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INFLUENCE ON DEPOSITION OF THE THREE GORGES RESERVOIR CAUSED BY THE RESERVOIRS BUILT UPSTREAM

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ABSTRACT

The reservoirs built in the upper stream of the Yangtze River intercept the sediment from upstream, this will decrease the sediment into the Three Gorges Reservoir (TGR) in downstream and slow down the deposition development of TGR, moreover, this also affect navigation condition for a long-term operation. In this paper, calculations are made about the influence of the deposition and navigation of TGR caused by the reservoirs built in the upper stream of the Yangtze River such as Xiluodu and Xiangjiaba Reservoir by using one-dimensional flow and sediment mathematical model. The results suggest that the deposition development in TGR will be postponed with the reservoirs built upstream. Under the condition of the upstream reservoir built, the sediment deposition would not appear at the fluctuating backwater area in the early operation 40 years. Chongqing reach shows scour tendency, deposition basically not occurring in 100 years.

Keywords: Deposition; navigation, The three gorges reservoir, The reservoirs built upstream.

1. INTRODUCTION

The condition of deposition and navigation in TGR is a complex process affected by upstream incoming water and sediment, as well as operation regulation of reservoir. With many reservoirs built such as Xiluodu and Xiangjiaba reservoir in the upper stream of the Yangtze River (Figure.1), upstream sediment is intercepted and the incoming sediment of TGR will be further reduced. Zhutuo station is located in the entrance of TGR. According to the calculated results by Yangtze River Scientific Research Institute (1998), with Xiangjiaba reservoir operating independently for 10 years, the sediment concentration at Zhutuo station is only 50% of that under the condition of no reservoir built upstream. With Xiangjiaba Reservoir operates for 30 years, the ratio above is only 59%; It was until Xiangjiaba Reservoir operates for 60 years that the ratio above was close to 100%. Xiluodu reservoir plays a more significant role to control sediment, for example, Xiluodu reservoir independently operates for 10 years, the sediment concentration at Zhutuo station is only 39.5% of that in the condition of no reservoir built upstream, when Xiluodu Reservoir is operated for 60 years, the ratio above is only 56.3%. All this will affect deposition and navigation condition when TGR begins to store water. Research about effects on deposition of TGR caused by Xingjiaba and Xiluodu Reservoir have been made by The Yangtze River Scientific Research Institute (1998) and China Institute of Water Resources and Hydropower Research (CIWHR) (1998), the results suggest that the speed of sediment deposition in TGR will slow down with Xiangjiaba or Xiluodu reservoir built upstream, and therefore the stress of controlling flood in Chongqing Reach will be relieved. However, these studies above do not take the effects on deposition and navigation condition caused by upstream reservoirs combined operation into account. In this paper, the further research is made about the sediment deposition of TGR under the condition of upstream reservoirs built in the upper stream of the Yangtze River by using flow and sediment mathematical model.

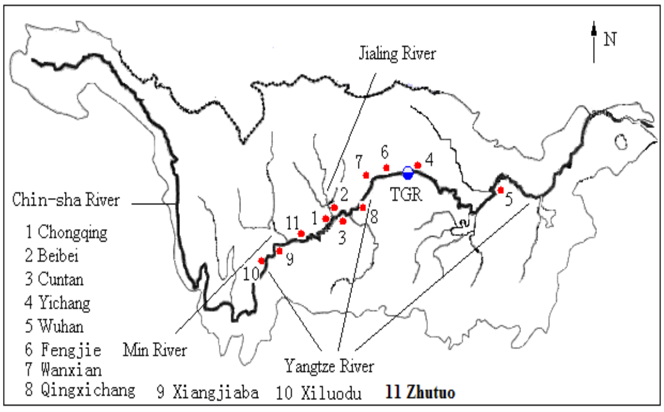


Figure 1. Sketch Map of the Yangtze River

2. METHODS AND MATERIALS

One-dimensional, unsteady flow and non-uniform flow and sediment mathematical model

Governing Equation

Governing Equation for Open-Channel Flows：
Continuity equation:

$$\frac{\partial Q}{\partial x}+\frac{\partial A}{\partial t}=q_l \tag{1}$$

Momentum equation:

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}(\frac{Q^2}{A})+gA(\frac{\partial Z}{\partial x}+J_f)=q_l u_l \tag{2}$$

Governing Equation for Sediment Transport:
Transport equation:

$$\frac{\partial (hS_k)}{\partial t}+\frac{\partial (UhS_k)}{\partial x}+\alpha_s\omega_k B(S_k-S_{*k})=S_l q_l \tag{3}$$

Suspended river deformation equation:

$$\gamma'\frac{\partial Z_{0sk}}{\partial t}=\alpha_s\omega_k(S_k-S_{*k}) \tag{4}$$

Total river deformation equation:

$$\frac{\partial Z_0}{\partial t}=\sum_{k=1}^{n_s}\frac{\partial Z_{0Sk}}{\partial t} \tag{5}$$

Transport capacity formula:

$$S_*=S_*(U,h,\omega,\ldots) \tag{6}$$

where x and t = spatial and temporal variables; Q = flow discharge; A = flow area; Z = water level; R = hydraulic radius; q_l = side discharge per unit channel length; u_l = side velocity of flow per unit channel length; h = water depth; U = velocity of flow; ω_k = fall velocity of sediment of size class k; S_k = sediment concentration of size class k; S_{*k} = sediment transport capacity of size class k; S_k = side sediment concentration of size class k; γ' = bulk density of sediment deposits; Z_{osk} = erosion/deposition depth of size class k; α_s = coefficient of saturation recovery; Z_o = cross-sectional erosion/deposition depth; n = manning coefficient; ω = fall velocity of sediment; and S_* = sediment transport capacity.

Supplementary explain about some problem in model

a. Demarcation of sediment transport characteristic

Incipient velocity is determined by Zhang Ruijin's formula (Zhang 1997):

$$u_c=(\frac{h}{d})^m[17.6\frac{\rho_s-\rho}{\rho}d+6.05\times10^{-7}(\frac{10+h}{d^{0.72}})]^{1/2} \tag{7}$$

u_c = starting flow velocity; ρ_s and ρ = density of the sediment and density of the clear water; d = grain size.

Suspension index is determined by z (suspension index):

$$z=\frac{\omega}{\chi u_*} \tag{8}$$

Generally, sediment is suspended when z<5 and sediment doesn't fall when z<0.01. z = suspension index; u_* = friction velocity; χ = wetted perimeter.

b. The sediment transport capacity of different class sizes

The sediment transport capacity is determined by Dou Guoren's method (Dou, 1990).

c. The correction factor for unsteady transport of a suspended load through a river.

The correction factor α is obtained by data fitting, according to research by Han Qiwei (Han, 1997), α = 0.25 for deposition and α =1.0 for erosion in Yangtze River.

d. The selection of Manning coefficient

Getting the Q-n curve through fitting the practice data and confirming the n correspond to discharge with Q-n curve. At the same time, the effect from resistance of boundary and deposition considered (Li, 2001).

e. Adjustment of the bed-material gradation at the mixing layer

The bed material is divided into several layers to allow the computation of changes in bed material gradation due to erosion or deposition. Here, the method brought forward by Wei Zhilin (Wei, 1997) is adopted to confirm the new bed-material gradation.

Model calibration

Zhutuo station is located in the entrance of TGR and Sabdouping station is located in the exit of TGR. The studied reach is ranged from Zhutuo station to Sandouping station with distance of 756.3 km, including 368 sections, and the average length between two sections is 2.06km. The stream coming from Jialingjiang River and Wujiang River is considered.

The data of discharge and sediment concentration of Zhutuo, Beibei and Wulong is adopted as imported hydrological data.

a. Calibrating with survey hydrological data.

With survey hydrological data from 1999 to 2003, water surface elevation, flow discharge and sediment transport rate of main positions is calibrated, besides, the deposition amount in different reaches is calibrated with sediment-transport balance method (Li, 2006).

The comparison between measured water-level and calculated water-level of some stations in 2000 is displayed by Figure.2, it is indicated that the average difference between measured water-level and calculated water-level is 0.29m, the errors is allowable.

The comparison between measured discharge and calculated discharge of some stations in 2000 is displayed by Figure.3, it is indicated that the average difference between measured discharge and calculated discharge is 256m^3/s, the errors is allowable.

All these indicate that simulation results agree well with measurements and the model is reliable.

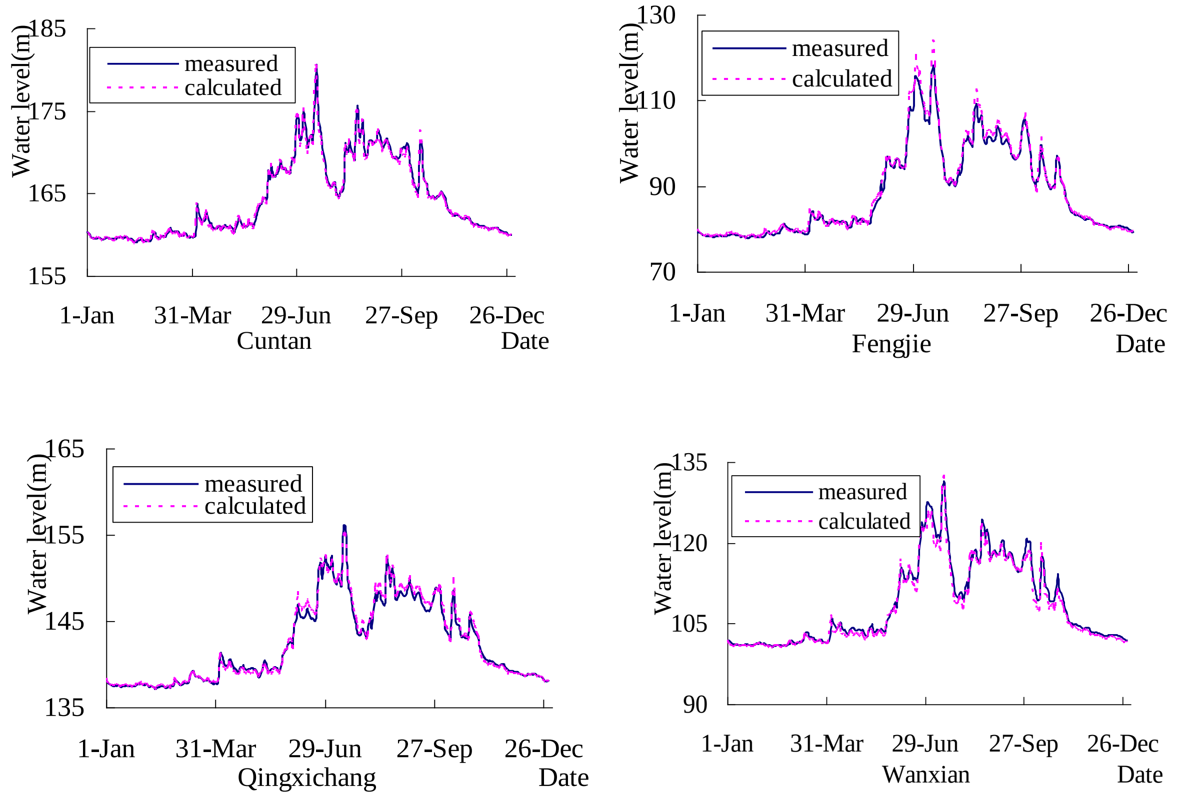


Figure 2. The comparison between measured water-level and calculated water-level of some stations in 2000

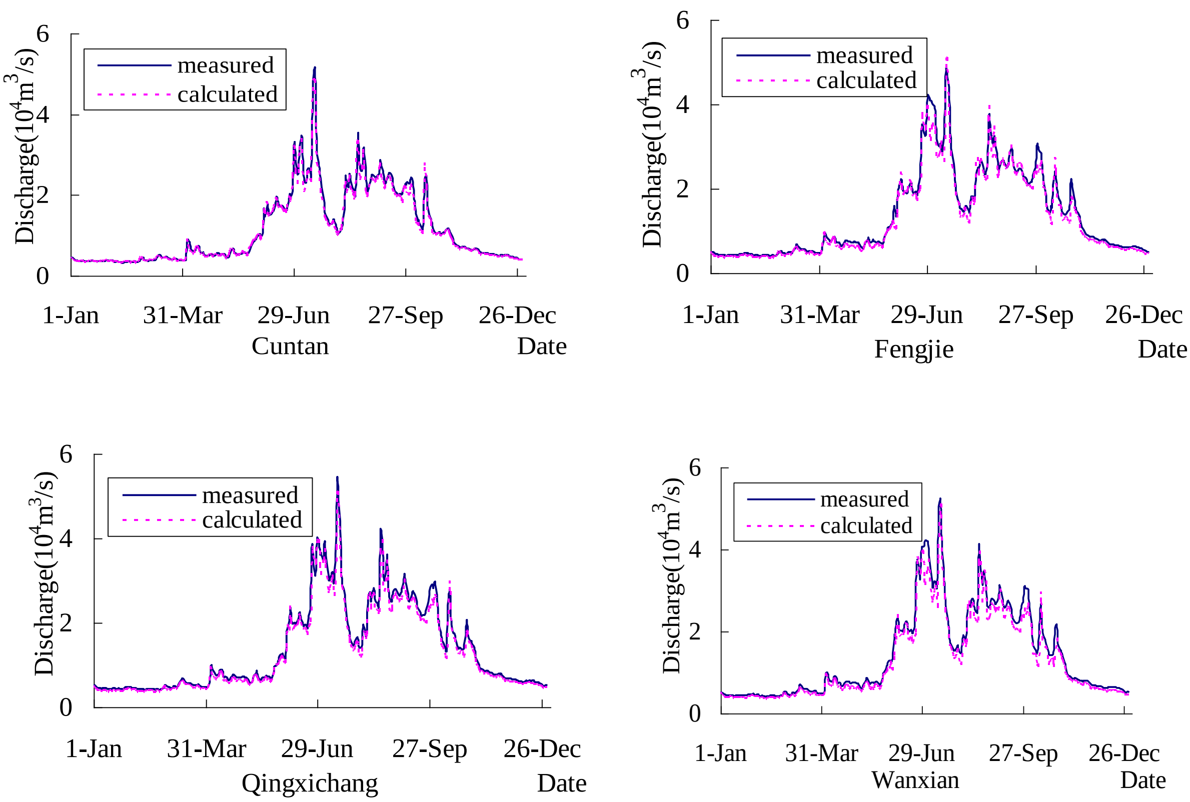


Figure 3. The comparison between measured discharge and calculated discharge of some stations in 2000

Table 1. The comparison between measured deposition amount and calculated deposit amount of some river reaches (10^4t)

	Zhutuo-Cuntan		Cuntan-Qingxichang		Qingxichang-Wanxian		Wanxian-Fengjie	
Year	Measured	Calculated	Measured	Calculated	Measured	Calculated	Measured	Calculated
1999	699.24	1379.6	-432.06	-549.20	-2886.12	-3777.0	-3598.37	-2776.2
2000	1524.00	647.01	-1078.58	-600.50	-3102.61	-2871.6	593.06	810.04
2001	339.27	1333.4	1703.79	1204.4	-3136.44	-2455.6	183.43	380.36
2002	386.61	99.45	1751.06	1283.2	-4085.51	-2257.8	——	——
2003	1589.89	1201.8	871.40	309.21	4712.89	1185.99	——	——
Total	4539.00	4661.2	2815.62	1647.2	-8497.79	-10176.	-2821.88	-1585.8

In order to calibrate the reliability of model, the comparison between measured deposition amount and calculated deposition amount of some river reaches is displayed in Table.1. the negative deposition amount means erosion. It is indicated that the difference between measured deposition amount and calculated deposition amount is little and the tendency between erosion is in accordance with deposition , balance of scouring and silting is keep, for example, the average difference between measured deposition amount and calculated deposition amount in Zhutuo-Cuntan is only 244.45×10^4t, the errors is allowable and the model is reasonable and refers to reality.

b. Long period calculation calibration

The flow and sediment series from 1961 to 1970 is adopt in the planning stage of TGR. In order to validate the model reliability deeply, TGR's deposition amount in 100 years is computed with the flow and sediment series from 1961 to 1970 and the operation regulation provided by the Yangtze River Water Resources Commission (YRWRC) (The water level before the dam keeps 135m from 2003 to 2007; from 2007 to 2009, the operation regulation of 156m—135m—140m (normal water level—flood water level—lowest navigable level) is adopted; from 2009 to 2102, the operation regulation of 175m—145m—155m (normal water level—flood water level—lowest navigable level) is adopted.). Figure.4 display the calculated deposition amount and the results provided by the Yangtze River Scientific Research Institute (YRSRI) (YRSRI, 1988, 1998), China Institute of Water Resources and Hydropower Research (CIWRHR) (IWRHR, 1998) and ZHOU (Zhou et al., 2000).

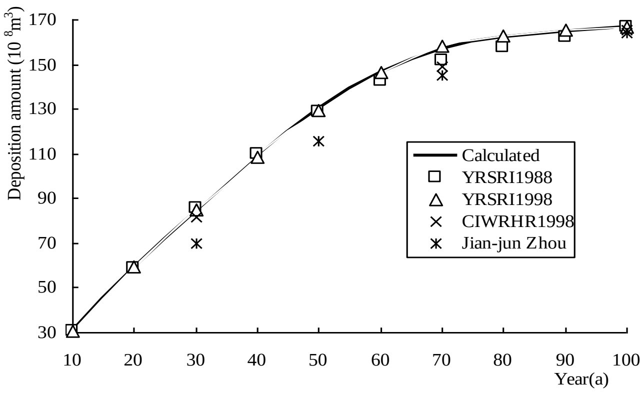


Figure 4. The deposition developing in TGR

The water level before the dam adopted in this paper is same to the one adopted by YRSRI in 1998, and it is different from others in the first 10 years. The result indicates the agreement between the calculated one and the YRSRI's in 1998. The calculated deposition has a little difference in some reaches from the former results for the difference of the water level before the dam in the first 10 years, but they are similar in the whole reservoir at silt-stable stage, the deposition amount of this paper, YRSRI 1988, YRSRI 1998, IWRHR 1998, ZHOU is 166.66×10^8m^3, 166.56×10^8m^3, 166.52×10^8m^3, 165.24×10^8m^3, 164.20×10^8m^3 respectively, the difference is little.

Through the comparison, it can be seen that the presented model is reliable and applicable.

3. SEDIMENT DEPOSITION OF TGR UNDER THE CONDITION OF UPSTREAM RESERVOIR BUILT

In this paper, calculation have been made about effects on sediment deposition of TGR under the condition of reservoirs built in the upper stream of the Yangtze River, by using one-dimensional unstable water and flow and sediment mathematical model. The scheme of the water level in front of dam is provided by Yangtze River Commission. The flow and sediment series from 1961 to 1970 is adopt.

Calculations about sediment deposition of Xiangjiaba reservoir within 100 years have been made by Hu Yanfen and Wu Weimin(Hu Yanfen and Wu Weimin, 2003), in this process, impacts of upstream Xiluodu reservoir has been considered. Outflow water and sediment characteristics values are given in Table.2, with upstream reservoirs combined operation.

From Table 2, with upstream reservoirs such as Xiluodu reservoir and Xiangjiaba reservoir combined operation, large quantities of sediment impounded by these reservoirs, making discharged sediment decreasing obviously. With the reservoir operating in the first 60 years, sediment delivery ratio of Xiangjiaba reservoir changed slightly, maintaining between 13% and 18%. With sediment deposition increasing in the later period, the sediment delivery ratio of Xiangjiaba reservoir also increases, however, until the 100th year, the sediment ratio of Xiangjiaba reservoir is less than 60%, still not reaching complete silt-stable. Incoming water and sediment condition of TGR changes according to the changes of Xiangjiaba reservoir's sediment delivery ratio, Zhutuo station is located in the entrance of TGR, the incoming sediment of Zhutuo station at Yangtze River mainstream increases gradually. In the first 60 years, it maintains between 34% and 39% of that in natural condition, increasing later, reaching 67% in 100 years. The change of upstream incoming water and sediment inevitably impacts on sediment deposition in TGR. In this paper, according to the incoming sediment decreased rate of Zhutuo station basically equal to that of data above, the effects on deposition of TGR caused by upstream reservoir built is calculated and analyzed.

Table 2. Sediment amount entering TGR with the reservoir construction upstream (average amount in 10 years)

Time of upstream reservoirs operation (years)	Sediment delivery ratio of upstream reservoirs in 10 years (%)	Incoming sediment of upstream reservoirs in 10 years (10^8t)	Discharged sediment amount of upstream reservoirs in 10 years (10^8t)	Deposition mount of upstream reservoirs in 10 years (10^8t)	Incoming sediment of TGR in 10 years without reservoirs built upstream (10^8t)	Incoming sediment of TGR in 10 years with reservoirs built upstream (10^8t)
0～10	12.98	24.7	3.21	21.49	33.00	11.51
11～20	13.72	24.7	3.39	21.31	33.00	11.69
21～30	14.46	24.7	3.57	21.13	33.00	11.87
31～40	15.64	24.7	3.86	20.84	33.00	12.16
41～50	16.83	24.7	4.16	20.54	33.00	12.46
51～60	18.01	24.7	4.45	20.25	33.00	12.75
61～70	22.58	24.7	5.58	19.12	33.00	13.88
71～80	27.14	24.7	6.70	18.00	33.00	15.00
81～90	41.44	24.7	10.23	14.47	33.00	18.53
91～100	55.73	24.7	13.77	10.93	33.00	22.07

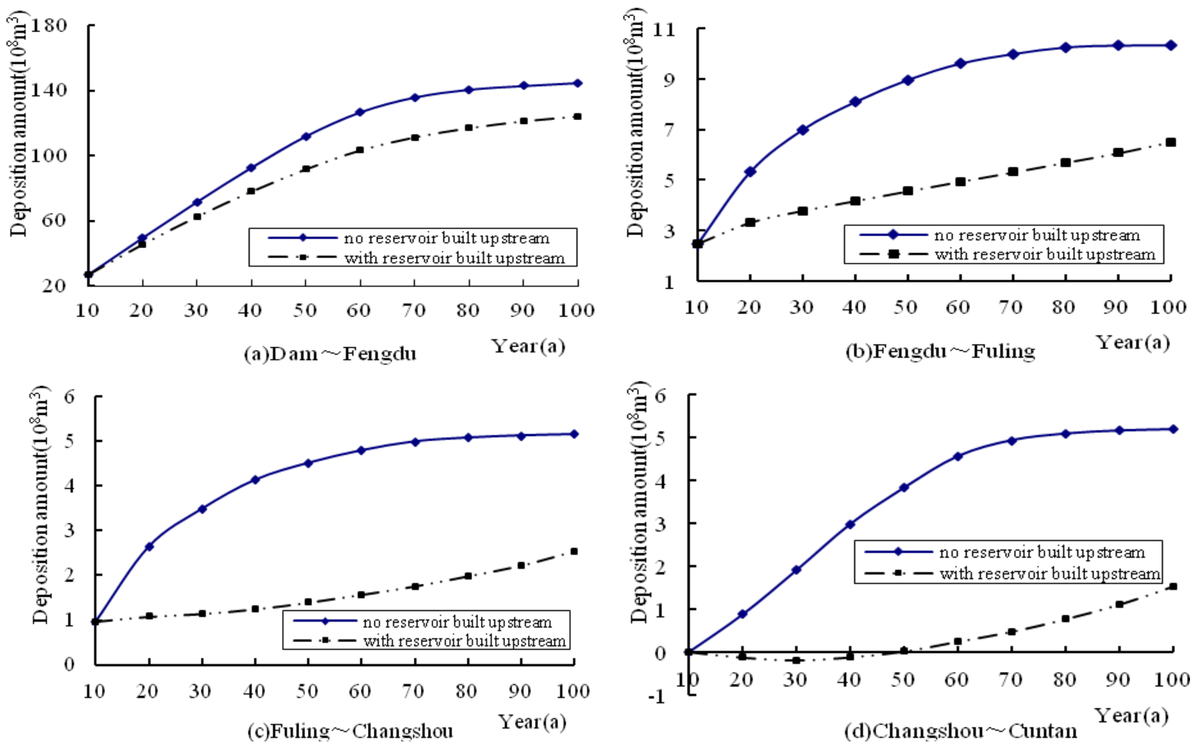
Figure.5a ~ f shows that the deposition development at each reach in TGR and the whole reservoir, under the conditions of upstream reservoir built or not built, Fengjie, Wanxian, Qingxichang, Cuntan are some important hydrological station(Figure.1).

a. When the reservoir operates in the first 10 years, the volume and distribution of reservoir deposition are completely same in both computing cases, with the upstream reservoir having not been used.

b. Incoming sediment of TGR greatly reduced under the condition of upstream reservoir built, decreasing sharply at the beginning and recovering later, leading the rate of reservoir deposition reducing and equilibrium time increasing. When TGR operates for 70 or 80 years, the deposition of the reservoir is close to equilibrium with no upstream reservoir built. However, the deposition of TGR doesn’t reach equilibrium when the reservoir operated for 100 years with upstream reservoirs built.

c. Building reservoirs in upstream or no reservoirs have different impact on the development of siltation in each reaches, especially have greater impact on the upstream fluctuating backwater area of TGR. Because the sediment is intercepted by the reservoirs upstream, sediment concentration of discharge flow becomes relatively small, this leads to the erosion in fluctuating backwater area of TGR. Among them, Changshou~Cuntan reach will turn into the siltation after 40 years, the reach above Cuntan have no siltation even after 100 years. To the reach below Changshou, in the condition of build reservoir in upstream, the sediment deposition processes will slower than that no reservoir upstream.

From the above analysis, upstream reservoirs will be beneficial to the reservoir flood control and power generation, slow deposition rate in TGR. After upstream reservoirs built, deposition will not occur in the fluctuating backwater area of TGR in 40 years, and deposition will not occur in Chongqing reach in 100 years, which is favorable for navigation.



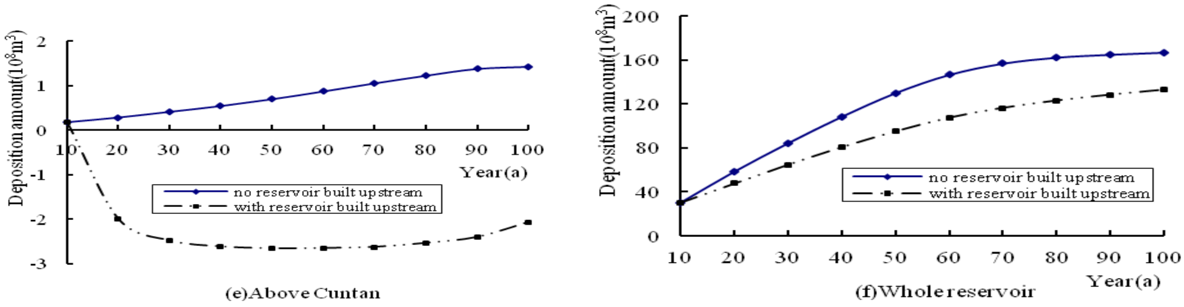


Figure 5. The deposition developing in TGR with reservoirs built upstream or not

6. CONCLUSIONS

In this paper, based on flow and sediment mathematical model, some conclusion can be drawn about deposition and navigation in TGR with the change of water and sediment.

Through can be concluded by computational analysis the navigation status of Chongqing Reach and the development of TGR deposition after by using flow and sediment mathematical model:

a. the deposition development speed of TGR will be slow down by the reservoirs building upstream, and the deposition balance will be delay.

b. With upstream reservoir built, the stem stream above Changshou will scour, especially the reach over Cuntan which has been in the state of scour within the 100 years.

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