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# Numerical Study on Transport of High Concentration Suspended Sediment Water in Artificial Seawater Lake

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**Abstract:** The sea water near the estuary of Yangtze River is high in sediment concentration and low in transparency. Clear coastal water can be found in artificial sea lakes, which are isolated from outer sea water by reclamation projects in the intertidal zone. But the water supplied by sea for the artificial lake exchanging is still a big problem. Transport of high concentration suspended sediment (SS) water in artificial seawater lake is studied. The water supplied from the small lake (sand basin) cannot meet the requirements of the landscape and recreation needs of the big lake, as the SS concentration is 0.2 kg/m<sup>3</sup>. After adding the ecological barrier in sand basin, the SS concentration of most water area in big lake is below 0.1 kg/m<sup>3</sup>. This idea can be used as reference for water quality control of seawater artificial lake.

## 1. Introduction

The sea water near the estuary of Yangtze River is high in sediment concentration and low in transparency. Clear coastal water can be found in artificial sea lakes, which are isolated from outer sea water by reclamation projects in the intertidal zone. These artificial sea lakes are all supplied by sea water from outer area. Water of high concentration can be clear after settlement if giving enough time. However, lakes would develop algal blooms if the residence time of water is too long.

In recent years, the research results show that the controlling of water residence time is still an effective method to control the excessive growth of algae. Most reservoirs exchange 10 to 15 percent of the total volume of water daily, and the water of medium-size reservoirs exchange once every 30 days to effectively control the algae blooms in the water (Li, 2013). Shallow water lake system design guide (Melbourne water, 2005) believes that the lake has a very low risk of large algal blooms if the lake has 80% exchange of the water in less than 20 days, and low risk of large-scale algae in the lake area if the lake has 80% exchange of the water in less than 30 days. Investigations show that the domestic famous city freshwater lakes, such as West Lake in Hangzhou city, do not have algae blooms of water body if the whole water of lake replace once a month.

Reducing the water residence time to avoiding algal blooms, means more water supplied by outer sea area with the high concentration sediment is needed. Therefore, during the limit interval time, how to get the clear sea water with lower concentration needed for artificial sea lake is necessary to be studied.



## 2. Description of the studied artificial sea water lake



FIG. 1 formation of artificial lake in seawater

This work focus on an artificial sea lake named BaiSha Lake (Fig 1), located in Zhejiang Province. The sea water flows through the sluice into the smaller lake, depositing sands, then through another sluice to the big major lake. From the level–area–storage curves of big lake (Fig 2), it gives that the area is  $1,670,000 \text{ m}^2$ , the storage is  $4,320,000 \text{ m}^3$  when the level is  $0.5\text{m}$ ; the area is  $1,730,000 \text{ m}^2$ , the storage is  $5,170,000 \text{ m}^3$  when the level is  $1.0\text{m}$ ; the area is  $1,880,000 \text{ m}^2$ , the storage is  $6,070,000 \text{ m}^3$  when the level is  $1.5\text{m}$ .

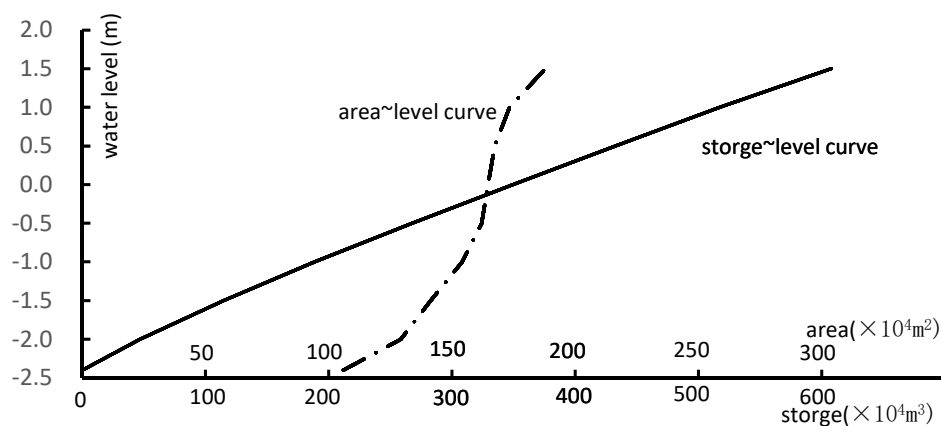


FIG. 2 the level–area–storage curves of big lake

It was studied that (zhou et al., 2018), the lake needs  $8,000,000 \text{ m}^3$  water supplied every month to achieve 80% exchange rate. Considering the tidal prism is varying according to tidal types, the artificial sea lake water needs to be changed every day (zhou et al., 2018). Changing water every day in big lake, means that the settle basin needs to enter water from the sea during the day, static sediment for 3 hours, and release water into the big lake at night.

According to the correlations between transparency-turbidity-suspended sediment concentration in this area (Zhou et al, 2018), if the water transparency of artificial sea lake wants to exceed  $70 \text{ cm}$ , the SS concentration should be below  $0.01 \text{ kg/m}^3$ . To meet the requirements of the landscape and recreation of the big lake, the transparency of most of the water area of the big lake should be above  $70\text{cm}$ .

### 3. Governing equations

Integration the three dimensional of momentums and the continuity equation over depth, the following two-dimensional shallow water equations are obtained:

$$\frac{\partial H}{\partial t} + \frac{\partial Hu}{\partial x} + \frac{\partial Hv}{\partial y} = HS_p \quad (1)$$

$$\frac{\partial Hu}{\partial t} + \frac{\partial Hu^2}{\partial x} + \frac{\partial Hv}{\partial y} = f_v H - gH \frac{\partial \zeta}{\partial x} - \frac{H}{\rho} \frac{\partial P_a}{\partial x} + \frac{\tau_{sx} - \tau_{bx}}{\rho} + \frac{\partial}{\partial x} (HT_{xx}) + \frac{\partial}{\partial y} (HT_{xy}) + Hu_s S_p \quad (2)$$

$$\frac{\partial Hv}{\partial t} + \frac{\partial Hu}{\partial x} + \frac{\partial Hv^2}{\partial y} = -f_u H - gH \frac{\partial \zeta}{\partial y} - \frac{H}{\rho} \frac{\partial P_a}{\partial y} + \frac{\tau_{sy} - \tau_{by}}{\rho} + \frac{\partial}{\partial x} (HT_{yx}) + \frac{\partial}{\partial y} (HT_{yy}) + Hv_s S_p \quad (3)$$

Where,  $t$  is the time;  $x, y$  are the Cartesian co-ordinates;  $h$  is the still water depth;  $\zeta$  is the surface elevation;  $H = h + \zeta$  is the total water depth;  $u, v$  are the velocity components in the  $x, y$  direction;  $f = 2\Omega \sin \Phi$  is the Coriolis parameter ( $\Omega$  is the angular rate of revolution,  $\Phi$  is the geographic latitude);  $g$  is the gravitational acceleration;  $\rho$  is the density of water;  $\tau_{sx}, \tau_{sy}, \tau_{bx}, \tau_{by}$  are the  $x$  and  $y$  components of the surface wind and bottom stresses;  $P_a$  is the atmospheric pressure;  $S_p$  is the discharge of source;  $u_s, v_s$  are the velocity components by which the water is discharged into the ambient water;  $T_{ij}$  is the lateral stress and the expression are:

$$T_{xx} = 2A \frac{\partial u}{\partial x}, T_{xy} = T_{yx} = A \left( \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right), T_{yy} = 2A \frac{\partial v}{\partial y} \quad (4)$$

Where  $A$  is the horizontal eddy viscosity.

The suspended sediment transport equation can be describe as:

$$\frac{\partial HS}{\partial t} + \frac{\partial (HuS)}{\partial x} + \frac{\partial (HvS)}{\partial y} = F_s + \frac{\partial}{\partial x} \left( D_x \frac{\partial HS}{\partial x} \right) + \frac{\partial}{\partial y} \left( D_y \frac{\partial HS}{\partial y} \right) \quad (5)$$

Where,  $S$  is the concentration of suspended sediment (SS);  $F_s$  is the generalized source term and the expression is  $F_s = F'_s + F''_s$ ,  $F'_s$  is the deposition of SS and the express is  $F'_s = -\alpha \omega S$ , where  $\alpha$  is the probability,  $\omega$  is the settling velocity of SS;  $F''_s$  is source of SS.  $D_x, D_y$  are the diffusion coefficients of SS in the  $x, y$  direction.

### 4. Discussion

#### 4.1 Transport process of suspend sediment (SS)

As described, the small lake is a sand depositing lake for the big one. When the sea water came from the sea flowed through the sluice of the small lake, through it, then flowed into the big lake, the suspended sediment (SS) will settle during these processes.

However, the settling time for SS is limit as the settling basin is so narrow. Specifically, the flow path is shorter when the straight-line distance is closer of the sluices of the two lakes. The high concentration SS from sea get the big lake fast.

Basing the model described above, the process of the suspended sediment transport is calculated. The results shows that the concentration of SS in the sluice outlet of the small lake is still as high as  $0.2 \text{ kg/m}^3$  or more (Fig. 3), after it settled 3 hours which is flowed through the sluice of the small lake from the outer sea area that the concentration of SS is  $0.7 \text{ kg/m}^3$ . The water flowed into big lake, which the SS concentration is  $0.2 \text{ kg/m}^3$ , cannot meet the requirements of the landscape and

recreation needs of the big lake obviously.

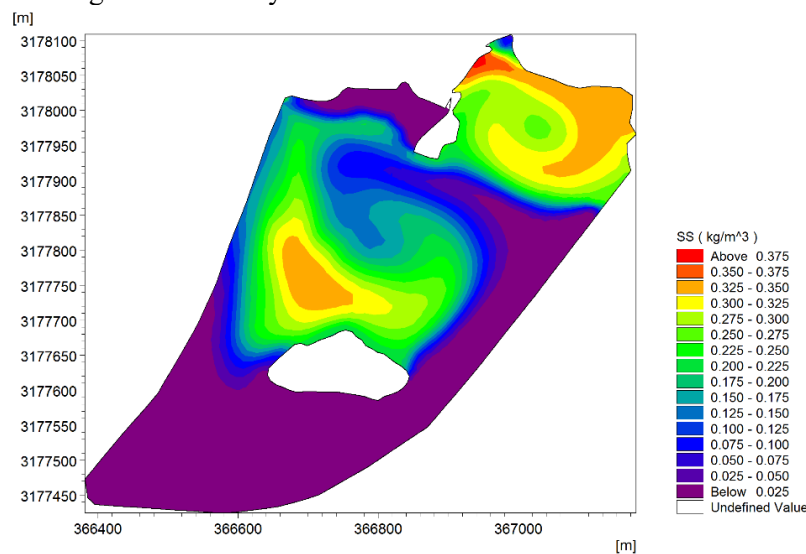


Fig. 3 The SS concentration distribution at a moment of water exchange process in the sand settle basin (small lake)

#### 4.2 Transport process of SS after adding ecological barrier

From site A to site B in the sand settle basin, an ecological barrier is built (Fig. 4). Aquatic organisms could be planted on the ecological barrier for landscape. By adding ecological barrier, the flow path can be extended. It is shown that (Fig. 4) the concentration of SS in the sluice outlet of the small lake is decreased significantly. The high concentration of SS, which is came from outer sea area, flow into the small lake and went south down bypass the barrier and island before it reached to the sluice outlet of the small lake.

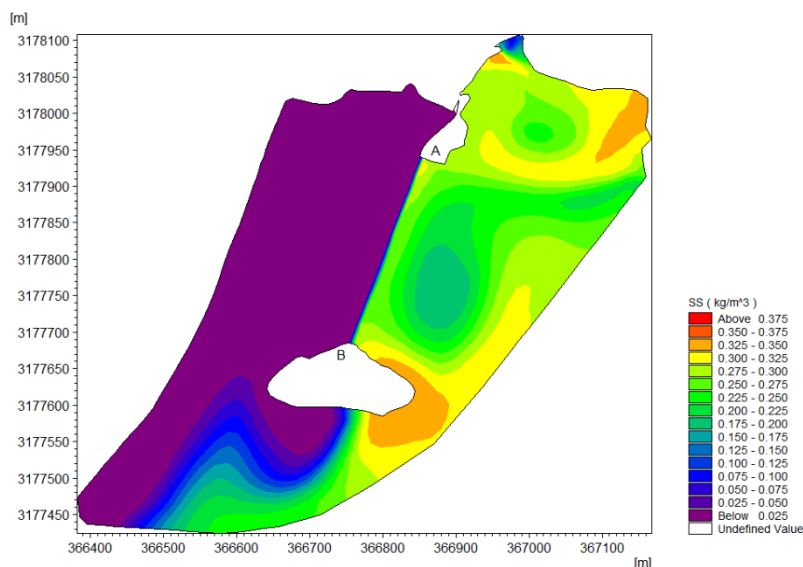


Fig. 4 The SS concentration distribution at a moment of water exchange process in the sand settle basin (small lake) after adding ecological barrier

The process of the SS transport is calculated after adding barrier. The results shows that the change process of the SS concentration tends to gradually stably. Finally, it becomes a cycle of diurnal periodic changes (Fig. 5). The concentration ranges from 0.010~0.016 kg/m<sup>3</sup>.

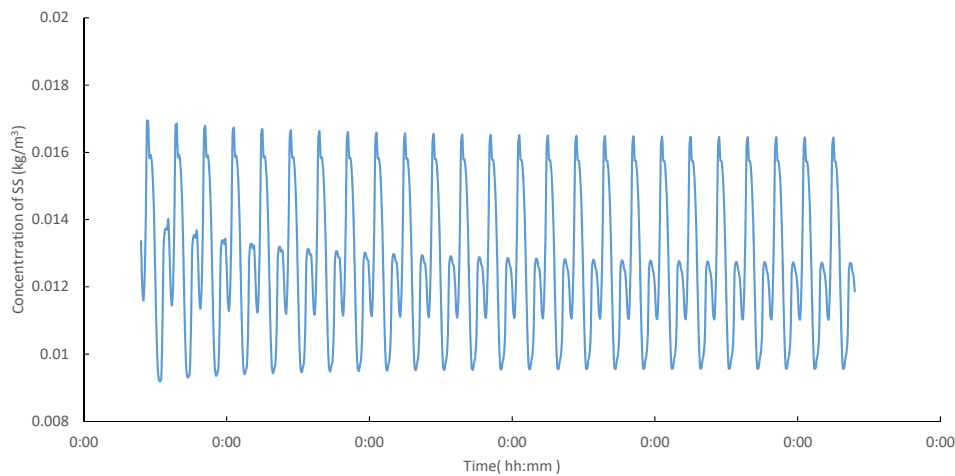


Fig. 5 the change process of the SS concentration in the outlet of the sand settle basin (small lake) after adding ecological barrier

The water containing concentration of SS, which has diurnal periodic changes after stabilization, discharged into the big artificial sea lake. The sedimentation experiment (Zhou et al., 2018) show that, the period of SS sedimentation can be divided into three stages: the initial stage of rapid settlement, the slow stage of settlement and the stage of extremely slow settlement. According to the results, the sedimentation process of SS ranges from  $0.010\sim 0.016\text{ kg/m}^3$  is the extremely slow settlement. So the settling velocity is  $0.015\text{ mm/s}$ .

The artificial sea lake water needs to be changed every day. Changing water every day in big lake, means that the settle basin needs to enter water from the sea during the day, static sediment for 3 hours, and release water into the big lake at night. According to this mode of operation, the maximum sediment concentration envelope distribution in artificial big sea lake can be calculated (Fig. 6). The results show that: the concentration of SS ranges from  $0.01\sim 0.02\text{ kg/m}^3$  (it means the water transparency ranges from  $50\sim 70\text{ cm}$ ) exists only near the sluice inlet of the big lake; the concentration of SS ranges from  $0.005\sim 0.01\text{ kg/m}^3$  (it means the water transparency above  $70\text{ cm}$ ) distributed in the north-east area near the sluice inlet; in most other areas of the big lake, the concentration of SS is below  $0.005\text{ kg/m}^3$ .

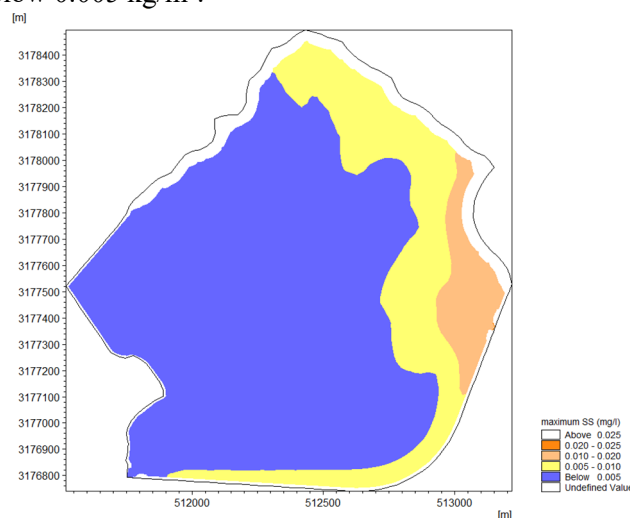


Fig. 6 the maximum sediment concentration envelope distribution in artificial big sea lake

## 5. Conclusions

The sea water near the estuary of Yangtze River is high in sediment concentration and low in transparency. More and more artificial sea lakes could be found by reclamation projects in the intertidal zone in recent years. But are these sea lakes water clear? The water supplied by sea for the artificial lake exchanging is still a big problem.

In this study the problem is effectively solved by building a sand settle basin and adding ecological barrier to the sand settle basin to extended the flow path and reduce the sediment concentration of SS. By adding the ecological barrier, the SS concentration of most water area in big lake is below  $0.1 \text{ kg/m}^3$ . The water transparency can be above 70 cm. Also the sufficient circulating water exchange can effectively prevent algae from exploding. This idea can be used as reference for water quality control of seawater artificial lakes.

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