Modeling of Fluvial Processes for Braided Channel in Down Yangtze River, Part 1: Model Building and Validation

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Abstract. A two-dimensional surface numerical model for braided channel of down Yangtze River was built, in which both the flow and sediment transport were included. Then the validation of the model was carried out based on a series field data. The results showed that the numerical model can well reflect the water and sediment movement in this reach. It will be able to provide an efficient and low-cost method for the river regulation and channel improvement in this reach.

1. Introduction
Hechangzhou reach is down Yangtze River, about 280 kilometres apart from the estuary, as shown in Figure 1. It is a typical braided channel, and has experienced a great of evolutions, such as bank-failure, alteration of mainstream and local drastic deposit. These evolutions have brought a series of problems to the waterway maintenance and river regime control. As a result, a lot of attention has been paid to the law of the evolution and the river regulation [1-6]. In this article, a two-dimensional surface numerical model, for both flow and sediment transport, was established, and then validated by using a series of field and hydrologic data. This model could provide an efficient and low-cost method for the river regulation and channel improvement in this reach.

Figure 1. Map of the Hechangzhou reach regime.
2. Model building

2.1. Governing equations
Based on the conception of the control volume, the governing equations for shallow water and sediment movement, which follow the law of conservation of mass and Newton’s second law of motion-force and acceleration, can be derived as [7]:

\[
\frac{\partial z}{\partial t} + \frac{\partial hu}{\partial x} + \frac{\partial hv}{\partial y} = 0
\]  

(1)

\[
\frac{\partial hu}{\partial t} + \frac{\partial huu}{\partial x} + \frac{\partial hv}{\partial y} + gh \frac{\partial z}{\partial x} + \frac{g}{c^2} \sqrt{u^2 + v^2} = \nu_l \left( \frac{\partial^2 hu}{\partial x^2} + \frac{\partial^2 hu}{\partial y^2} \right)
\]  

(2)

\[
\frac{\partial hv}{\partial t} + \frac{\partial hvu}{\partial x} + \frac{\partial hvv}{\partial y} + gh \frac{\partial z}{\partial y} + \frac{g}{c^2} \sqrt{u^2 + v^2} = \nu_l \left( \frac{\partial^2 hv}{\partial x^2} + \frac{\partial^2 hv}{\partial y^2} \right)
\]  

(3)

\[
\frac{\partial hu}{\partial t} + \frac{\partial huu}{\partial x} + \frac{\partial huv}{\partial y} + gh \frac{\partial z}{\partial x} + \frac{g}{c^2} \sqrt{u^2 + v^2} = \nu_l \left( \frac{\partial^2 hu}{\partial x^2} + \frac{\partial^2 hu}{\partial y^2} \right)
\]  

(4)

\[
\frac{\partial hs}{\partial t} + \frac{\partial hss}{\partial x} + \frac{\partial hs}{\partial y} = \alpha \left( \frac{\partial^2 hs}{\partial x^2} + \frac{\partial^2 hs}{\partial y^2} \right) - \alpha \omega (s - s^*)
\]  

(5)

\[
\rho_s \frac{\partial z}{\partial t} = \alpha \omega (s - s^*)
\]  

(6)

Where \( z \) = water level; \( h \) = water depth; \( u, v \) = the depth averaged velocity parallel and perpendicular to the water flow; \( \nu_l \) = coefficient of viscosity; \( c \) = Chezy coefficient; \( s \) = sediment concentration; \( s^* \) = sediment carrying capacity; \( \alpha \) = recovery saturation coefficient; \( \omega \) = settling velocity of the sediment particle; \( \varepsilon \) = diffusion coefficient of the sediment particle; \( \rho_s \) = sediment dry density; \( z_b \) = elevation of the river bed; \( x, y, t \) = spatial and temporal axes.

In this model, the Coriolis force and the surface wind stress were ignored since their effects in the inland river were negligible.

2.2. Grid and solution
In order to well generalize the river reach, the orthonormal curvilinear grid system [8] was used to subdivide the calculated area. With an overall consideration of the river regime and the field data distribution, the range of the simulation was limited from Guazhou town to Dagang town, with a length of about 37 kilometres. The total nodes of the grid system were 282 × 100, with a scale of 20~200 meters and 10~150 meters, parallel and perpendicular to the stream wise, respectively. To solve the (1) - (4), the finite volume method [9] was used to discrete the control equations in this numerical model. And then the SIMPLE algorithm [10] was used to solve the discretized control equations. After the solution of (1) - (4), all the variables of the flow, such as \( u, v, h \), and the sediment concentration can be derived, then the (5) can be solved by substitution.

3. Model validation

3.1. Field data
A series of field data was used to carry out the validation of the numerical model. The information of the field data was shown in Table 1. The position of the hydrometric sections mentioned in the field data was shown in Figure 1.
Table 1. Information of the field data.

| No. | Date    | Discharge [m$^3$/s] | Details                              |
|-----|---------|---------------------|--------------------------------------|
| 1   | 2012-9  | 45400               | split ratio                          |
| 2   | 2013-7  | 45000               | water level                          |
| 3   | 2014-6  | 35400               | split ratio; water level; velocity distribution |

3.2. Water level validation

Both the process of the tide level and the water surface profile were included in the validation. The results was shown in Figure 2 and Table 2. It can be seen that the calculated tide levels and the water surface profile agree well with the measured values. The maximum error of the water level was only about 0.05m. It indicates that the numerical model has a good ability to reflect the water surface change in this reach.

Table 2. Validation of the water surface profile.

| Staff gauge | Measured | Calculated | Error | Measured | Calculated | Error |
|-------------|----------|------------|-------|----------|------------|-------|
| 1#          | 3.37     | 3.35       | -0.02 | 3.00     | 3.02       | +0.02 |
| 2#          | 3.18     | 3.22       | +0.04 | 2.90     | 2.92       | +0.02 |
| 3#          | 3.03     | 3.06       | +0.03 | 2.78     | 2.76       | -0.02 |
| 4#          | 3.04     | 3.02       | -0.02 | 2.74     | 2.79       | +0.05 |
| 5#          | 2.81     | 2.78       | -0.03 | 2.59     | 2.61       | +0.02 |
| 6#          | 3.00     | 3.01       | +0.01 | 2.75     | 2.75       | +0.00 |
| 7#          | 2.87     | 2.92       | +0.05 | 2.79     | 2.76       | -0.03 |
| 8#          | 2.87     | 2.86       | -0.01 | 2.74     | 2.72       | -0.02 |

3.3. Velocity distribution validation.

Figure 3 has given the comparison of the measured and calculated averaged vertical velocity distribution of the hydrometric sections. It can be seen that, the calculated velocity distribution agrees well with the field data. The general error of the velocity distribution was about 0.06 m/s, and the maximum error value was about 0.15 m/s. Overall, the numerical model has a very high precision in simulating the water flow movement.
3.4. Velocity distribution validation

Table 3 gives the measured and calculated split ratio of this braided reach. As shown by the calculated results, the numerical model has a good precision in simulation the of split ratio for the braided reach.

| Date               | Measured [%] | Calculated [%] | Error [%] |
|--------------------|--------------|----------------|-----------|
| September 5, 2012  | 73.9         | 74.0           | +0.1      |
| June 22, 2014      | 74.6         | 74.8           | +0.2      |

3.5. River bed scour & deposition validation

The validation of the scour & deposition of the river bed was carried out based on the day-averaged field data of Datong, Zhenjiang hydrologic station from 2013-1-1 to 2014-6-30. The Datong hydrologic station is about 314 kilometres upstream the Hechangzhou reach. There is no big enough water and sediment input needed to be considered during the reach from Datong hydrologic station to Hechangzhou reach. As a result, the field data of Datong hydrologic station, including the quantity and the sediment concentration, can be treated as the inlet boundaries. The Zhenjiang hydrologic station, shown in Figure 1, is at the entrance of the Hechangzhou reach. As a result, the outlet boundary of the model was generated according to the gradient between the Datong and Hechangzhou hydrologic station by using an extension method. The process of the inlet quantity and sediment concentration was shown in Figure 4.

The comparison of the measured and calculated scour & deposition of the river bed was carried out by using the terrain data measured in 2012-12 and 2014-6, as shown in Figure 5. It can be seen that, the calculated and measured range and distribution of the scour & deposition agree well to each other. Overall, the scouring has played an important role in the bed evolution in this period, ranging from -2
to -7m. Especially at the back of the submerged dike built at 2002, the local scouring can reach to about 20m. The amount of the calculated scour & deposition is about \(-2053\times 10^4\) m\(^3\), which is close to the measured values, \(-1928\times 10^4\) m\(^3\). The error is only about 6.5%.

Figure 5. Validation of the scour & deposition of the river bed

4. Conclusions

A numerical model for the typical braided channel in down Yangtze River was built, including the flow and sediment movement. By using a series of field data, the validation was carried out. It shows that the calculated result well agrees to the measured, not only the water level or velocity, but also the scour & deposition of the river bed. This model will be able to provide an efficient and low-cost method for the river regulation and channel improvement in this reach.

Acknowledgments

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