Influence of Seawards Water and Sediment Conditions on the Turbidity Maximum Zone in Yangtze Estuary

Libing Huang1,2 and Baoqiang Zheng3*
1 Yellow River Institute of Hydraulic Research, Zhengzhou, China
2 State Key Laboratory of Water Resources and Hydropower Engineering Sciences, Wuhan University, Wuhan, China
3 Henan Yellow River Hydrological Survey and Design Institute, Zhengzhou, China
Email: zhengbaoqiang.love@163.com

Abstract. On the combined influence of runoff and tide, seawards sediment forms the turbidity maximum zone (TMZ) nearby the sandbar of Yangtze estuary. The water and sediment transport of the sandbar has important theoretical and practical significance for ecosystem, waterway regulation, and so on. According to the situation of seawards water and sediment variation, and based on the ECOMSED simulation of flow and suspended sediment dynamic process, the relation of the seawards water and sediment and the TMZ, and the law of water and sediment motion after the Three Gorges Project are discussed. It enhances the comprehension of suspended sediment concentration (SSC) variation law of the TMZ always seawards discharge. As the lower seawards sediment concentration, the SSC of the TMZ center is gradually decreasing with the increasing discharge. As the sediment concentration is higher than some critical value, the SSC of the TMZ center is gradually increasing with the increasing discharge.

1. Introduction
Sediment is obviously affected by local hydrodynamic conditions in the estuary area. The suspension, sedimentation and resuspension processes can change the estuarine landforms. Affected by the combined effects of runoff and tide, there is a turbidity maximum zone (TMZ) in the estuary. The change of the TMZ is related to the development of the sandbar and the underwater delta. There has important theoretical and practical significance to research the TMZ.

Since the French researchers first discovered the TMZ in Girent estuary in 1938 [1], domestic and foreign scholars have done a lot of research on estuaries around the world [2]. A lot of research results have concluded that the position of the TMZ moves downstream as the runoff increases in estuaries. However, the suspended sediment concentration (SSC) is different in different estuaries. For example, the SSC is decreasing with increasing runoff in Loire estuary [3], Oujiang River estuary [4], etc. But the SSC is increasing with increasing runoff in Yangtze estuary. The reason is that existing studies have not considered sediment as a distracting factor. Therefore, for the study on the influence of the TMZ in Yangtze estuary, it should combine the own characteristics to analyse the influence of the runoff, sediment factors.

Using the Estuarine, Coastal and Ocean Modeling System with Sediments (ECOMSED) to simulate the variation process of the suspended sediment in the TMZ of Yangtze estuary under the different combinations of the runoff and tidal conditions, it can provide reference for the distribution of suspended sediment and geomorphological trends in Yangtze estuary.
2. Research Area

The Yangtze River has 6800 kilometers long, and it is the third longest river in the world. The runoff power is gradually decreasing and the tidal power is gradually increasing along the river in Yangtze River. According to the relative relationship between runoff and tide power, Yangtze Estuary is divided into three regions from upstream to downstream [5]: near mouth section(from Datong to Jiangyin), estuary section (from Jiangyin to the mouth of Yangtze Estuary), outer beach area(from the mouth of Yangtze Estuary to the 30m–50m depth contour). A large number of observations show that the TMZ is distributed near the mouth. Therefore, the study scope is from Xuliujing to 123.0° E. the longitudinal length is 92 kilometers as shown in figure 1.

![Figure 1. The study area.](image)

3. Research Methods

3.1. ECOMSED

ECOMSED is a fully integrated three-dimensional hydrodynamic, wave and sediment transport model. The model is designed to simulate with as much realism as possible time-dependent distributions of water levels, currents, temperature, salinity, tracers, cohesive and noncohesive sediments and waves in marine and freshwater systems [6-8].

The three-dimensional advection-dispersion equation for transport of sediment of size class k (k=1,2) is:

\[
\frac{\partial C_k}{\partial t} + \frac{\partial UC_k}{\partial x} + \frac{\partial VC_k}{\partial y} + \frac{\partial (W - W_{s,k})WC_k}{\partial x} = \frac{\partial}{\partial x} \left( A_H \frac{\partial C_k}{\partial x} \right) + \frac{\partial}{\partial y} \left( A_H \frac{\partial C_k}{\partial y} \right) + \frac{\partial}{\partial z} \left( K_H \frac{\partial C_k}{\partial z} \right)
\]

where \( C_k \)=suspended sediment concentration of size class k (represented by 1 and 2, for cohesive and noncohesive sediments, respectively); \( U, V, W \) = velocity in the x, y and z-direction; \( A_H \) = horizontal diffusivity; \( K_H \) = vertical eddy diffusivity.

The process of cohesive and noncohesive resuspension is according to the given formulas from the literature [6]. The parameters in the formulas are determined and verified from the measured data.

3.2. Verification of ECOMSED

According to the measured data, the model verified the average suspended sediment concentration based on the measured data (figure 2). Where the figure from (a-c) is in Baimao station, and the figure from (d) to (f) is in Shihua station. Calculated and measured value of the error is within 0.2 kg/m³.
Figure 2. Comparison of the calculated values (solid lines) and measured values (points) of the average SSC.

The suspended sediment distribution is shown in figure 3 (a) is the SSC distribution of bottom layer in spring tide, and (b) is the SSC distribution of bottom layer in neap tide. This is consistent with the results of the measured data [9].

Figure 3. The verification of the horizontal distribution of the SSC.
According to the verification results, the calculation results of the model are true and reliable. Therefore, it uses the model to research the effect of water and sand into sea on the TMZ.

### 3.3. Calculation Conditions

In order to analyse the influence of single factor on the TMZ in Yangtze Estuary, it analyses the varied laws of the TMZ on the conditions of changed discharge flux or sediment only. The calculation conditions are shown in Table 1.

| No. | Q/ (m$^3$/s) | SSC/ (kg/m$^3$) | No. | Q/ (m$^3$/s) | SSC/ (kg/m$^3$) |
|-----|--------------|-----------------|-----|--------------|-----------------|
| 1-1 | 19000        | 0.15            | 4-1 | 32900        | 0.4             |
| 1-2 | 19000        | 0.2             | 4-2 | 32900        | 0.5             |
| 1-3 | 19000        | 0.25            | 4-3 | 32900        | 0.6             |
| 2-1 | 22500        | 0.15            | 5-1 | 45700        | 0.4             |
| 2-2 | 22500        | 0.2             | 5-2 | 45700        | 0.5             |
| 2-3 | 22500        | 0.25            | 5-3 | 45700        | 0.6             |
| 3-1 | 32500        | 0.15            | 6-1 | 75100        | 0.4             |
| 3-2 | 32500        | 0.2             | 6-2 | 75100        | 0.5             |
| 3-3 | 32500        | 0.25            | 6-3 | 75100        | 0.6             |

### 4. Study of the Influence of Water and Sediment into Sea on the TMZ

#### 4.1. Study of the Influence of Sediment into Sea on the TMZ

The average SSC varied laws in the center of the TMZ with the change of the sediment into sea are shown in figure 4(a). With the increase of the sediment into sea, the average SSC showed an increasing trend.

![Figure 4](image)

**Figure 4.** The variation trend of the turbidity maximum zone with the seaward sediment.

As shown in figure 4(b), when the discharge flux is 32900 m$^3$/s, 45700 m$^3$/s, 75100 m$^3$/s, the area which the SSC is larger than 1.0 kg/m$^3$ is gradually increasing.

In summary, with the increase of the sediment into sea, the SSC is gradually increasing no matter what in the center of the TMZ or the overall area.

#### 4.2. Study of the Influence of Water into Sea on the TMZ

The average SSC varied laws in the center of the TMZ with the change of the water into sea are shown in figure 5. When the sediment concentration is 0.15 kg/m$^3$, 0.2 kg/m$^3$, 0.25 kg/m$^3$, and with the flux increasing from 19000 m$^3$/s to 32500 m$^3$/s, the average SSC showed a decreasing trend. When the sediment concentration is 0.4 kg/m$^3$, 0.5 kg/m$^3$, 0.6 kg/m$^3$, and with the flux increasing from 32900 m$^3$/s to 75100 m$^3$/s, the area which the SSC is larger than 1.0 kg/m$^3$ is gradually increasing.
The variation trend of the turbidity maximum zone with the seaward water.

When the sediment concentration into sea is less than 0.25 kg/m$^3$ and the discharge flux into sea is less than 25000 m$^3$/s, the SSC in the center of the TMZ is showed a decreasing trend with the increasing flux. In other conditions, the SSC in the center of the TMZ is showed an increasing trend with the increasing flux. The effect of water into sea on the SSC in the TMZ is manifested in two aspects. On the one hand, the increase flow has a dilute effect on the TMZ, which reduces the SSC. On the other hand, the increase of the flow rate enhances the interaction between the runoff and the tidal current, enhances the turbulence of the water flow, resuspends the deposited sediment, and increases the SSC. Therefore, when the sediment concentration is low, the turbulent replenishment of the water flow is not enough to fill the dilution effect of the flow increase on the water body, and the SSC is lowered. When the sediment concentration is higher than a certain value, the water flow turbulently replenished the mud. The sand exceeds the flow rate and the dilution effect on the water body, and the suspended sediment concentration increases. This is also the main source of sediment. The estuary dominated by the land area increases with the increase of the flow rate, and the suspended sediment concentration increases. The main sediment source is the ocean-based estuary. Therefore, if the sediments entering the sea in the Yangtze Estuary continue to decrease, the TMZ in the Yangtze Estuary will show a decreasing trend.

In summary, the decrease in sediment concentration after storage of water causes the concentration of suspended sediment in the TMZ to decrease, while the change in flow affects the distribution pattern of suspended sediment.

5. Conclusions

Based on the three-dimensional ECOMSED model, the dynamic process of water flow and suspended sediment in the Yangtze Estuary is simulated. The relationship between the intrusion of seawater and the TMZ and the change of water and sediment movement in the sand area after the Three Gorges water storage are discussed. The conclusions are as follows.

(1) Both seawater and sand have an impact on the TMZ, but the impact mechanism is different. The change of seawater flow changes the hydrodynamic conditions in the estuary area, which in turn affects the dynamic mechanism of the formation of the TMZ.

(2) When the sediment concentration into the sea is less than 0.25 kg/m$^3$, when the inflow rate is less than 25000 m$^3$/s, the concentration of suspended sediment in the center of the TMZ decreases with the increase of the flow rate. And when the flow into the sea is greater than 25000 m$^3$/s, with the increase of flow rate, the SSC in the center of the TMZ and the area larger than 1.0 kg/m$^3$ increased.

Acknowledgements

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