Statistical Analysis of Sedimentation Tendency in Xiaolangdi Hydrometric Station of the Yellow River

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Abstract: Based on the water lever and flow data of Xiaolangdi Hydrometric Station of Yellow River from 1960 to 2002, the macroscopic riverbed sedimentation tendency in Xiaolangdi Hydrometric Station of Yellow River was studied with statistical analysis. This study result indicated that the riverbed of Xiaolangdi Hydrometric Station remained basically balanced from 1960 to 1992, and evident souring trend from 1992 to 2002 due to water storage of Xiaolangdi Reservoir and its first water and sedimentation regulation in the Yellow River.

Key words: Xiaolangdi Hydrometric Station, Sedimentation, Statistical Analysis

Flood in the lower reaches of the Yellow River was related to national economic development and social stability. After the founding of new China, downstream flood control was a main strategic objective of harnessing of the Yellow River. As the Yellow River basin had its special natural and geographic environment, namely, climatic condition with semi-arid as main conditions and surface material with loess as main, coupled with intensive human activities undermining most natural vegetation, made mud and sand amount and sand content in the lower reaches of the Yellow River rank first in the world, watercourses in the lower reaches be in a state of sustained elevation and water lever continuously rise, which made flood control in the lower reaches of the Yellow River increasingly difficult, caused a passive situation of embankment heightening～riverbed sedimentation rising～flood water level lifting, extremely unfavorable to flood control and made people realize that solving the problem of mud and sand was the key to flood control in the lower reaches of the Yellow River.

To shake off the above passive situation, ease downstream flood control pressure basically, beginning from 1950s, the state took 2 major measures to reduce mud and sand flow into the Yellow River in the upper and middle reaches of the Yellow River, namely construction of reservoirs and large-scale water and soil conservation, greatly reducing mud and sand amount flowing into the Yellow River. At the same time, with the industrial and agricultural development in the Yellow River basin, demand of people for water increased vigorously, obviously reducing runoff into watercourse downstream of the Yellow River, correspondingly decreasing sediment transport capacity of watercourse in the lower reaches of the Yellow River. The former probably reduced downstream watercourse sedimentation amount while the latter probably increased downstream watercourse sedimentation amount [1].

Based on hydrologic data actually measured of Yellow River Xiaolangdi Station, this paper analyzed macroscopic change tendency of watercourse sedimentation amount in the lower reaches of the Yellow River under the influence of the above 2 factors.

1. Basic data

Basic data used in this research were water lever and flow data of Xiaolangdi Hydrometric Station actually measured at 17085 periods of time from 1960 to 2002.

1960～2002 witnessed 2 station removals of Xiaolangdi Hydrometric Station of the Yellow River from 1960. The first occurred in 1984～1985. In July 1992, Xiaolangdi Multipurpose Project resulted in the second removal, namely, from current Xiaolangdi Dam position to 4km downstream, namely current Xiaolangdi Hydrometric Station position.

Relation between water lever and flow of Xiaolangdi Hydrometric Station in 1960～2002 was shown by Diagram 1.

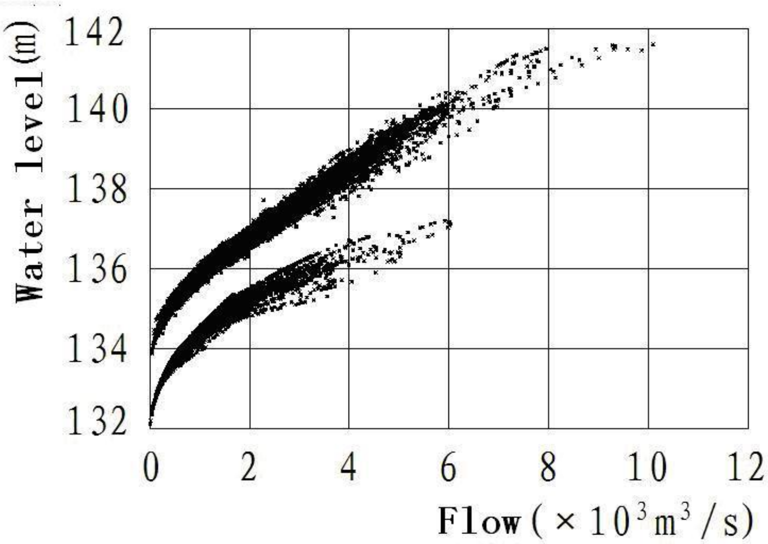

Diagram 1 Relation between water level and flow of Yellow River Xiaolangdi from 1960 to 2002

2 Riverbed sedimentation yardsticks

As the Yellow River natural riverbed sections is complex and varied, with diffluence and flood land, it would be very difficult to accurately reflect souring or sedimentation of a particular section of the riverbed. But usually it could be considered that in case of 2 identical flows passed through a certain section, water lever rising indicated riverbed in this period of time witnessed sedimentation, and the higher the rising value was, the more serious sedimentation would be; water lever lowering indicated riverbed in this period of time witnessed souring, the lower the lower value was, the more serious souring would be; water lever having no significant change indicated riverbed in this period of time witnessed basically balanced sedimentation.

3. Riverbed sedimentation tendency statistical analysis

According to riverbed section sedimentation yardstick, it was possible to select a certain section and have the identical flow pass through it at different periods of time and use water lever change to analyze this section sedimentation change.

In 1960～1984, Xiaolangdi Hydrometric Station had a flow of 1050m^3/s, witnessed 29 times in succession, water lever transformation relation was shown by the broken line in Diagram 2. In the diagram, the horizontal coordinate indicated the number of days from January 1, 1960 witnessing this flow and the longitudinal coordinate indicated water level corresponding to this flow.

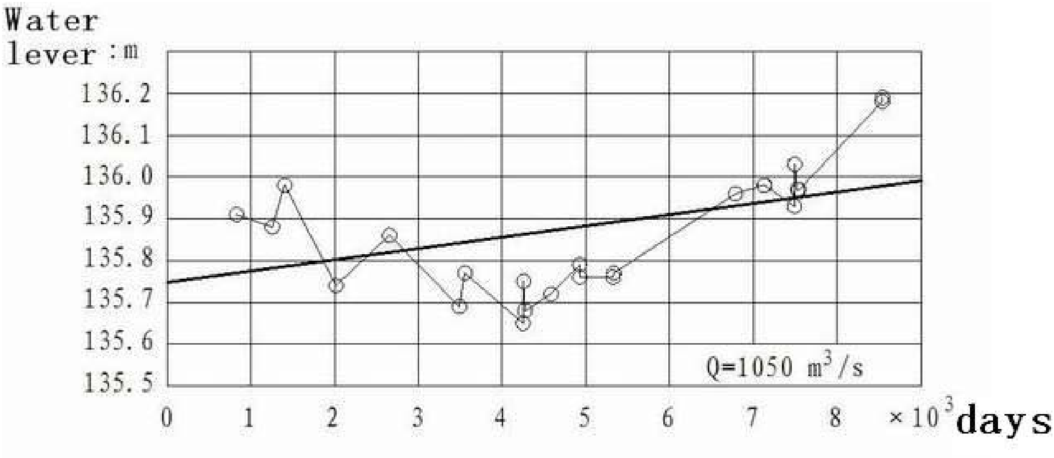

Diagram 2 Transformation relation of water lever when flow was 1050m3/s

Diagram 2 indicated under the identical flow, in different periods of time, water lever might rise or fall. Certainly it should not be simply considered that the riverbed in this period of time witnessed souring or sedimentation, but it was necessary to make statistical analysis according to these data and observe riverbed overall sedimentation change tendency in this period of time.

According to statistics, it could be assumed that water lever and time had 1st-order correlation, namely,

$$Y=a+bX+\varepsilon \quad (1)$$

In the formula(1), Y referred to water lever, X referred to time, $\varepsilon \sim N(0, \sigma^2)$. In formula (1), a, b might adopt minimum quadratic multiplication for estimation. Significance level α of correlation coefficient of Y and X might be examined with correlation coefficient ρ_{XY}. Y and X having significant correlation with $b>0$ indicated the riverbed had a sedimentation souring tendency; Y and X having no significant correlation with $b<0$ indicated the riverbed had a souring tendency. Y and X having no significant correlation indicated riverbed had a balanced sedimentation trend.

According to 29 water level and time correlation data points when Xiaolangdi Hydrometric Station flow was 1050m^3/s, it could be obtained that a=135.747, b=2.70009×10^{-5}, ρ_{XY}=0.165846. Y and X regression line was shown by straight line in Diagram 2.

Table 1 "Table of correlation coefficient critical value of correlation significance examination"[2] indicated in case of significance level α=0.05, Y and X had significant correlation with $b>0$. Therefore, in case of a single flow, it could be considered the riverbed in this period of time had evident sedimentation tendency.

Table 1: Table of correlation coefficient critical value of correlation significance examination (α=0.05)

n-2	18	19	20	21	22	23	24	25	26	27	28
$R_\alpha(n\text{-}2)$	0.444	0.433	0.423	0.413	0.404	0.396	0.388	0.381	0.374	0.367	0.361

The above analysis was made under a certain flow, but in fact in this period of time, there were multiple flows of different sizes, each flow had its own occurrences. 2 different flows might result in different conclusions.

Take Xiaolangdi Hydrometric Station of Yellow River as example, from 1960 to 1984, flow was 3160m^3/s, witnessed 21 times in succession, transformation relation of water lever and time was shown by the broken line in Diagram 3. Through calculation, it could be obtained that a=137.896, b=-3.02482×10^{-5}, ρ_{XY}=-0.579592, and the regression line was shown by the straight line in Diagram 3.

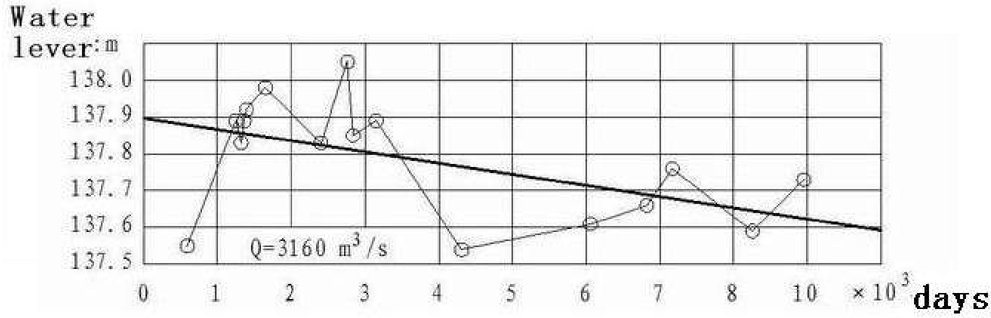

Diagram 3 Transformation relation of water lever when flow was 3160m3/s

Table 1 *Table of correlation coefficient critical value of correlation significance examination* indicated, in case of significance level α=0.05, Y and X had significant correlation with b<0. Therefore, in case of a single flow, it could be considered the riverbed in this period of time had evident souring tendency.

The above indicated, analysis according to sedimentation of different flows in the same section might lead to contrary conclusions, which did not indicate it was improper to come to a conclusion for riverbed sedimentation change from the water lever change tendency under a single flow. It was necessary to make researches on multiple groups of flow and come to a rational conclusion.

In the empirical regression equation (1), b reflected riverbed sedimentation or souring speed under a certain flow. Therefore it was proper to seek for the average of b, and consider its average value comprehensively reflected riverbed souring or sedimentation speed in a certain period of time.

4. Statistical analysis of Yellow River Xiaolangdi riverbed sedimentation tendency

According to the above statistical analysis, this author made studies on Xiaolangdi Hydrometric Station riverbed sedimentation tendency.

According to different locations of Xiaolangdi Hydrometric Station, the research was correspondingly divided into 3 periods of time, namely, 1960～1984, 1985～1992 and 1992～2002, including 9423 water lever～flow correlation points in 1960～1984， 2982 in 1985～1992， 4680 in 1992～2002. Within each period of time, there were different flows, and each flow had a minimum number of water levers, namely, 6, otherwise this flow would be abandoned so as to make statistical analysis representative. The calculation result was shown by Table 2.

Table 2 b value statistics

Period of time.	Calculated number of flows	b×10^{-5}(maximum)	b×10^{-5}(minimum)	b×10^{-5}(average)
1960~1984	419	13.50	-15.26	0.64
1985~1991	158	91.09	-68.00	-1.98
1992~2002	252	58.44	-133.85	-6.99

According to average value b in Table 2, it was possible to calculate annual riverbed sedimentation or souring thickness, the result is shown by Table 3.

Table 3 indicated average annual sedimentation thickness of Xiaolangdi Hydrometric Station of Yellow River.

Period of time.	$b\times10^{-5}$(average)	Average annual sedimentation thickness (cm)
1960~1984	0.64	0.23
1985~1991	-1.98	-0.72
1992~2002	-6.99	-2.55

Table 3 indicated, Yellow River Xiaolangdi Station ,from 1960 to 1984, had an average annual sedimentation of 0.23cm, riverbed was in a slow sedimentation or sedimentation balanced state; from 1985 to 1991, had an average annual souring of 0.72cm, riverbed was in a sedimentation balanced or slow souring state; from 1985 to 1991, had an average annual souring of 2.55cm, indicating riverbed was in an evident souring state.

Xiaolangdi Project carried current in October 1997, stored water as the sluice gate started to close. In October 1999, riverbed being in souring trend should be directly related with Xiaolangdi Project. Analysis indicated the following reasons: 1. Xiaolangdi reservoir water storage impounded some mud and sand, decreasing drained water sand content, decreasing sedimentation degree and simultaneously increasing water flow riverbed souring capacity; 2. first water and sedimentation regulation in the Yellow River.

6. Conclusion

Since statistics gained period average speed, it is necessary to observe whether Riverbed of Xiaolangdi Hydrometric Station of Yellow River is in a new sedimentation balanced state before judgment, either in a new balanced state, or in a continuous souring state.

This paper adopted statistics for research, hence certain uncertainty. And the research result would be possibly different from facts or that of other researches.

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黄河小浪底水文站河床冲淤趋势统计分析

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摘要：以黄河小浪底水文站 1960～2002 年间的水位和流量系列资料，采用统计分析的方法研究了该站河床泥沙淤积的宏观趋势。结果显示，1960 年到 1992 年间，黄河小浪底水文站河床基本上处于冲淤平衡态势，1992 年到 2002 年间，小浪底水文站河床处于明显冲涮态势。分析其原因，主要是由于小浪底水库蓄水和黄河第一次调水调沙的影响。

关键词：小浪底水文站　泥沙淤积　统计分析

黄河下游的洪水问题一直是关系到国家经济发展与社会稳定的重大问题，新中国成立后，下游防洪一直是黄河治理的主要战略目标。由于黄河流域特殊的自然地理环境，即以半干旱为主体的气候条件和以黄土为主体的地表组成物质，再加上强烈的人类活动破坏了大部分天然植被，使得黄河下游泥沙量和含沙量均位居世界首位，下游河道处于持续抬升的状态，同流量下的水位持续上升。这使得黄河下游防洪的困难程度大大增加，出现了堤防加高～河床淤高～洪水位抬升的被动局面，对防洪极为不利。这使人们认识到，解决泥沙问题是黄河下游防洪的关键所在。

为了摆脱上述被动局面，从根本上缓解下游防洪的压力，从 20 世纪 50 年代开始，国家在黄河上中游流域中采取了两项主要的措施来减少入黄泥沙：一是修建水库，二是开展大规模的水土保持，大大减少了入黄泥沙量。与此同时，随着黄河流域工农业生产的发展，人类用水的需求也急剧增大，使进入黄河下游河道的径流量显著减少，黄河下游河道的输沙能力也相应减小。前一方面的变化可能使下游河道淤积量减少；后一方面的变化则可能使下游河道的淤积量增大[1]。

本文将以黄河小浪底站的实测水文资料为基础，对上述两方面因素影响下的黄河下游河道淤积量的宏观变化趋势进行分析。

1 基本资料

研究中使用的基本资料是小浪底水文站 1960 年至 2002 年间在 17085 个时刻实测的水位和流量数据。

黄河小浪底水文站 1960～2002 年间有过两次迁站。第一次迁站为 1984～1985 年间。1992 年 7 月因兴建小浪底水利枢纽而进行了第二次迁站，由现在的小浪底大坝位置迁到了下游 4km 处，即目前的小浪底水文站位置。

1960～2002 年间小浪底水文站的水位与流量关系点绘如图 1。

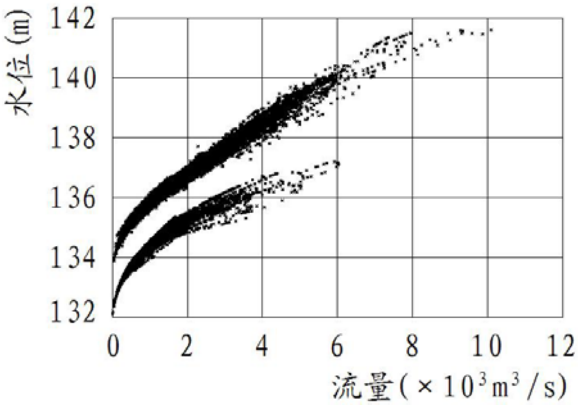

图 1：黄河小浪底 1960 年至 2002 年间水位与流量关系

2 河床冲淤的判断标准

由于黄河天然河床断面复杂多变，且存在分流与漫滩等情况，若要准确反应河床某一断面的冲涮或淤积情况是相当困难的。但通常可以这样认为：在某一断面前后两次通过相同流量的情况下，若水位升高，则表明河床在该时段内发生了淤积，升高值越大，淤积越严重；若水位降低，则表明河床在该时段内发生了冲涮，降低值越大，冲涮越严重；若水位无明显变化，则表明河床在该时段内基本上处于冲淤平衡。

3 河床冲淤趋势的统计分析方法

根据河床断面冲淤判断标准，可以选取某一断面在不同时间通过相同流量下水位的变化情况来分析该断面的冲淤变化。

黄河小浪站在 1960～1984 年间，流量为 1050m^3/s共先后出现 29 次，水位随时间的变化关系如图 2 中的折线所示。图中横坐标为出现该流量时离开 1960 年 1 月 1 日的天数，纵坐标为该流量下对应的水位。

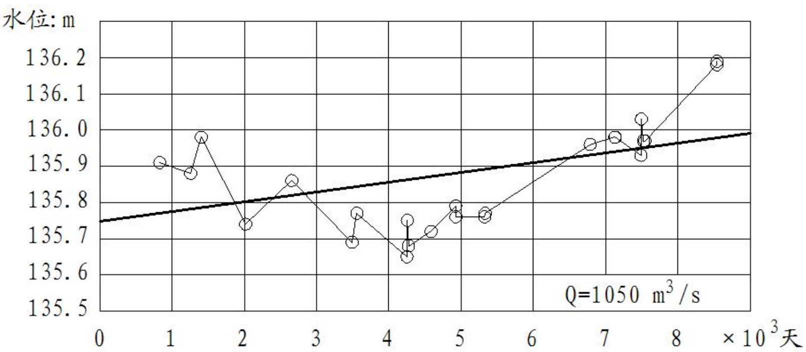

图 2：流量为 1050m^3/s时的水位随时间变化关系

从图 2 中可以看出，在同一流量下，水位随时间的不同有升有降，显然不应简单认为河床在该时段内时冲时淤，而应根据这些数据进行统计分析，来观察河床在该时段内的总体冲淤变化趋势。

根据统计学理论，可假定水位与时间一阶相关，即

$$Y=a+bX+\varepsilon \tag{1}$$

式(1)中Y为水位，X为时间，$\varepsilon \sim N(0,\sigma^2)$。式(1)中的$a$、$b$可采用最小二乘法进行估计，$Y$与$X$

相关关系的显著性水平α可用相关系数ρ_{XY}进行检验。若Y与X显著相关且$b>0$，则表明河床有淤积趋势；若Y与X显著相关且$b<0$，则表明河床有冲刷趋势；若Y与X相关关系不显著，则表明河床处于冲淤平衡态势。

根据小浪底水文站流量为1050m^3/s时的29个水位与时间关系数据点，可求得a=135.747、b=2.70009×10^{-5}、ρ_{XY}=0.165846。Y与X的回归直线如图2中直线所示。

根据表1“相关关系显著性检验相关系数临界值表”[2]可知，在显著性水平α=0.05时，Y与X显著相关，又$b>0$，因此在单一流量的情况下，可认为河床在该时段内有明显淤积趋势。

表1：相关关系显著性检验相关系数临界值表（α=0.05）

n-2	18	19	20	21	22	23	24	25	26	27	28
$R_\alpha(n\text{-}2)$	0.444	0.433	0.423	0.413	0.404	0.396	0.388	0.381	0.374	0.367	0.361

上述分析是在某一流量下进行的，而实际上在该时段内，存在着多个不同流量，每个流量有着不同的出现次数，根据两个不同的流量有可能得出不同的结论。

同样以黄河小浪底水文站为例，在1960年到1984年间，流量为3160m^3/s共先后出现21次，水位随时间的变化关系如图3中的折线所示。经计算可得a=137.896、b=-3.02482×10^{-5}、ρ_{XY}=-0.579592，回归直线如图3中直线所示。

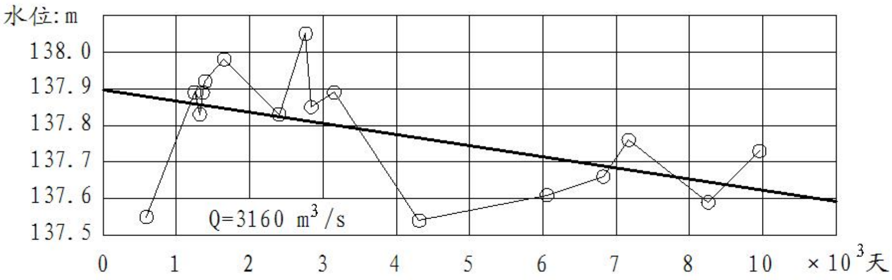

图3：流量为3160m^3/s时的水位随时间变化关系

根据表1“相关关系显著性检验相关系数临界值表”可知，在显著性水平α=0.05时，Y与X显著相关，又$b<0$，因此在单一流量的情况下，可认为河床在该时段内有明显冲刷趋势。

从上面可以看出，根据不同流量对同一断面的冲淤情况进行分析，有可能得出截然相反的结论，这说明不应从单一流量下的水位变化趋势来对河床的冲淤变化做出结论，有必要对多组流量下进行研究，得出合理的结论。

经验回归方程式(1)中b反映的是在某一流量下河床淤积或冲刷的速度。因此可对b求其平均，认为其平均值综合反应了某一时段内河床的冲刷或淤积速度。

4 黄河小浪底河床冲淤趋势统计分析

根据前面介绍的统计分析方法，对小浪底水文站的河床冲淤趋势进行研究。

根据小浪底水文站所处位置的不同，研究相应地划分为1960～1984年、1985～1992年和1992～2002年三个时段。其中1960～1984年间的水位～流量关系点9423个，1985～1992年的水位～流量关系点2982个，1992～2002年的水位～流量关系点4680个。在每个时段内，都有不同的流量，每个流量对应的水位个数有多有少，为使统计分析具有一定的代表性，

因此每一个流量下的数据点不应太少，若某个流量下对应的数据点少于 6 个，则该流量舍弃不用。计算结果如表 2。

表 2：*b* 值统计表

时段	计算的流量个数	$b\times10^{-5}$（最大）	$b\times10^{-5}$（最小）	$b\times10^{-5}$（平均）
1960~1984	419	13.50	-15.26	0.64
1985~1991	158	91.09	-68.00	-1.98
1992~2002	252	58.44	-133.85	-6.99

根据表 2 中的平均值 *b* 可以推算出每年河床的淤积或冲涮厚度，结果如表 3。

表 3：黄河小浪底水文站平均每年冲淤厚度

时段	$b\times10^{-5}$（平均）	平均每年冲淤厚度（cm）
1960~1984	0.64	0.23
1985~1991	-1.98	-0.72
1992~2002	-6.99	-2.55

从表 3 可以看出，黄河小浪底站在 1960 年到 1984 年间，平均每年淤积 0.23cm，河床处于缓慢淤积或冲淤平衡状态；1985 年到 1991 年间，平均每年冲涮 0.72cm，河床处于冲淤平衡或缓慢冲涮状态；1985 年到 1991 年间，平均每年冲涮 2.55cm，说明河床处于明显冲涮状态。

小浪底工程于 1997 年 10 月载流，1999 年 10 月下闸蓄水，河床处于冲涮态势应与小浪底工程有直接关系，分析原因如下，一、小浪底水库蓄水同时拦蓄了一部分泥沙，使下泄水流含沙量降低，在淤积程度降低的同时增加了水流对河床的冲涮能力；二、黄河第一次调水调沙的影响。

6．结语

由于用统计方法得到的是时段内的平均速度，黄河小浪底水文站河床是否已经处于新的冲淤平衡状态还需要观察后才能做出判断，可能已经处于新的平衡状态，也可能处于继续冲涮状态。

鉴于本文中采取的研究方法为统计方法，既然是统计方法，就存在一定的不确定性，因此研究的结果存在与实际或其它研究方法所得到的成果有一定差异的可能性。

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Abstract：Based on the water lever and quality data of Xiaolangdi Hydrometric Station of Yellow River from 1960 to 2002, the riverbed sedimentation tendency in Xiaolangdi Hydrometric Station of Yellow River is researched with statistical analysis method. This study indicates that the riverbed of Xiaolangdi Hydrometric Station remained unchanged from 1960 to 1992, and decreased from 1960 to 1992 due to the Water-Storing of Xiaolangdi Reservoir and its first water and sediment regulation in the Yellow River.

Key words：Xiaolangdi Hydrometric Station, sediment; Statistical Analysis

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