Study on ecological regulation of coastal plain sluice

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Abstract: Coastal plains are densely populated and economically developed, therefore their importance is self-evident. However, there are some problems related with water in coastal plains, such as low flood control capacity and severe water pollution. Due to complicated river network hydrodynamic force, changeable flow direction and uncertain flood concentration and propagation mechanism, it is rather difficult to use sluice scheduling to realize flood control and tackle water pollution. On the base of the measured hydrological data during once-in-a-century Fitow typhoon in 2013 in Yuyao city, by typical analysis, theoretical analysis and process simulation, some key technologies were researched systematically including plain river network sluice ecological scheduling, “one tide” flood control and drainage scheduling and ecological running water scheduling. In the end, single factor health diagnostic evaluation, unit hydrograph of plain water level and evening tide scheduling were put forward.

1. Introduction
Sluice is one of the main popular projects for flood control, drainage, water resources allocation and water ecological environmental protection in coastal plain rivers. There are many sluices in coastal plain area. Due to changeable flow direction and uncertain flood concentration and propagation mechanism in river network, difficulties and problems exist in sluice scheduling such as design flood calculation, flood forecasting and water ecological restoration. Therefore, it has important ecological, economic and social benefits to establish scientific and effective flood control system of water conservancy project in plain river network, water resources allocation system, water ecological environmental protection and water landscape operation guarantee system by strengthening research on sluices in plain river network, mastering river network flood evolution rules and water ecological environmental protection.

2. Dissipative structure characteristics of plain river network
Due to the increasing development of river by human beings, the river system has switched from a natural ecosystem to a complex ecosystem composed of society, economy and nature and it has dissipative structure characteristics. Dissipative structure is a new ordered structure in a non-equilibrium state. In sluice group scheduling, we must increase the negative entropy flow, orderly expand the exchange of energy, material and information, enable the internal subsystems to coordinate with each so as to form an ordered self-organization structure\textsuperscript{13}. First of all, plain river network ecosystem has the characteristic of open system which can input and output material. Secondly, the hydrodynamic changes caused by the opening and closing of the sluice will lead to different propagation modes of plain flood wave. The flood propagation in plain river network is characterized by unbalanced and orderly structure.
of flow velocity zone and wave velocity zone. Then, due to its nonlinear characteristic, unit hydrograph of plain water level can be established. Finally, because the plain river network has the characteristic of reaching an orderly and harmonious state through the rise and fall of the water level, we must strengthen the opening and closing of the sluice gate to input the negative entropy constantly by controlling the fluctuation of water level.

3. Single factor health diagnostic evaluation

Based on a comprehensive reflection of the structure function, the single factor health diagnostic evaluation is an evaluation index system which can objectively reflect and represent the health condition of river network. According to the basic principle of index selection, the whole index system is divided into 4 layers, which are target layer, sub target layer, criterion layer and index layer. Not only should the comprehensiveness of evaluation index be considered, but also the representativeness of each index should be considered to avoid repeatability [2]. As a comprehensive evaluation of river health, the river health condition evaluation index is analyzed from the perspectives of the river network structure, the social and economic function of a river and the ecological function of a river. Secondly, the key limiting factor which can mainly reflect the problem is selected to help river network restoration. Despite the loss of certain information, single factor (principal factor) health diagnostic evaluation not only simplifies the evaluation index but can also grasp the principal contradiction, thus has strong operability in practical work.

4. Unit hydrograph of plain water level

There are abundant water level data in plain river network, thus the method of unit hydrograph of plain water level which is reliable on a large amount of water level data can be applied to solve flood wave confluence calculation in plain river network. The nonlinear relation between the net rainfall process and the water level change rate process can be got by analyzing the net rainfall process, the water level rising process and water level change rate process of a typical massive flood in a river area (polder area) in plain river network. The unit hydrograph of plain water level is the change rate process of water level at a representative cross section caused by a unit net rainfall process with uniform spatial and temporal distribution in a given runoff generation and concentration region. By the following 3 steps, unit hydrograph of plain water level can be deduced. Firstly, get water level change rate within a unit time by subtracting water level at time t+1 from water level at time t

\[ Z'(t) = \frac{\Delta Z}{\Delta t} = \frac{Z_{t+1} - Z_t}{t} \]  

(1)

\( Z'(t) \) --water level change rate (m/s) at time t, \( \Delta Z \)--water level change (m) at time t, \( \Delta t \)--time interval (s), \( Z_{t+1} \)--water level (m) at time t+1, \( Z_t \)--water level (m) at time t

Secondly, according to the water level and network channel storage relation or the assumption that the artificial plain river network is basically a rectangular river channel, the area of water (F) can be derived, so that the virtual flow process can be deduced by multiplying \( Z'(t) \) by \( F \).

\[ Q(t) = Z'(t)F = \frac{\Delta ZF}{\Delta t} = \frac{(Z_{t+1} - Z_t)F}{\Delta t} \]  

(2)

\( Q(t) \)--virtual flow (m³/s) at time t, \( F \)--area of water (m²)

On the basis of discharge and net rainfall process at a representative cross section, the unit hydrograph of plain water level can be reversely deduced by moments method, direct algebraic method, trial-and-error method or least square method.

5. “One tide” flood control and drainage model

The "one tide" flood control and drainage scheduling model of coastal plain water gate group includes three modules: water yield calculation, confluence calculation and water gate dispatching calculation. The coastal flood control model "design time" must be "a tide time (about 12 hours) as the main control parameters in hydrology calculation, On the basis of "runoff yield under saturated storage", " Unit
hydrograph of plain water level "as the core computational method, the one-dimensional hydrodynamic simulation technology to solve plain river network area hydrodynamic flow, model framework is shown in fig.1. According to the diagram, the calculation of water yield is mainly to calculate the net rainfall process and the accumulated net rainfall during the one tide period, and to solve the total amount of water production in the "one tide period" of the sluice gate and the maximum flood position caused by the river network. The calculation of runoff concentration calculation: input is mainly through the net rainfall process, the calculation process of river water utilization in Unit hydrograph of plain water level. A tidal sluice scheduling calculation: flood water level line through the two modules, and combined to determine the on-off time of the gate and the gate downstream of irregular tide (The time of the last tide closing time — the tide gate time—— the tide turn off time, the total tide is the period of "one tide", generally about 12h ), and to comprehensively consider the flood discharge capacity of sluice and river network , to carry out coastal plain tidal sluice scheduling and control by using the water balance and water power module.

Fig.1 Sketch map of “One tide” flood control and drainage model
6. Ecological running water scheduling and evening tide scheduling technology

Due to the gentle topography and the control of the gate dam system, the plain river network loses the form of natural water flow and the reoxygenation by water body reduces which causes disturbance and stress to the ecological environment of the water supply. The research shows that the flow velocity is the most critical factor affecting the reoxygenation capacity of water, and the reoxygenation coefficient increases greatly with the increase of flow rate [3]. As for the running water dispatching of plain network river, once the reoxygenation capacity of water body is enhanced, the contaminants in water body will be degraded more quickly.

6.1. Concept of ecological water demand in plain river network

The ecological water demand in plain river network is the base of the ecological and environmental functions of the river [4]. The plain river network area is flat, rich in water quantity, poor in water quality, and affected by water conservancy projects such as sluices and pumping stations regulated by manpower. The ecological water demand in plain river network is the water amount required to ensure the division of river function, protect the biodiversity of rivers and maintain the basic function of the environment under the condition of sufficient water, weak hydrodynamic force and poor water quality. The ecological water demand in plain river network is a flow range close to the natural fluctuation with the minimum ecological discharge as the lower limit and the local flood control standard as the upper limit. The ecological water demand in plain river network should be calculated according to the combination of water quantity and water quality and assess the minimum ecological water demand, the suitable ecological water demand and the maximum ecological water demand.

6.2. Running water scheduling of the sluice

The running water scheduling must take both the hydraulic characteristics of the river network and the storage capacity of the river network into account. The reasonable flow velocity and scheduling period should be scientifically determined depending on the specific condition of water inflow and ensuring the safety of water distribution as well.

6.2.1. Flow velocity. The flow velocity of network river (v) is generally determined in the interval of 0.00042m/s and silt stable velocity (the velocity which will cause neither scour and sediment) according to the experiment and relevant experience. Based on the simulation experiments, effects of the hydrodynamic conditions of plain rivers, the width depth ratio of river courses, the light-shading of building and water temperature on the long-term degradation process of organic compounds in water body were studied [5]. The results show that improving the hydrodynamic conditions of the simulated river channel and controlling the flow velocity above 1.5m/h (0.00042m/s) can effectively reduce the pollution of organic pollutants in the simulated river channel and the accumulation rate of the sediment. At the same time, in order to maintain the stability of riverbed, the average velocity of the river section should be kept below the silt stable velocity.

6.2.2. Scheduling period. It is very complicated to determine the reasonable period of the sluice's running water scheduling. It is not only related to water quantity, water quality, flow velocity and river network characteristics, but also related to temperature, light, weather and the chlorophyll content of aquatic organisms. According to the semi-diurnal tide in the coastal plain and the relevant research, in general, the scheduling period of 2~3 days is reasonable while considering water amount and economic condition. In the case of sufficient water, unlocking the sluice at each tide is the most ideal state.

6.2.3. Calculation of ecological water demand in plain river network. The ecological water demand in plain river network is the water amount required to ensure the division of river function, protect the biodiversity of rivers and maintain the basic function of the environment under the condition of sufficient water, weak hydrodynamic force and poor water quality. Within the period of time, the ecological water demand of a river network cross section can be calculated by the following formula.
\[ W = AvT \]

\( W \)--ecological water demand (m³), \( A \)--river network cross section area (m²), \( v \)--flow velocity at the river network cross section (m/s), \( T \)--period of time (s)

6.3. Evening tide scheduling
In surface water, the dissolved oxygen (DO) content can be used as a clean index directly reflecting water body pollution and self-purification capacity. In eutrophic water (containing chlorophyll-a), algae and aquatic plant photosynthesis on sunny day is an important factor affecting the dissolved oxygen in the water and the main source and has diurnal variation (Fig. 2): dissolved oxygen content increases gradually to the peak at around 16:00 and then decreases to the bottom at 8:00 on the next morning [6]. The running water scheduling should make full use of the characteristics that aquatic plants and algae phytoplankton (Chl-a) generate oxygen by photosynthesis during the daytime and consume oxygen at night, combined with the rule of tidal movement, to implement “evening tide scheduling” (the night scheduling) as far as possible for water reoxygenation and to raise self-purification ability of water greatly.

![Fig.2 diurnal variation of dissolved oxygen content in static water (a. on sunny days, b. on cloudy days) (Chlorophyll content in water is 77.83 mg / L)](image)

7. Application and demonstration
Northwest Yao coastal plain of Yuyao city is set as the study area with the area of 400 km². It is a part of Xiaoshan-Shaoxing-Ningbo plain, bounded by Hangzhou Bay in the north which is famous for its strong tidal estuary, endowed with abundant water from Caoyejiang river in the southwest. There are many sluices with hierarchical control and good representation in it.

7.1. Single factor ecological health diagnosis
The diagnosis of the ecological health of the single factor that in the premise of the overall River Sewage Interception under plain river ecosystem health assessment key main factor limiting DO, we must strengthen the orderly flow of water, accelerate the reaeration, enhance self-purification capacity of water bodies.

7.2. Water level unit line
Fitow typhoon rainstorm began on 2013.10.5 and ended on 2013.10.9 in Northwest Yao coastal plain.
From figure 3, we can see that runoff concentrates quickly in plain rivers, and the net rain has a similar process with the water level rising rate which illustrates that due to high density of river network, short time of overland flow concentration, high speed of river network flow in the form of wave, river network storage capacity is limited. In addition, the water level rises from 2.39m to 3.88m at the peak and then falls with the maximum rising rate of 0.25m/h. The river network area can be got according to the ratio (9.5%) of river network area and the total area of northwest. The virtual flow process of Q(t) can be calculated on the basis of water level change rate and river network area according to formula 2. Then unit hydrograph (UH) can be deduced by trial and error method according to the process of discharge and net rainfall. The parameter n and K in instantaneous unit hydrograph are respectively 1.3 linear reservoirs with the runoff concentration time of 0.7 h. Finally, the runoff concentration calculation by UN provides the boundary condition for the next one-dimensional river network hydrodynamic calculation.

7.3. One-tide flood control and drainage scheduling model
The runoff generation module was established by mutual corroboration of API module and runoff generation module in Xin’anjiang model and the runoff concentration module was established on the basis the above unit water level hydrograph. The one-dimensional river network hydrodynamic module (Figure 4) was generalized with 112 reaches, 374 cross sections, 9 main river sluices and calculated by one-tide flood control and drainage scheduling model.

7.4. Running water scheduling scheme
The engineering condition of sluices and river network at the end of 2014 was set as the current year and 45 combination schemes were designed according to the condition. The total water amount schemed by sluices is limited by the local water yield and diversion and the water level in Linshan station is controlled between 2.5 m and 2.9m, the regional water diversion sluice water shall be limited to the amount of real estate content and the amount of water, and water level control Linsan station water level between 2.5 and 2.9m. The study area is endowed with abundant water from Caoejiang river in the southwest. There are many sluices with hierarchical control and good representation in it. On the basis of simulating flow velocity calculation, the running water scheduling scheme was made by optimizing the original scheme, selecting reasonable flow velocity and scheduling period and allocating “evening scheduling” in a reasonable way. With the implementation of East Zhejiang Water Transfer Project, water quality in most parts of river network in northwest Yao plain has been greatly improved. Disturbing the water body in particular region by different methods and combinations of sluice group scheme, the scheme which makes flow velocity in the key parts of the region (towns and river ends) reach the maximum, maintain the status for the longest time and keep the water level between 2.5 m and
2.9 m is the optimal scheme. In allusion to the current status of river network and sluice group in northwest Yao plain, it is suggested to adopt the overall scheme: hierarchical control, joint operation, multi-sluice scheduling; pre-discharge and water level adjustment in northern part in advance; running water diversion, west diversion and east drainage, evening tide with running water; preventing silt with the north sluice, ecological landscape, interval control.

8. Conclusion
The main conclusions are as follows:
- In allusion to the plain river network ecosystem, a complex ecosystem with dissipative structure is proposed. The scientific scheduling of sluice group in plain river network should be strengthened by constantly inputting the negative entropy in order to maintain various functions of plain river network and freshwater ecosystem health;
- A "one tide" flood control and drainage model based on "runoff generation under saturated storage and unit hydrograph of plain water level" is established;
- Based on the tidal movement rules and the rule of dissolved oxygen concentration change affected by aquatic plants and algae, ecological running water scheduling and evening tide scheduling technology is proposed.
- The sluice group scheduling is applied and demonstrated in northwest Yao plain (400 km²) river network.

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