Influence of the North Branch of the Qingshuigou River on the Lower Reaches of Yellow River Based on Two-dimensional Numerical Model

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Abstract. The estuary regulation of the Yellow River is closely related to the regulation of the lower Yellow River. The flow and sediment entering the sea block the sediment entering the sea under the action of tidal rise and blocking sand, which has a significant impact on the flood control of the lower Yellow River. In the present study, there are many studies on the analysis of measured data and the empirical formula of inductive reasoning regression, and the use of two-dimensional mathematical model of water and sediment is still rare. In this study, based on the established mathematical model of marine water and sediment in the Yellow River estuary, the typical water and sediment conditions are selected to calculate the sediment movement and siltation erosion in the sea. The calculation results show that under the action of tide and blocking sand, the influence distance of the flow and sediment in the sea on the downstream river is about 90 km-110 km below the Luokou. The flow and sediment in the sea are mainly deposited in the range of 6-8 km along the direction of the flow in the sea near the entrance. The highest point of backwater is in the front of the blocking sand ridge. The backwater surface is relatively steep in the direction of the sea, and the backwater surface is relatively slow in the direction of the river.

1. Introduction
The spirit of the sixth meeting of the Central Finance and Economic Commission, chaired by General Secretary Xi Jinping on 3 January 2020. The meeting emphasized to implement major projects such as wetland ecosystem restoration in the Yellow River Delta and play a leading role in Shandong Peninsula urban agglomeration and promote the high-quality development of central cities and urban agglomerations along the Yellow River. The role of estuary regulation in the Yellow River Delta, Yellow River regulation in Shandong Province and efficient utilization of water resources in promoting ecological protection and high-quality development of the whole Yellow River Basin in Implementation Plan of Ecological Protection and High Quality Development in the Yellow River Basin of Shandong Province is further illustrated. [1]
In the study of the governance of the Yellow River estuary, the governance of the lower reaches of the Yellow River is the main influencing factor, and the scouring and deposition of the flow and sediment into the sea on the riverbed are the main research directions. Among them, tidal surges and barrage sand have a blocking effect on the flow and sediment entering the sea. For the study of the influence of the change of water and sediment conditions on the lower reaches of the Yellow River, there are many studies on the analysis of measured data, the empirical formula of inductive reasoning regression and the calculation of one-dimensional model[2][6].

At present, the research results on the Yellow River estuary and siltation are not only quite different in quantitative but also in qualitative. According to the author’s analysis, there are many factors influencing the river channel evolution and estuary evolution in the lower reaches of the Yellow River. The riverbed (including the estuary) has a very severe scouring and silting deformation, and the interaction between various factors is extremely complex. The traditional data analysis method cannot fully and comprehensively analyze the complex situation, which is the root cause of the divergence of the above conclusions. Therefore, it is necessary to carry out research by means of river engineering model test or mathematical model calculation, so as to completely reveal the influence law of Yellow River estuary evolution on river channel feedback.

Although many people have established the one-dimensional model of the Yellow River estuary, the one-dimensional model simplifies the problem too much and the calculation is semi-empirical. At present, the two-dimensional mathematical model of the Yellow River estuary is rare to analyze the influence of sediment entering the Yellow River on the lower Yellow River. In this paper, the established two-dimensional mathematical model of the Yellow River estuary is used to calculate and analyze the influence of sediment entering the Yellow River on the lower Yellow River.

2. Numerical simulation basic theory methodology

2.1. The governing equations and deterministic conditions (Li Dongfeng, 2004, Zhang Shiqi, 1990)
It is viable to use depth-averaged planar 2-D shallow water equations as the governing equations for tidal computation. They are as follows:

The equations of continuity:
\[
\frac{\partial Z}{\partial t} + \frac{\partial (HU)}{\partial x} + \frac{\partial (HV)}{\partial y} = 0
\]  

The equations of motion:
\[
\frac{\partial U}{\partial t} + U \frac{\partial U}{\partial x} + V \frac{\partial U}{\partial y} + g \frac{\partial Z}{\partial x} + \frac{g n^2 U \sqrt{U^2 + V^2}}{H^{1/3}} - fV - \frac{\mu}{\partial x} \left( \frac{\partial^2 U}{\partial x^2} + \frac{\partial^2 U}{\partial y^2} \right) = 0
\]
\[
\frac{\partial V}{\partial t} + U \frac{\partial V}{\partial x} + V \frac{\partial V}{\partial y} + g \frac{\partial Z}{\partial y} + \frac{g n^2 V \sqrt{U^2 + V^2}}{H^{1/3}} + fU - \frac{\mu}{\partial y} \left( \frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2} \right) = 0
\]

where \(\mu, \nu\) is \(x, y\) direction components of depth averaged velocity; \(z, h\) is water level (or tidal level) and depth; \(g\) is acceleration due to gravity; \(\epsilon\) is turbulent viscosity coefficient; \(C\) is Checy’s coefficient, \(C\) is calculated by Checy’s formulation,
\[
C = \frac{1}{n}
\]
\(n\) is Manning roughness coefficient; \(f\) is Coriolis force coefficient; \(f = 2\sigma \sin \phi\); \(\sigma\) is rotation angular velocity of earth; \(\phi\) is the latitude of computed reach.
2.2. Boundary conditions
The deterministic conditions involve boundary conditions and initial conditions. Boundary conditions include opening boundary and closing boundary. The former is inlet and outlet water boundary, and is governed by field tidal process for model. The latter is land boundary and the normal velocity is treated as zero for model.

The outlet and open boundary condition: the tidal spring and ebb are control by the tidal level. It is calculated by the formulation:

\[ Z(x, y, z)\mid_{r_1} = Z'(x, y, t) = A_0 + \sum f H \cos(qt + G(v_0 + \mu) - g') \]

in which \( \Gamma_1 \) expresses open boundary; subscript * expresses a given value (the measured value or analyzed value).

At the entrance, flow discharge is given, such as \( Q(x, y, t) = Q_0(x, y, t) \), \( Q_0(x, y, t) \) is the discharge process.

For the closed and rigid boundary the velocity is zero, ie: \( \mu_n\mid_{r_2} = v_n\mid_{r_2} = 0 \) in which, \( \Gamma_2 \) expresses closed boundary; \( \vec{n} \) expresses normal unit vector.

2.3. Model validation
The boundary conditions and validation of the model can be found in [7]-[10].

3. Calculation and analysis
Based on the analysis of literature, it can be concluded that the influence of sediment channel deposition extension in the Yellow River estuary on the lower Yellow River is mainly located below the Luokou section of the lower Yellow River. According to the comprehensive treatment plan of the Yellow River estuary, the water level of 10 000 m\(^3\)/s in the Xihe Estuary is 12 m as the diversion control condition. In the planning period, Qingshuigou is mainly used to flow into the river, and to maintain stable and long-term use as far as possible. Diaokouhe wetland ecological water supplement is carried out. After the completion of Qingshuigou flow path, Diaokouhe standby flow path is preferred. The Qing 8 branch river is used in the Qingshuigou flow path, and the Qing 8 branch river is finally changed to the north branch of the Qingshuigou after meeting the conditions of diversion.

According to the above planning and the electronic chart of the Bohai Bay and the topography of the Yellow River, the scope of the model is as follows: the Luokou section of the lower reaches of the Yellow River is taken as the import of the model, and the sufficient sea area of the Bohai Bay is taken as the export of the model. Based on the river and sea topography data in 2017 after flood season, a two-dimensional mathematical model of the lower reaches of the Yellow River is established. Taking the Luokou water and sediment process in 2018 and the north branch of Qingshuigou river road as the calculation conditions, the transport diffusion and deposition erosion of sediment into the sea under the action of marine dynamics are calculated.

3.1. Water level analysis
The change of river water level, on the one hand, is affected by the process of water and sediment at the Luokou entrance of the model, on the other hand, the influence of marine dynamic conditions such as tidal fluctuation. At the same time, with the continuous expansion of the mouth bar and the extension of the estuary to the sea, it will also affect the change of river water level. According to the water and sediment process of Luokou Hydrological Station in 2018, the water level of river channel and the distribution of ocean tide level with typical discharge of 500 m\(^3\)/s are selected for analysis, as shown in Fig. 1.
3.1.1. River water level and ocean tidal level distribution
It can be seen from the contour distribution of river water level and ocean tide level in Fig. 1 that the water level in the river is relatively large, and the specific drop in the sea area is small. The measured data of water level calculation results are consistent.

3.1.2. Velocity contour and velocity vector
It can be seen from the velocity contour and velocity vector diagram shown in Fig. 2 that after the flow enters the river from the inlet, at the flow rate of 500 m$^3$/s, the flow flows in the curved river, and only in the main channel in the wide reach, including the northern levee of the oilfield and the wide reach near the flood detention area. After the flow enters the estuary area, it moves under the action of runoff. On the one hand, the flow moves towards the deep sea, and on the other hand, it shows the characteristics of coastal flow under the action of marine dynamics.

3.1.3. Distribution map of water depth contour
From the contour lines of water depth shown in Fig. 3, it can be seen that the river bed is silted up after the deposition of sediment into the sea at the entrance, and the contour lines from 1 m to 12 m extend obviously to the offshore analysis.

3.1.4. Water level difference before and after flood season
It can be seen from Fig. 4 of the water level difference before and after the flood season that under the action of tide and blocking sand, the maximum damming is 0.19 m at the flow rate of 3000 m$^3$/s, and the influence distance on the downstream is about 90 km below the Luokou. The maximum damming is 0.022 m at the flow rate of 500 m$^3$/s, and the influence distance on the downstream is about 110 km below the Luokou.

3.2. Sediment movement and sedimentation scouring

3.2.1. Sediment concentration distribution.

The distribution of sediment concentration is shown in Fig. 5, this shows that sediment transport and diffuse along sea coast shore and the sediment concentrations of turbidity maximum zone at sand bar, the sediment concentration tends to be lower obvious outside the sandbar.

3.2.2. Distribution of scour thickness of sediment deposition

It can be seen from the riverbed elevation difference before and after flood season in Fig. 7, that is, the thickness of scouring and silting, that under the action of tide and barrage, the sediment in the inflow water is mainly deposited in the range of 6-8 km along the direction of the inflow water near the entrance, and the upstream channel is about 100 km away from Luokou. The main reason is that the result of sediment deposition lags behind the rise and fall of water level.

3.3. Comparative Analysis of Sedimentation Thickness and Water Level Difference

It can be seen from the comparison of deposition thickness and water level difference in Fig. 8 that the point with the largest deposition thickness is the vertex of the barrage, and the highest backwater point is in the front of the barrage. The backwater surface is relatively steep in the direction of sea, and the backwater surface is relatively slow in the direction of river.
4. Conclusion
In this study, based on the established mathematical model of marine water and sediment in the Yellow River estuary, the typical water and sediment conditions are selected to calculate the sediment movement and siltation erosion in the sea. The calculation results show that under the action of tide and blocking sand, the influence distance of the flow and sediment in the sea on the downstream river is about 90 km-110 km below the Luokou. The flow and sediment in the sea are mainly deposited in the range of 6-8 km along the direction of the flow in the sea near the entrance. The highest point of backwater is in the front of the blocking sand ridge. The backwater surface is relatively steep in the direction of the sea, and the backwater surface is relatively slow in the direction of the river. The analysis and research show the practicability of the model.

![Figure 7. River bed elevation difference before and after flood season (scour deposition thickness)](image)

![Figure 8. Comparison chart of deposition thickness and water level difference](image)

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