A Simplified Model for Narrowing the River Increase Sediment Transport in the Lower Yellow River

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Abstract: Narrowing the main channel by the river training works is a scenario which is designed to deal with the increasing of the river bed and disadvantageous route of the Lower Yellow River. 1-D SOBEK is applied to predict what the river morphology is after narrowing the river. The establishment, calibration and validation, simulations, computational results and interpretation are introduced firstly and then discussions. Finally some conclusions and recommendations are proposed based on the SOBEK model.

Keywords: Model Narrowing the river Sediment transport the Lower Yellow River

The Yellow River is well known as sediment-laden river and the Lower Yellow River is a wandering and hanging river due to more sediment deposited in the channel. Though we have done so much to deal with the sediment including “intercepting, draining, releasing, regulating, digging” in recent half century, the Lower Yellow River is still a hanging river and wandering river and will be existing for a long time. After the operation of the Xiaolangdi reservoir in 2000, the riverbed of the Lower Yellow River degraded gradually due to more sediment depositing in the reservoir. However, now the reservoir stored so much sediment which is over 1/3 of the total dead storage. That means the Lower Yellow River will aggrade again when the reservoir can not store more sediments.

1 Problem definition

The wandering stretch of the Lower Yellow River starts from Baihe in the Mengjin County, Henan province and ends at Gaocun in the Dongming County, Shandong province. The total length of the wandering stretch is about 300km.

In order to reduce the threatening of the flood, about 3500 groynes and revetments were built in the wandering reaches. Emphasis has been on reducing the flood damage, controlling the main flow, improving the irrigation conditions and protecting the beach and villages in the flood plain.

However, as we know, the river training in the Lower Yellow River is a single side measure, which means the training works are only built at the outer bank of the bend and there were no groynes constructed at the inner bank of the bend and straight stretch. This is an economic way to deal with the problems of flood control and bank erosion in the past years and it plays a major role to protect the dyke safety both sides after the implementation of many groynes. However, this measure does not limit the river width. The river can still be a nature river partly. As a result, the slope increased with the length extending of the main channel due to the river training. As a result, the capacity of the sediment transport decreased.

Narrowing the main channel by the river training works is a scenario which is designed to deal with the increasing of the river bed and disadvantageous route of the Lower Yellow River. Based on the preliminary study, the design discharge in this scenario is $1000m^3/s$ and the design river width is 400m. A simplified mathematics model is used to predict the river morphology after narrowing the main channel of the Lower Yellow River.

2 Establishment of the Mathematics Model

2.1 Choice of the Model Area

The stretch from Huayuankou to Gaocun is chosen as the model area in this basic study. There is many field data, no tributary and no big variable bed material in this stretch, which is the reason why we choose as the model reach.

2.2 Choice of the Model

The study emphasizes the macro-scale change of the river instead of the local changes at special locations. At the same time, the length of the modeled river is about 200km. It is more appropriate to choose one dimension to understand the river morphological changes instead of choosing two or three dimensions because a two or three dimensional model will take a very long time to simulate the river morphology for a long model.

Here, we apply SOBEK as a one-dimensional model to the case studies to illustrate the applicability of the proposed method and further to analyze the effect of the morpho-dynamic behavior after narrowing the main channel.

2.3 Schematization

The dimensions and the parameter settings of the case studies are based on the Lower Yellow River, which is an alluvial lowland river. It is schematized as a compound channel (Fig. 1). In the 1-D model this channel is represented by two sections, one for the main channel and one for the floodplains. In fact, in the physical river the part of the floodplain in the model will usually cover the water in the flood season. The high lands of the Lower Yellow River were never inundated after the operation of the Xiaolangdi reservoir. So the whole cross section in the model is just part of the cross section of the physical river which could be inundated during the flood season. As a result, the bed roughness of the main channel and that of the floodplain are represented by same constant Chezy coefficients of $75m^{1/2}/s$.

We further consider a reach length of 69km from Weicheng to Jiahetan which will be narrowed, and extend to 200 km to Huayuankou in the upstream direction and to Gaocun in the downstream direction.

Based on the filed data, the slope in this reach can be divided into three parts, namely from Huayuankou to Weicheng, from Weicheng to Dongbatou and from Dongbatou to Gaocun. They are 0.000183, 0.000154 and 0.000143 respectively.

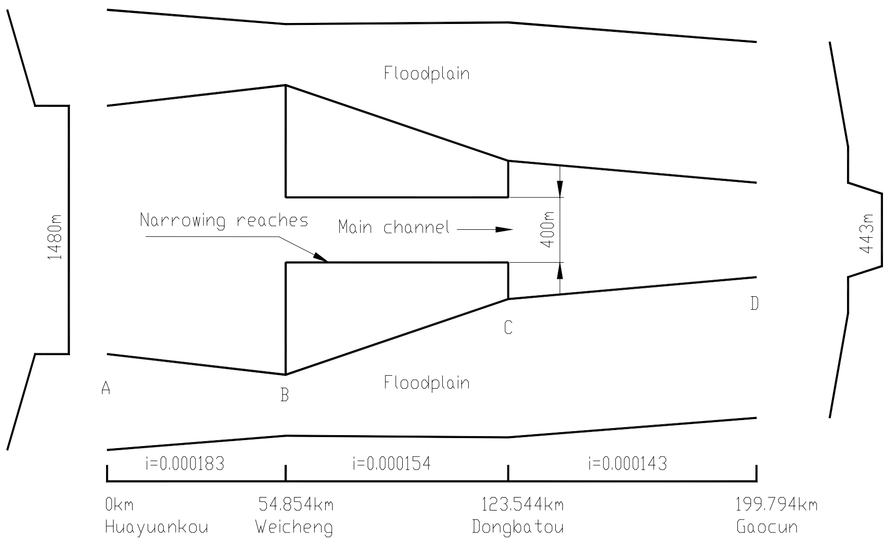

Fig.1 Schematization of the model

2.4 Cross section

A cross-section is defined as an input element of SOBEK in which the shape and size of the river profiles perpendicular to the flow is described.

The measured cross section is so complicated cross section. So it has to be simplified to input into the SOBEK model. The first thing is to find an appropriate width and water depth. In this model, the width of the bank-full discharge is chosen and then the depth.
In the model, several cross sections at the different location are schematized based on the average value in different cross sections. Fig.2 shows the schematization of the cross section.

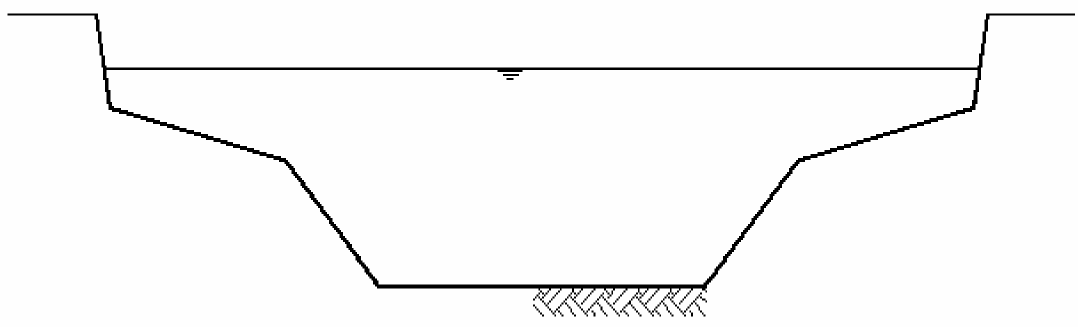

Fig.2 Schematization of the cross-section

2.5 Bed material size

The sand diameters at the different locations are shown in the table1 based on the field data. We can see that the sand diameter in the bed decreases along the river. At K54.854 and K98.006 the sand diameter shows a little difference. It can be caused by the location which be measured. As we know, the sand diameter may be different even in the same cross section in the river due to the different location in the bend.

Table1 Sand diameter at different location

Distance to Huayuankou (km)	0	38.41	54.854	72.856	98.006	129.692	151.202	173.488	199.794
Sand diameter(mm)	0.1609	0.1476	0.102	0.1222	0.0951	0.1164	0.0953	0.0974	0.0786

2.6 Boundary condition

Flow condition

Usually the discharge has to be specified at boundaries where water flows into the model and the water level where water flows out of the model.

We should choose a typical year to compare the difference between before and after narrowing the river. The average discharge in 2003-2004 and 2004-2005 are almost the average discharge in a long series. So we select the year 2003-2006 as a typical period. As we know, the river evolution is a slow procedure and morphological processes need a long time. So in order to study the river morphological procedure, we repeat the hydrograph eight times, which means the procedure starts from 2003 and ends at 2027.

Based on the simplified the cross section, the rating curve at the downstream boundary can be calculated as the following Fig.3.

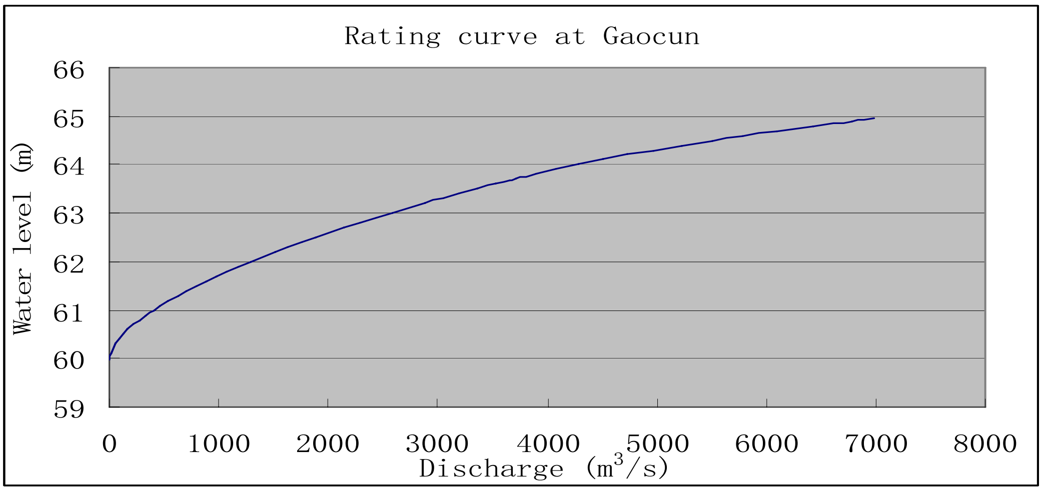

Fig.3 Rating curve at Gaocun used as downstream boundary

Sediment/Morphology condition

The continuity equation for the sediment requires a boundary condition at the inflow boundaries. No conditions are required for outflow boundaries. The inflow boundary condition can be either a specified load or a conditional for the bed level. We selected the different sediment conditions for the boundary to predict the change of the river after narrowing. This can be seen in the following section 4.

2.7 Initial conditions

Initial conditions define the starting situation for a calculation with SOBEK. SOBEK will calculate the flows, sediment transport, etc, for the subsequent time-steps of a simulation. There is no special requirement for the initial conditions. Usually, the better the initial conditions fit into the conditions imposed on the first-time steps of the calculation, the shorter the adaptation period will be. For this model, the initial condition comes from the field data and we need a straight line as bed level. Because of the variation of the width of the river a curved line would have been a better choice.

2.8 Sediment transport

Sobek River provides a general user-adjustable formula which is a generally shaped sediment transport formula available for the user to adjust according to his wishes. This formula reads:

$$\phi = \frac{1}{1 - \varepsilon} \beta_u (\mu\theta_s)^{\gamma_u} (\mu\theta_s - \theta_c)^{\alpha_u}$$

With ϕ = the transport parameter μ = the ripple factor, and θ_S = Shields parameter (-).

In the general user-adjustable formula, Shields parameter is an important parameter. As we know, the Shields parameter is a parameter characterizing the sediment transport conditions. It is defined as:

$$\theta_s = \frac{\bar{u}^2}{C^2 \Delta_d D_r} = \frac{hi}{\Delta D_r}$$

in which, $\bar{u}$=average flow velocity, C= Chézy coefficient, Δ_d = relative density of the sediment, D_r= representative grain size.

The Engelund & Hansen was revised on the basis of the Yellow River field data by Zhang Yuanfeng etc. as the following.

$$\phi = \frac{0.0075}{1-\varepsilon} \frac{C^2}{g} (\theta_s)^{2.3}$$

which is about 7.5 times smaller than the original Engelund & Hansen formula.

So in the general user-adjustable formula, α_u=0, β_u =2.2876, γ_u=2.3, μ=0.76.

In the Sobek, there is a multiplication factor would be used to revised the sediment transport. Based on the comparison between the field data and calculation data, the factor is determined as 150.

We calibrated the model based on the filed data. So in the calibration procedure, the sediment transport calculated by the revised Engelund & Hansen formula had to be validated and exaggerated to satisfy the real sediment transport in the real river. As a result, a bigger multiplication factor is chosen.

2.9 Time step and space step

The space step is 2km and the time step is 1 hour in this model.

3 Calibration and validation

The main purpose of this simplified model is to predict the river morphology after narrowing the river. The objective of the model emphasizes the qualitative difference of the capacity of the sediment transport and change of the bed level in different scenarios. In order to show similar relation to the real morphology, all schematization are based on the filed data although the model is an ideal model. The cross section is schematized based on the field data. In order to compare the difference, the longitudinal profile is flattened instead of the fluctuated thalweg in the physical river. That means the field data can not directly used to calibrate and validate the model. However, the tendency of the river morphology in large scale by the model should be correspond with the real river.

In this model, the flow condition come from the field data and the simplified cross section is based on the measure data at the same time. So the model is calibrated by the data based on the field data in 2003-2004 and validated based on the data in 2004-2005. At the same time, the comparison is implemented based on the same condition. So it could show reasonable results. However, we have to say that the calibration and validation is qualitative analysis and the result mainly shows theories difference in different scenarios.

4 Simulations

8 different cases are chosen to study the river morphology with different sediment flowing into the model and different widths of the river. They indicate that different scenarios: river bed degradation due to the operation of Xiaolangdi reservoir, river bed aggradations when sediments filling in the reservoir and the combination with these two scenarios.

In the model two different widths are applied, notably the original river width and a narrowed river width of 400m. The river morphological changes for both scenarios are analyzed and compared in the following. In order to describe the results in simple terms, only a limited number of cross-sections are considered in the following, namely:

K54.854-----the mouth of the narrowed reach
K123.544-----the end of the narrowed reach
K50.854-----4km above the narrowed reach
K55.942-----1.088km below the mouth of the narrowed reach
K111.855-----11.689km above the end of the narrowed reach
K125.544-----2km below the end of the narrowed reach

A--- the beginning of the model
B--- the beginning of the narrowed reach
C--- the end of the narrowed reach
D--- the end of the model

In order to better identify and explain what the effect of narrowing the river over a length of about 70km is, 8 cases are chosen to be simulated with the model.

- Case 0: Sediment supply at point A according to transport capacity (boundary condition no bed level change at point A) and no narrowing in reach BC.
- Case 1: Sediment supply at point A according to transport capacity (boundary condition no bed level change at point A) and narrowing in reach BC.
- Case 2: No sediment supply at the upstream boundary A and no narrowing in reach BC.
- Case 3: No sediment supply at the upstream boundary A and narrowing in reach BC.

- Case 4: Sediment supply at point A according to an increased sediment supply (1.2 times the sediment transport of Case3 at point A) and no narrowing in reach BC.
- Case 5: Sediment supply at point A according to an increased sediment supply (1.2 times sediment transport of Case3 at point A) and narrowing in reach BC.
- Case 6: Simulation of 25 years with initially no sediment supply in point A. After 15 years (the year 2018) an increase in the sediment supply at point A to approach the original sediment supply in say 9 years. Reach BC narrowed from the beginning.
- Case 7: Same as Case 6, but narrowing only after 15 years.

Table 2 shows the different assumptions which characterize the eight cases.

Table2 Characteristics of the 8 considered cases

Case	Upstream boundary			Narrowing		Multiplication factor
	S=0	Bed level constant	S (Defined)	yes	no	
0		√			√	150
1		√		√		150
2	√				√	150
3	√			√		150
4			√		√	150
5			√	√		150
6	√ (1)		√ (2)	√		150
7	√ (1)		√ (2)	√ (1)	√ (2)	150

Note: (1) shows beginning and (2) shows after (1).

5 Computational results

A brief result are described in this article and there is only one case are introduced in detail.

- Case 0 shows only the adaptation to equilibrium (so no narrowing and sediment u/s according to the transport capacity). This is base case used for comparison with other simulations and shows the adaptation of the bed level to adjust to an equilibrium condition. This equilibrium is not a straight line as both B and D are a function of time.
- Case 1 is similar as the one above but now a narrowing implemented. The bed level degrades in the narrowed reach BC.
- Case 2 is adaptation to equilibrium plus effect of reduced upstream sediment supply. Due to the operation of the Xiaolangdi reservoir, less sediment supply flows into the

model. We assume S=0 in the upstream reach without narrowing the reach. Under this condition, the bed level degrades more than in Case 0.

- Case 3 is like the previous one. The difference is the narrowing the reach BC. More degradation occurs in the contraction reach BC in Case 3 than in Case 2.
- Case 4 is adaptation to equilibrium plus effect of increased upstream sediment supply without narrowing the reach BC. After a long time, the reservoir will not be able to store more sediment and the sediment supply into the model will recover to its original values. Under those conditions, the sediment supply is more than the equilibrium because originally the lower reaches of the Yellow River is an aggrading river. As a result, the bed levels increase again.
- Case 5 is like the previous Case 4. The difference is the narrowing the reach BC. Due to the narrowing the reach BC, the sediment transport in this condition increases substantially. As a result, the bed levels in the contraction reach BC still decrease highly compared with Case 0.
- Case 6 is a combination of Case 2 and Case 5. The bed level decreases when no sediment supply from upstream and then it increases a little when sediment starts to increase again to reach the original transport capacity.
- Case 7 is a combination of Case 2, Case 4 and Case 5 and the change of bed levels, water depths and sediment transport are also similar to the combination of Case 2, Case 4 and Case 5.

The results of Case1 are described hereafter in some detail.

Case 1: Sediment supply at point A according to transport capacity (boundary condition no bed level change at point A) and narrowing in reach BC. Case 1 is similar to Case 0 but now a narrowing over a reach with 70km length is implemented. The bed level degrades more in the narrowed reach BC.

Fig. 4 shows the change of the bed levels. After a long time, the river slope will reach a dynamic equilibrium. At this condition, the slope in narrowing reaches BC is milder than the slope in the upstream reach AB and almost downstream reach CD. The increase in the reach AB is due to the boundary condition at point A (constant) and it causes that the sediment supply from upstream increases over time.

The bed level at the upstream keeps constant. However, that does not mean the sediment from the upstream is constant. With the slope increase in the upstream reach, the sediment transport also increases even the same bed level.

Fig.4 Change of bed level at the different time (Case 1)

Fig.5 shows the change of sediment transport at over time at K50.854. In the beginning (2003), the sediment transport is very low due to the influence of the backwater. Subsequently, the sediment transport increases gradually and then keeps a fluctuating state with the change of the discharge until the end of the model.

Fig.6 shows the change of sediment transport over time at K55.942. It is clearly that the sediment transport increases.

Fig.7 shows the change of sediment transport over time at K125.544. It is clearly that the sediment transport increases. Subsequently sediment transport is decreasing gradually and then continues to a fluctuation with the change of the discharge.

The slope in the reach AB changes from 0.000183 at the beginning to 0.000222 at the end of the simulation. Based on the Lane equation, the sediment transport and the total sediment transport are by then increased 34%. This is due to the fact that all the sediment which is eroded in the reach BC has to passed K125.544.

Comparing to the un-narrowing the river, the slopes at the end of simulation are 0.000192 and 0.000222. The sediment transport and total sediment transport are increased 25%.

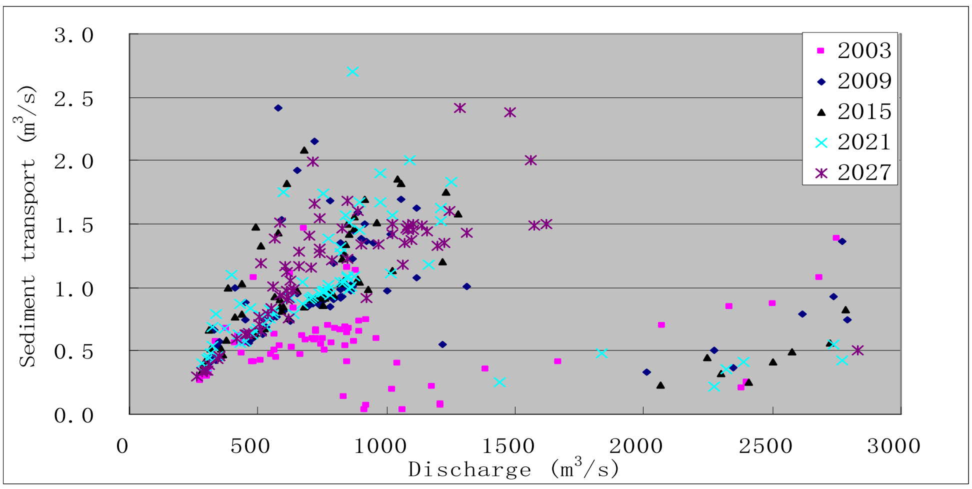

Fig.5　Change of sediment transport at the different time at K50.854 (Case 1)

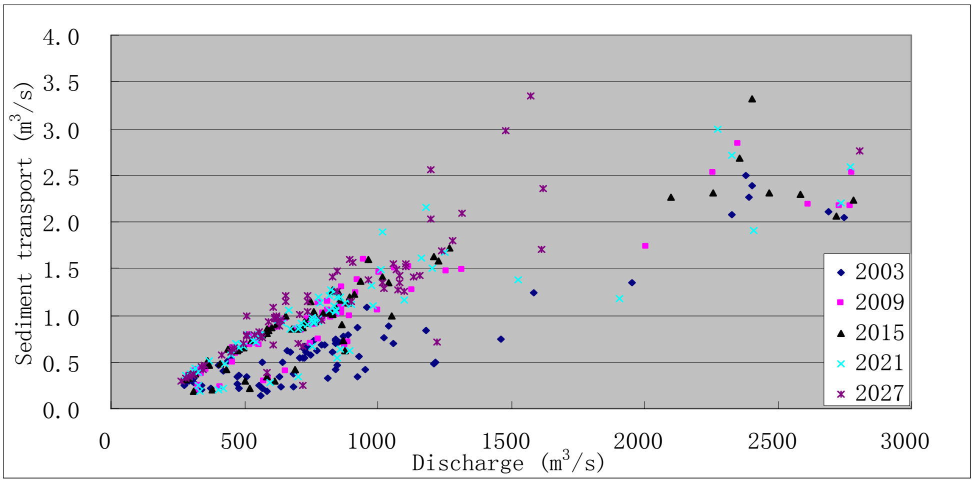

Fig6　Change of sediment transport at the different time at K55.942 (Case 1)

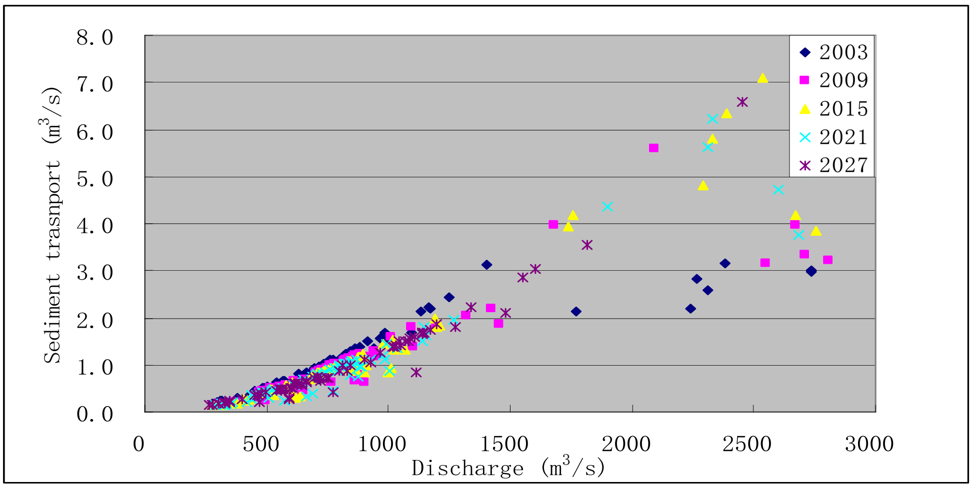

Fig. 7　Change of sediment transport at the different time at125.544(Case 1)

6 Interpretation

Table3 shows bed levels and slopes in 8 cases at the end of the simulation.

Table3　Change of the bed level and slope

Case	Bed level location			Slope of the reaches		
	K50.85	K55.94	K125.5	AB	BC	CD
0	81.70	80.82	68.94	0.000192	0.000172	0.000124
1	80.61	78.74	69.45	0.000220	0.000135	0.000131
2	79.00	78.40	68.30	0.000110	0.000140	0.000120
3	77.51	75.78	68.58	0.000147	0.000104	0.000121
4	82.12	81.21	69.06	0.000200	0.000176	0.000125
5	81.01	79.14	69.60	0.000223	0.000139	0.000136
6	78.19	76.39	68.63	0.000199	0.000113	0.000121
7	77.39	75.64	68.39	0.000192	0.000106	0.000118
original	82.21	81.31	70.63	0.000183	0.000154	0.000143

The original slope in the reach AB is bigger than the slope in the reach BC and reach

CD. As we know, the Yellow River before 2000, in which the Xiaolangdi reservoir begun to operate, was aggrading every year. At Huayuankou the bed level increased about 8 cm every year. For the whole lower reaches of the Yellow River, the river was in aggradation. At the same time, because more sediment flowed into the lower reach and the capacity of the sediment transport is less than the sediment transport, the bed level in the upper reach deposited more sediment than in the lower reach. The slope just explains this phenomenon.

Case 0 and Case 1 have the same boundary conditions but have a different width in the middle reach BC, corresponding to non-narrowing and narrowing respectively. Firstly, the bed level at K55.94 decreases more comparing to without narrowing the middle reach BC. At the same time, the bed level at K125.5 decreases less than without narrowing the reach BC. That means the slope in BC becomes milder than without narrowing BC. So it is clear that narrowing BC increases the sediment transport in BC and leads to more gradations in the beginning of the reach BC. Secondly, the slope in the reach AB with these two cases narrowing the reach BC is steeper than the original slope and the slope with narrowing the reach BC is steeper than without narrowing the reach BC. That means the sediment transport increases and it increases even more with narrowing the river. Then we compare the change of the slope in Case 4 and Case 5 with Case 0 and Case 1. With the more sediment flowing into the model, the bed level at the upstream boundary increase and it is same at K55.94 in Case4. However, even with the more sediment flowing into the model, the bed level at K55.94 is still lower than the bed level in Case 0. At the same time, the bed level at K55.94 is lower than the original bed. This shows that the increase of the capacity of the sediment transport at K55.94 is bigger than the sediment transport in the original river. As a result, the bed level still degrades.

Case 2 and Case 3 have the same boundary condition and are different in the middle reach BC with respect to non-narrowing and narrowing respectively. It is clearly that after narrowing the reach BC, the bed level at K55.94 decreases more comparing to without narrowing the middle reach BC. At the same time, the bed level at K125.5 decreases less than without narrowing the reach BC. That means that the slope in BC becomes milder than without narrowing BC. So it is clear that narrowing BC increases the sediment transport in BC and leads to more gradations in the beginning of the reach BC. The slope in the reach AB shows a different change. That is caused by the more increased degradation at K55.94 due to the increase of the sediment transport in the reach BC.

Case 6 and Case 7 show the decrease of the river bed due to no enough sediment carrying from the upstream reach. During the simulation period, the river is always degrading. The slope in reach BC is milder than the slope in Case 0 and Case 1. When the reservoir can not store more sediment in the reservoir, the slope will have to become steeper and the effect due to narrowing the reach will be of no use. So in conclusion, it is not necessary to narrowing the river when the deposition in the Xiaolangdi reservoir is still taking place.

7 Discussions

As we know, the more sediment flows into, the more sediment flow out in the Lower Yellow River. The capacity of the sediment transport can increase substantially with the increase of the sediment concentration with the same current condition. This is explained by the increase of the density of the sediment-laden water. This makes it easier to pick up sediment from the river bed and to transport it. More sediment is transported into the sea instead of depositing in the river. There is no appropriate formula to model this behaviour. As a result this induces a difference in the change of the river bed between the model and the real river. In the model, we did not pay attention to the sediment flowing into the lower reach of the Yellow River based on the field data.

The downstream boundary is an important condition for the model. Due to influence of the downstream condition, the river bed does not change so much and it does not correspond with the change in the real river. So it could be better if we make the model longer than the length that we used in the model. But it will spend more time to model.

The model presents an idealized model to predict the river morphology after narrowing the river. The cross section in the model is schematized into a single compound section. In the real river, the cross section is a complicated compound section. The deposition and erosion in the cross section depend on the local velocity, the size of the sand and the ingredient of the sand. At the same time, the Manning coefficient or Chezy coefficient is changing with the location in the cross section, sediment concentration, discharge and even the procedure of the deposit or erosion. In the model, the Chezy coefficient is constant. This could have an impact on the accuracy of the prediction.

8 Conclusions and recommendations

Based on the simulation, we can draw the following conclusions:

☆ Narrowing the river is helpful to increase the sediment transport. It is more helpful and needed when more sediment flows into the lower reaches of the Yellow River.

☆ It is not so necessary to narrow the river now in a period that lots of sediment deposit in the Xiaolangdi reservoir. Once the reservoir is full and the sediment supply to the lower reaches of the Yellow River may be back to its old values, narrowing the river will be very useful to increase the sediment transport.

☆ The sediment transport increases due to narrowing the river. The sediment transport increases 25% comparing to the care of no narrowing of the river with an equilibrium sediment transport at upstream boundary.

☆ The current slope of the river is almost in an equilibrium state. The bed level decreases 4.7m with narrowing the reach BC and it is bigger than it with no narrowing the reach BC with an equilibrium sediment transport at upstream boundary.

We also found some problems during the modeling. In order to make a better prediction, some recommendations are given hereafter.

☆ It might be considered to use a Chezy coefficient different for the different location and different size of the sand. But it is wise to first study the influence of such a refinement on the simulation results.

☆ The complicated compound cross section should be adopted in the model and at the same time, a more real cross section should be used in the model. So we can make an accurate calibration and validation for the model.

☆ It is very important to know whether the narrowed river will have a large impact on the conveyance capacity during the extreme. So the big flood should be included in the model. Then we can understand what the influence is with big flood.

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