual total drainage volume of Erhai Lake basin is 146 million m³, including 35 million m³ of domestic drainage, 28 million m³ of industrial drainage, 83 million m³ of irrigation waste water, 45 million m³ of wastewater intercepted and discharged to the downstream of Erhai Lake, 10 million m³ of wetland consumption and 91 million m³ of water discharged into the river (Erhai Lake). In 2035, the total drainage volume of Erhai Lake Basin will be 135 million m³, including 55 million m³ of domestic drainage, 28 million m³ of industrial drainage, 82 million m³ of irrigation waste water, 51 million m³ of sewage around the lake discharged to the downstream of Erhai Lake, 18 million m³ of wetland consumption, 44 million m³ of irrigation reuse, 22 million m³ of water discharged into the river (Erhai Lake), and the amount of water discharged into the river (Erhai Lake) is 69 million m³ less than the current situation. Based on the output coefficient model and SWAT model, the discharge of non-point source pollution load in Erhai basin in 2035, after adopting the measures of reclaimed water irrigation and comprehensive application of farmland backwater, efficient water conservation irrigation and comprehensive regulation and control of farmland water and fertilizer, construction of wetland and ecological pond, etc, the total nitrogen (TN) emission in irrigation area will be decreased by about 39.3% compared with the current situation, and the total phosphorus (TP) emission will be decreased about 46.3% compared with the current situation.

According to the observation data from 1952 to 2016, the total amount of water resources in Erhai Lake basin was 1.171 billion m³, the evaporation of lake surface was 319 million m³, the current clean water consumption in this area was 379 million m³, the water diversion from Erhai to Binwaiwas 90 million m³, and the development and utilization rate of water resources was 55%. After deducting the amount of water discharged to the downstream of Xi'erRiver, lake surface evaporation, reservoir evaporation, upstream water consumption and transferred out water volume, the net inflow into the lake will be 404 million m³, of which the inflow of clear water will be 313 million m³, as shown in
Table 6. In 2035, the clean water supply in Erhai Basin will be 286 million m³, the water diversion from Erhai to Binhai will be reduced to 49 million m³, and the development and utilization rate of water resources in the basin will be 39.3%. After deducting the amount of water discharged to the downstream of Xi'errive, lake surface evaporation, reservoir evaporation, upstream water consumption and transferred out water, the net inflow into the lake will be 469 million m³, including 447 million m³ of clear water, and the net inflow into the lake will be 134 million m³ higher than the current year. As shown in Figure 2, under the premise of constant water supply guarantee rate, the average water level of Erhai long series simulation in 2035 level year will be 0.72m higher than that in the current year, with an average increase of 0.15m; and the annual minimum water level will be 0.74m higher than that in the current year, with an average increase of 0.25m, which will increase the lake water ecological environment capacity.

| Level year | Total water resources | Water consumption | Local clean water used | Water quantity transferred | Water inflow into Lake | Total water volume | Clear water quantity |
|------------|----------------------|------------------|-----------------------|---------------------------|-----------------------|------------------|---------------------|
| Current year | 11.71 | 5.78 | 3.79 | 0.90 | 0.45 | 0.54 | 55.0% | 4.04 | 3.13 |
| 2035 | 11.71 | 5.77 | 2.86 | 0.49 | 0.51 | 0.54 | 39.3% | 4.69 | 4.47 |

Figure 2. Change simulation of annual average water level and annual minimum water level in Erhai Lake

5. Conclusion
Based on the goal of water ecological environment protection for the Erhai Lake, following the principle of "ecological priority, clear water entering into lake, double control of total amount and consumption, and water reservation and emission reduction", the MIKE BASIN simulation model of water resources system in Erhai Lake irrigation area is constructed, and the multi scheme scenario optimization is carried out through the unified allocation of water resources, so as to realize the healthy water system cycle in the basin. Study shows:

(1) The irrigation area of Erhai Lake basin shall be gradually reduced to 452,600 mu, and 48,200 mu of wetland ecological pond shall be added as the node of the basin landscape and irrigation and drainage system to collect the farmland waste water for storage. Under the premise of ensuring food security and basic grain self-sufficiency, the crop planting structure shall be adjusted according to depth water conservation. In 2035, the proportion of rice planting will be decreased from 50.6% to 36.9%, corn from 26.1% to 8.3%, and broad bean from 25.8% to 14.3%. Controlled agricultural water consumption shall be decreased from the current 242 million m³ to 201 million m³, industrial water
consumption shall not exceed the current situation, and the total water consumption of irrigation area shall be reduced from 379 million m$^3$ to 366 million m$^3$.

(2) After the unified allocation of water resources and irrigation with reclaimed water, the amount of clean water intake in rice growing period can be decreased by 46.4%, the amount of nitrogen fertilizer application can be decreased by 30.2%, and the replacement rate of reclaimed water of garlic can reach 100%. Due to the large demand of garlic for fertilizer, it is suggested that in term of the reclaimed water used for garlic, the TN treatment process shall be properly simplified to improve the TN concentration of the reclaimed water. In 2035, after the unified allocation of water resources, it will supply 510 million m$^3$ of instream ecological water and 359 million m$^3$ of off-stream water, in which, 286 million m$^3$ in Erhai basin, 44 million m$^3$ of reclaimed water, 29 million m$^3$ of water diversion from Central Yunnan, 49 million m$^3$ of water diversion into Binchuan, 129 million m$^3$ of water drawn by pumping station from Erhai Lake, and 34 million m$^3$ less than the current situation. The development and utilization rate of water resources in the basin will be decreased to 39.3%.

(3) Combined with the comprehensive utilization project of farmland waste water and ecological regulation and storage belt, etc, the full reuse and zero discharge of irrigation return water will be realized. Compared with the current situation, the inflow of Erhai Lake and clear water entering the lake increased by 65 and 134 million m$^3$ respectively, and the TN and TP emissions in the irrigation area will be decreased by about 39.3% and 46.3% respectively. Under the premise of constant water supply guarantee rate, the annual average water level of Erhai Lake in 2035 will increase by 0–0.72m, with an average increase of 0.15m; the annual minimum water level will increase by 0.02–0.74m, with an average increase of 0.25m, which will increase the lake water ecological environment capacity.

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