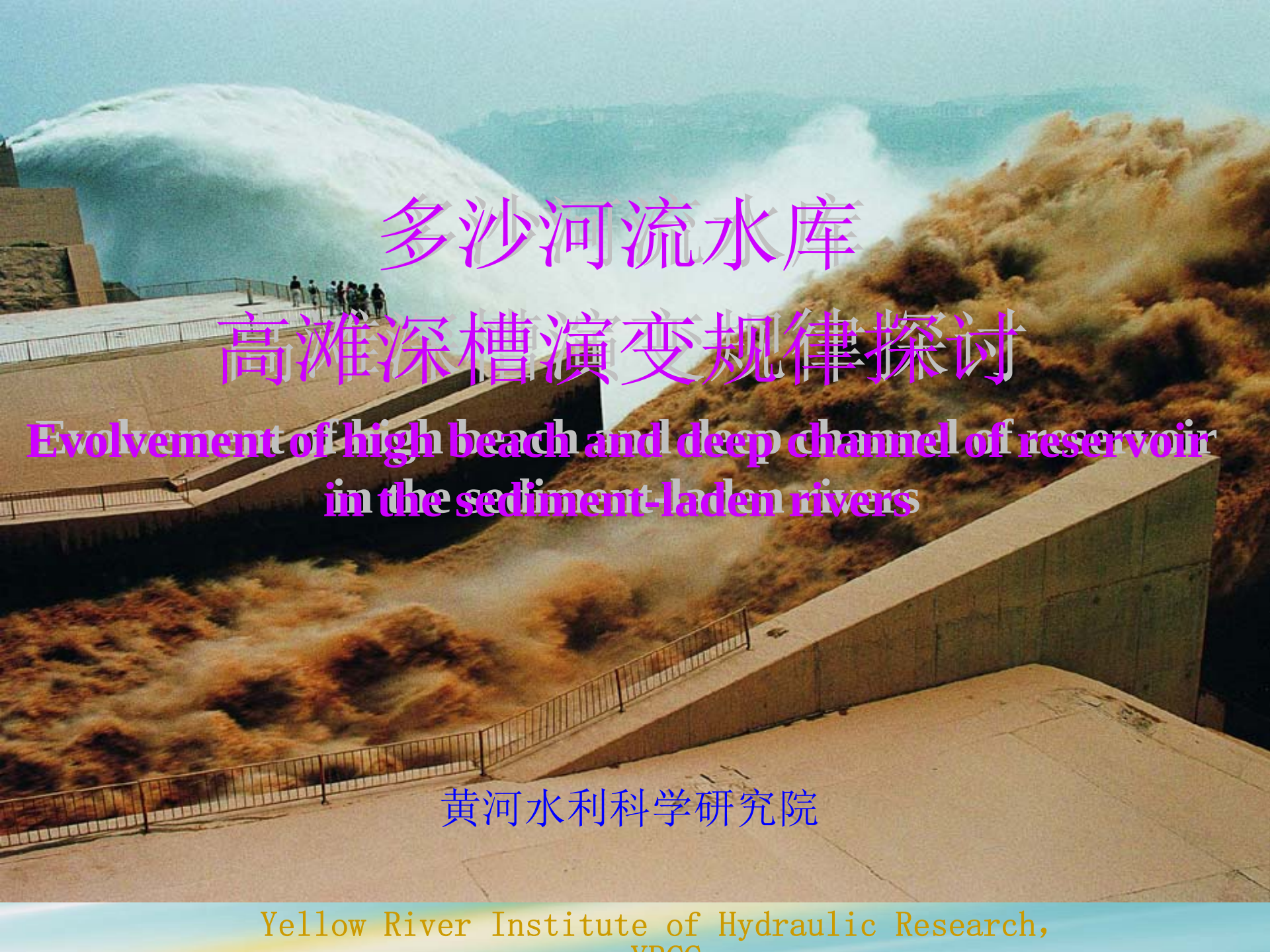
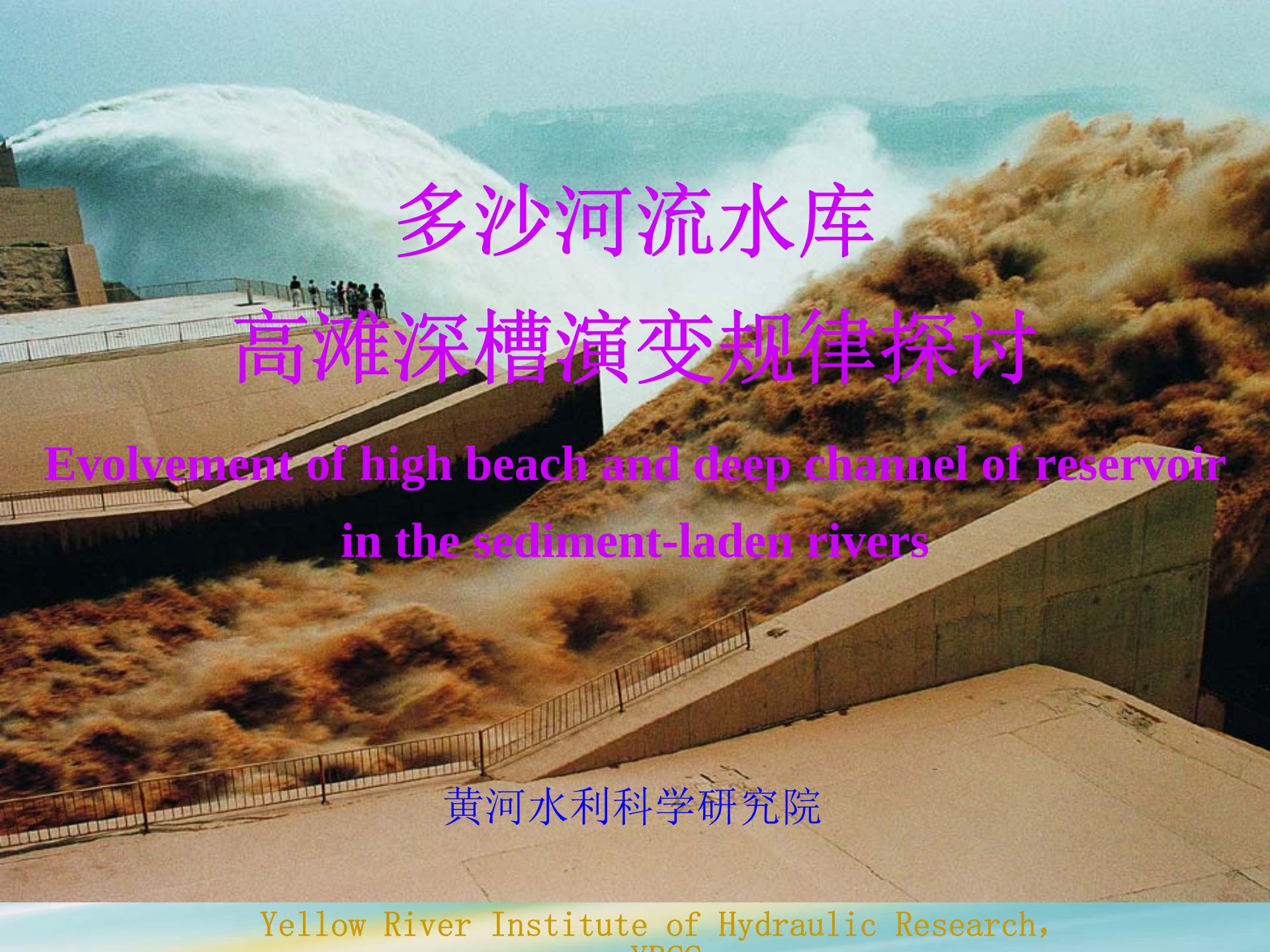


多沙河流水库
高滩深槽演变规律探讨

Evolvement of high beach and deep channel of reservoir in the sediment-laden rivers

黄河水利科学研究院

Yellow River Institute of Hydraulic Research, YRCC



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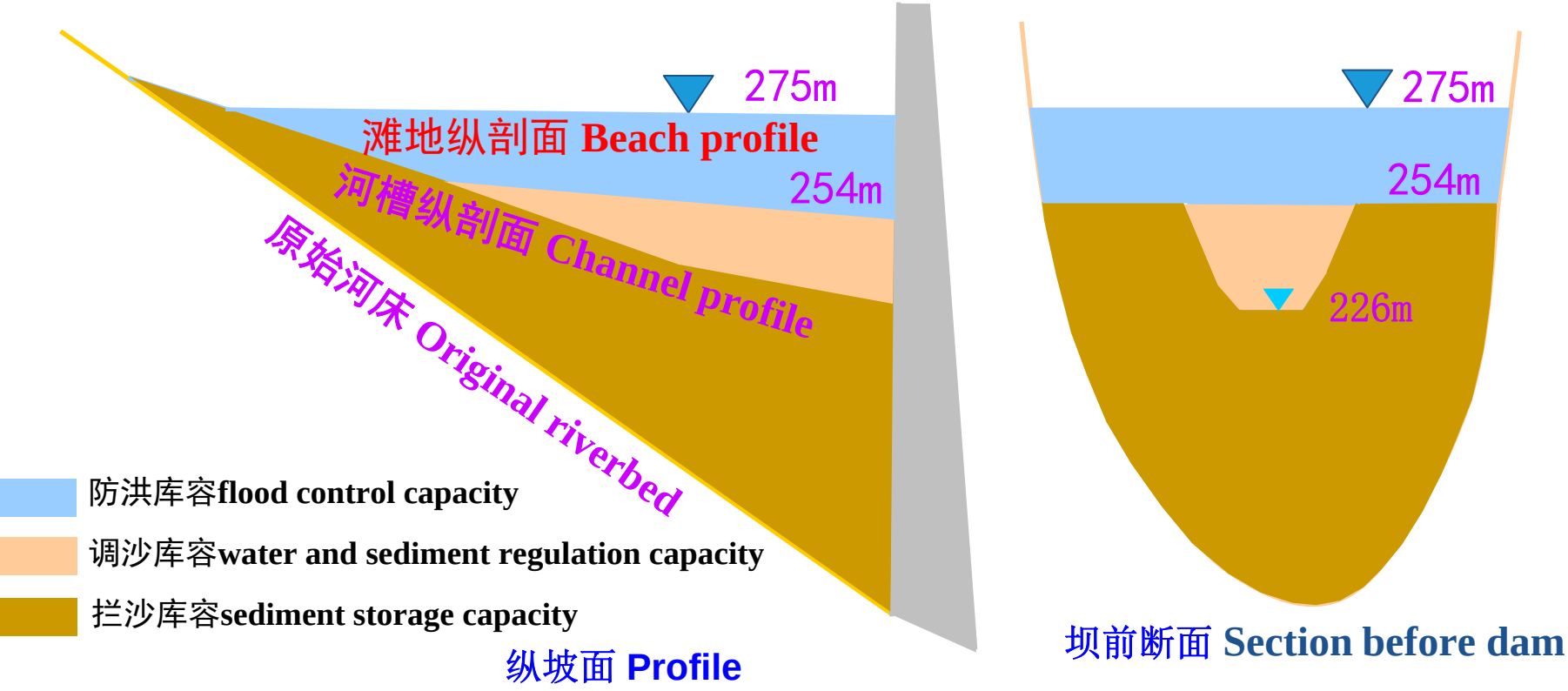
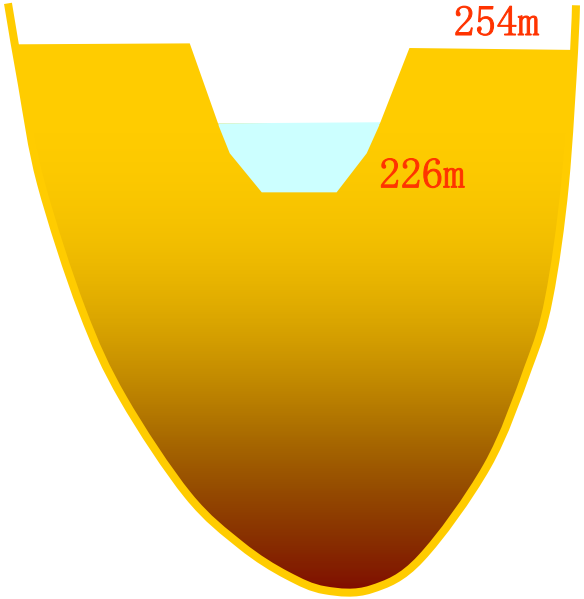
1、概述 Introduction

◆小浪底水库总库容127.5亿m^3，其中防洪库容40.5亿m^3、调水调沙槽库容10亿m^3、拦沙库容约75亿m^3 。 **The initial storage capacity in Xiaolangdi Reservoir (XLD) is 12.75 billion m^3. Among them, the flood control capacity is 4.05 billion m^3, the water and sediment regulation capacity is 1.0 billion m^3, and the sediment storage capacity of is 7.5 billion m^3.**



1、概述 Introduction

◆水库拦沙后期推荐的运用方式为“多年调节泥沙，相机降水冲刷”，即一般水沙条件时拦粗排细，库区淤积面逐步提升，遇较大水流过程降低库水位冲刷，河槽下切。最终形成高滩深槽淤积形态。**The operational mode of multi-year sediment regulation and man-made precipitation washout at right occasion is recommended as reservoir operational mode in later sediment retaining period.**



➢降水冲刷是小浪底水库拦沙后期重要的排沙方式。**Precipitation washout is an important way of sediment ejection of Xiaolangdi reservoir in later sediment retaining period.**

➢三门峡水库高滩深槽演变过程**Evolution of high beach and deep channel in Sanmenxia Reservoir**

➢小浪底水库拦沙后期模拟试验**Simulation test of XLD in later sediment retaining period**

2、三门峡水库高滩深槽演变过程

Evolution of high beach and deep channel in Sanmenxia Reservoir

- 三门峡水库是黄河干流上修建的第一座以防洪为主的综合利用大型水利枢纽。 **Sanmenxia Reservoir (SMX) is the first comprehensive utilization project built in the Yellow River and its development mission was oriented to flood control.**

- 蓄水拦沙运用期（1960年9月~1962年3月） **Period of water storage and sediment retaining (Sep., 1960-Mar., 1962)**

- 滞洪排沙运用期（1962年3月~1973年10月） **Period of flood detention and sediment ejection(Mar., 1962-oct., 1973)**
  - 枢纽工程改建，水库泄流能力加大，潼关以下库区冲刷，恢复槽库容。 **With the reconstruction of project, discharge capacity increasees, reservoir below tongguan scoures and and channel storage recoveries.**

- 蓄清排浑控制运用期（1973年11月~目前） **Period of storing clear and releasing muddy(Since Nov. 1973)**
  - 汛期较大流量排沙与汛前排沙。 **Sediment ejection of large flood in flood season and preflood season**

2、三门峡水库高滩深槽演变过程
Evolution of high beach and deep channel in Sanmenxia Reservoir

❖ 滞洪排沙运用期 Period of flood detention and sediment ejection

潼关断面以下库区发生了6次较为强烈冲刷：

Six times intense scour have occur downstream tongguan section.

1、1964年10月9日至1965年3月18日 **Oct. 9, 1964 – Mar. 18, 1965**

2、1966年10月5日至1967年5月13日 **Oct. 5, 1966 - May 13, 1967**

3、1968年10月8日至1969年10月8日 **Oct. 8, 1968 - Oct. 8, 1969**

4、1970年6月1日至1970年10月12日 **Jun. 1,1970 - Oct. 12, 1970**

5、1972年6月25日至1972年7月31日 **Jun. 25, 1972 - Jul. 31, 1972**

6、1973年7月1日至1973年8月19日 **Jul. 1, 1973- Aug. 19, 1973**

2、三门峡水库高滩深槽演变过程

Evolution of high beach and deep channel in Sanmenxia Reservoir

❖ 滞洪排沙运用期 Period of flood detention and sediment ejection

站名 station	时段 period	洪峰流量 Peak discharge	流量flow>3000m³/s			流量flow>2000m³/s			流量flow>1000m³/s		
			历时 duration (d)	水量 water (10^8 m³)	沙量 sediment (10^8 t)	历时 duration (d)	水量 water (10^8 m³)	沙量 sediment (10^8 t)	历时 duration (d)	水量 water (10^8 m³)	沙量 sediment (10^8 t)
潼关 Tong guan	1	5210	24	79.35	1.17	14	29.25	0.42	25	34.60	0.41
	2	3310	10	27.36	0.56	19	35.66	1.28	68	77.41	0.95
	3	5680	14	47.98	3.18	16	34.05	2.96	115	126.90	5.03
	4	8420	13	44.19	8.19	20	40.20	3.25	53	61.75	3.60
	5	8600	1	4.18	0.71	1	1.80	0.04	27	32.92	1.52
	6	4840	1	2.85	0.32	2	3.93	0.40	15	20.67	1.56
	合计 sum		63	205.91	14.13	72	144.89	8.35	303	354.25	13.07
三门峡 San Men xia	1	4350	25	84.97	1.23	12	25.54	1.51	27	37.30	1.81
	2	3430	12	33.54	1.01	21	43.77	1.46	94	111.68	2.00
	3	5080	16	54.52	2.43	25	54.52	3.66	126	143.96	6.45
	4	4930	9	31.12	4.72	23	48.65	6.44	48	58.54	4.69
	5	5000	2	5.65	0.76	1	1.81	0.50	28	33.76	1.70
	6	3350	0	0	0	4	8.36	1.17	17	21.15	1.69
	合计 sum		24	209.80	10.15	86	182.65	14.74	340	406.39	18.34

2、三门峡水库高滩深槽演变过程
Evolution of high beach and deep channel in Sanmenxia Reservoir

❖ 滞洪排沙运用期 Period of flood detention and sediment ejection

时段 Period	冲淤量 Scour and silting amount （10^8m^3）					
	黄淤 01～12 section	黄淤 12～22 section	黄淤 22～31 section	黄淤 31～36 section	黄淤 36～41 section	合计 01～41 sum
1	-0.3627	-1.2133	-0.9380	-0.7455	0.0182	-3.2413
2	-0.1740	-0.4419	-0.4591	-0.0641	-0.0254	-1.1645
3	-0.3128	-0.7360	-0.5984	-0.0999	0.0902	-1.6569
4	-0.1868	-0.2351	-0.4060	-0.3545	-0.3087	-1.4910
5	-0.2528	-0.1497	-0.0636	-0.1573	0.0001	-0.6235
6	-0.1550	-0.1146	-0.1463	-0.1533	-0.1128	-0.6820

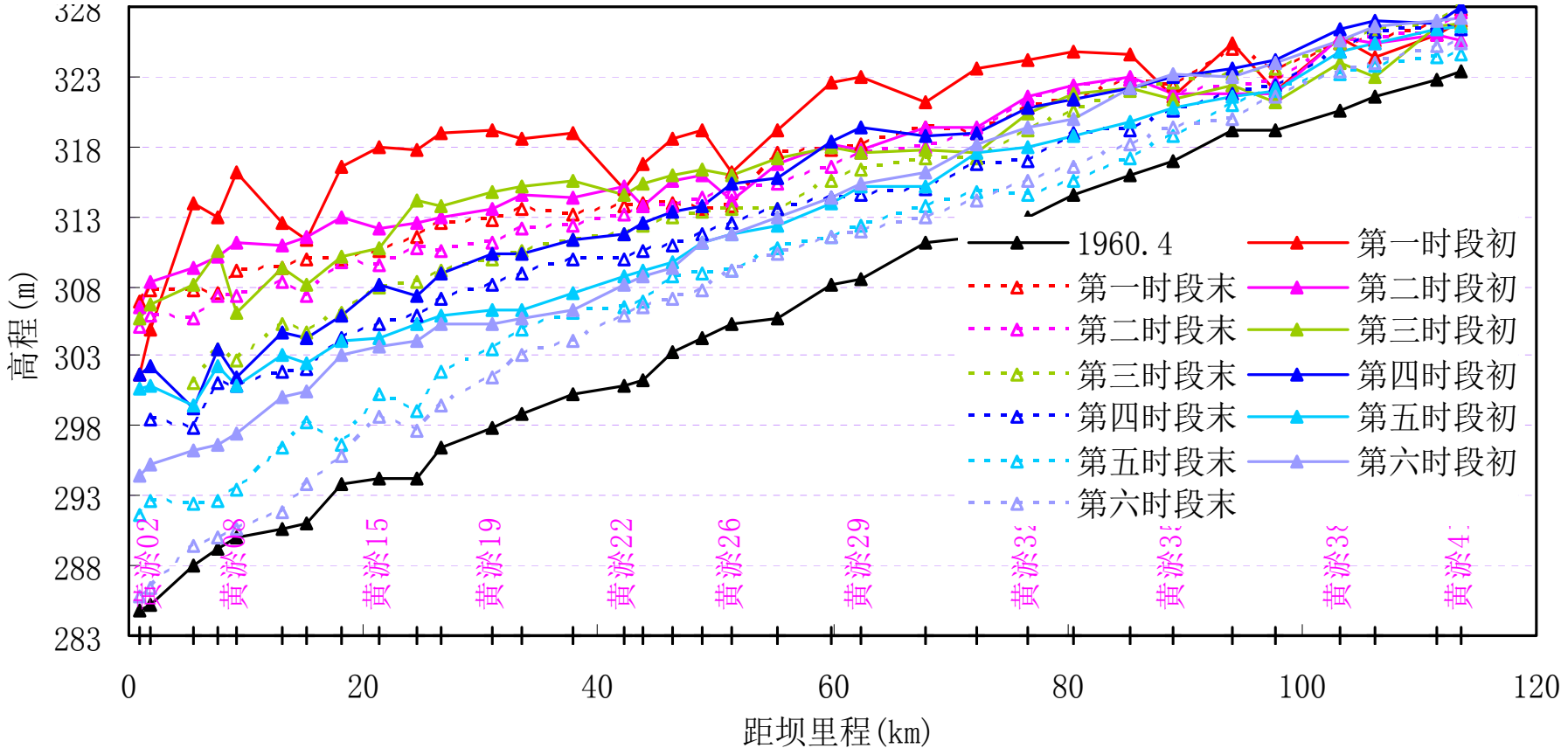
◆ 6个冲刷时段潼关以下冲刷8.86亿m^3，主要集中在黄淤12～36河段，该河段共冲刷7.08亿m^3，占总冲刷量的80%。**The total volume of six scour downstream tongguan is 0.886 billion m^3. Scour is mainly in reaches between Huangyu 12 and 36, and the volume of scour is 0.708 billion m^3 and acounts for 80% of the total.**

2、三门峡水库高滩深槽演变过程

Evolution of high beach and deep channel in Sanmenxia Reservoir

❖ 滞洪排沙运用期 Period of flood detention and sediment ejection

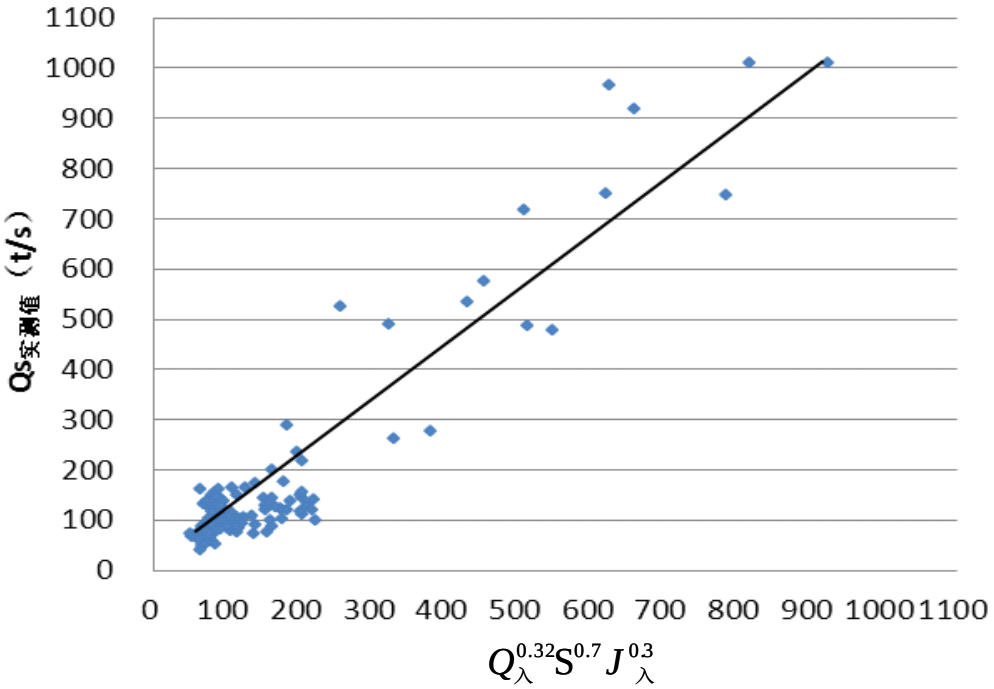
❖ 纵比降变化趋势是逐渐增大。 **The longitudinal gradient increases gradually.**



2、三门峡水库高滩深槽演变过程
Evolution of high beach and deep channel in Sanmenxia Reservoir

❖ 滞洪排沙运用期 Period of flood detention and sediment ejection

对6个冲刷时段实测资料中流量大于1500m³/s的时段进行回归分析，得到经验关系式：**Base on the measured data of six scour, we choose data with discharge more than 1500m³/s to make regressive analysis and obtain empirical relationship which is as follows:**



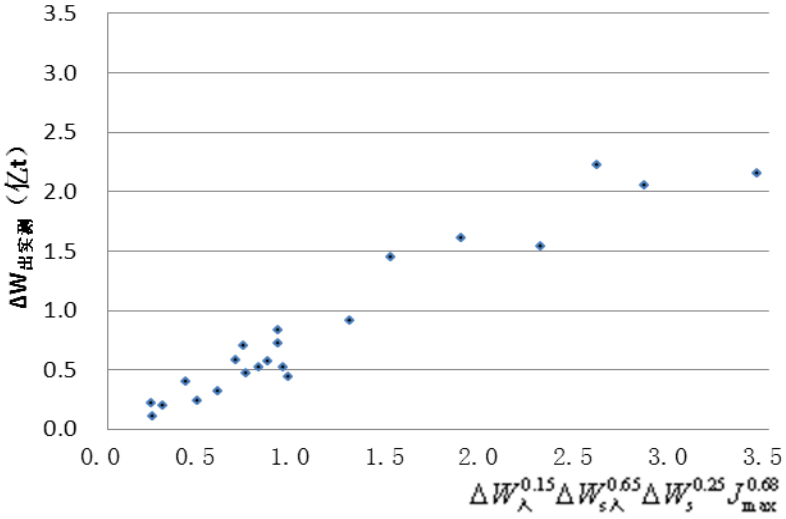
$$Q_{s出}=1.1Q_{入}^{0.32}S_{入}^{0.7}J^{0.3}$$

2、三门峡水库高滩深槽演变过程

Evolution of high beach and deep channel in Sanmenxia Reservoir

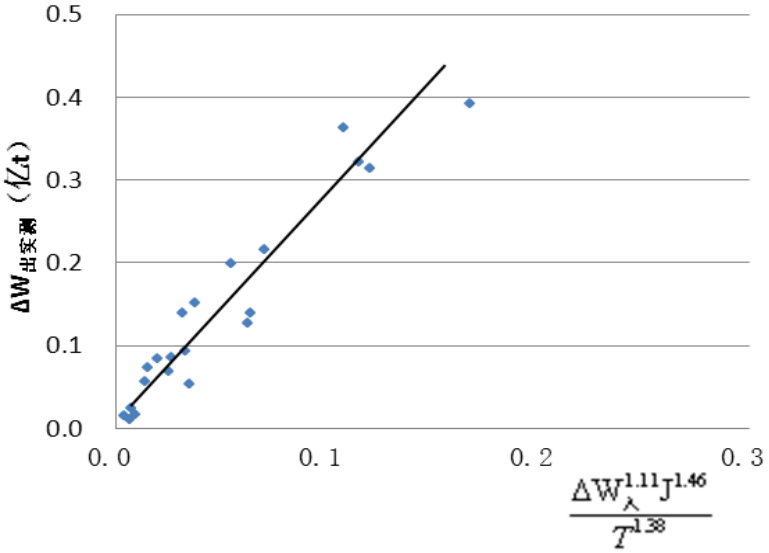
❖ 蓄清排浑运用期 Period of storing clear and releasing muddy

小浪底水库运用之前历年第一次降水冲刷期 **According to data of the first open discharge sediment ejection in each year, We obtain empirical relationship which can be used to calculate sediment ejection process of scour.**



$$\Delta W_{s出}=0.69\Delta W_{入}^{0.15}\Delta W_{s入}^{0.65}\Delta W_{s}^{0.25}J_{max}^{0.68}$$

小浪底水库运用之后水库汛前调水调沙期**By analyzing data during preflood water and sediment regulation period, we obtain empirical relationship which can be used to estimate amount of sediment ejection.**



$$\Delta W_{s出}=2.83\frac{\Delta W_{入}^{1.11}J^{1.46}}{T^{1.38}}$$

3、小浪底水库降水冲刷试验

Test on precipitation washout in Xiaolangdi Reservoir

利用小浪底水库模型专题研究冲刷时机、方式、冲刷流量与持续冲刷历时与冲刷效果之间的关系等。**By means of physical model of XLD, the relationship between scour timing, methods, scour flow and continuous scour duration and scour effect are studied.**

3、小浪底水库降水冲刷试验

Test on precipitation washout in Xiaolangdi Reservoir

模型覆盖了库区100%的干流及各支流大部分库段。垂向涵盖了285m高程至155m高程之间部分。则模型长约420m，高约2.5m。

Xld Model includes 100% of the main stream and the most of tributaries. The elevation range is from 155m to 285m. The length of model 420m and the height is 2.5m.

比尺名称 Scale name	水平比尺 Horizontal scale	垂直比尺 vertical scales	流速比尺 Velocity scale	沉速比尺 Settling velocity scale	含沙量比尺 Sediment concentration scale	干容重比尺 Dry density scale	时间比尺 Time scale
比尺数值 scal value	300	60	6.71	1.34	1.7	1.74	45.8

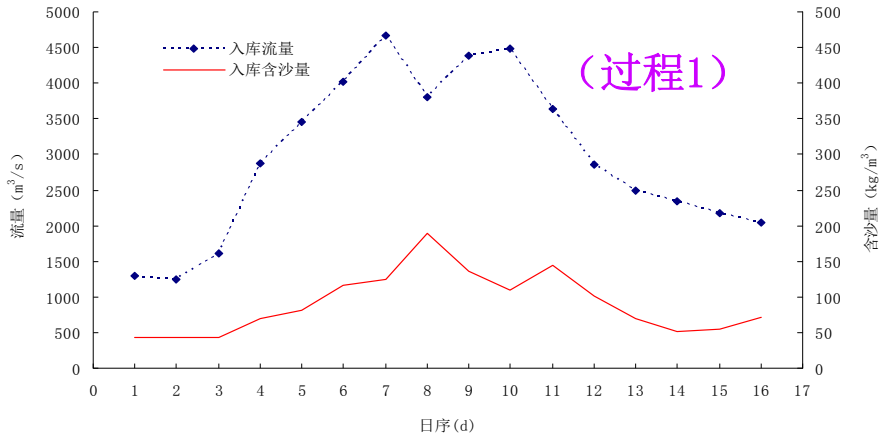
3、小浪底水库降水冲刷试验

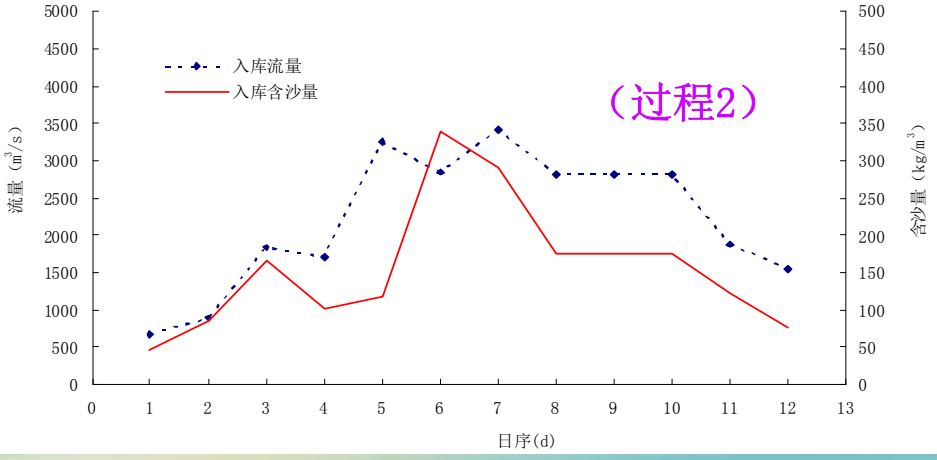
Test on precipitation washout in Xiaolangdi Reservoir

（1）降水冲刷专题试验方案及其特征值 Scheme and eigenvalue of test

淤积量 amount of sediment（10^8m^3）	控制水位 Control water level（m）	历时 duration（d）	组次（方案）scheme	入库流量 Inflow（m^3/s）		入库含沙量 sediment concentration（kg/m^3）	
				平均 average	范围 range	平均 verage	范围 range
32	210	16	1（32/210/16）	2962	1240～4660	103.22	43.0～189
	210	12	2（32/210/12）	2210	677～3410	179.66	75.5～340
42	210	12	3（42/210/12）	2210	677～3410	179.66	75.5～340
	220	12	4（42/220/12）	2210	677～3410	179.66	75.5～340

（2） 降水冲刷试验入库水沙过程 Incoming water and sediment process of test





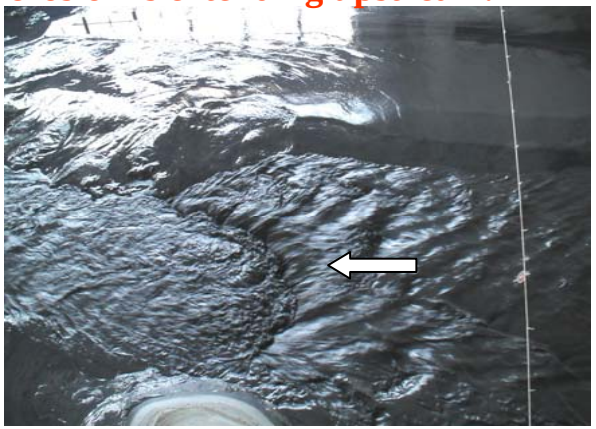
3、小浪底水库降水冲刷试验

Test on precipitation washout in Xiaolangdi Reservoir

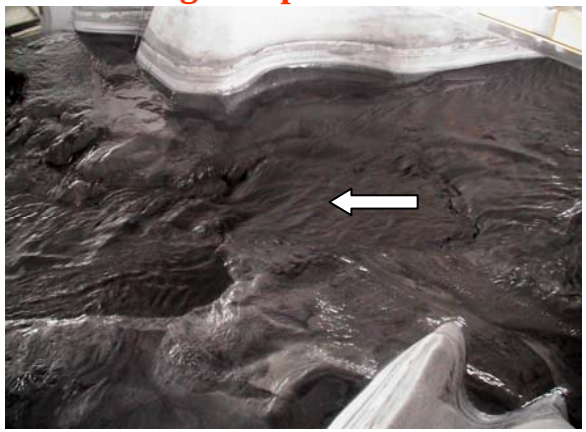
（3） 冲刷过程 Scour process

（a）漏斗区上缘为溯源冲刷起点，主槽先行冲刷 Scour starting point is on the edge of funnel before dam, then channel scour follows.

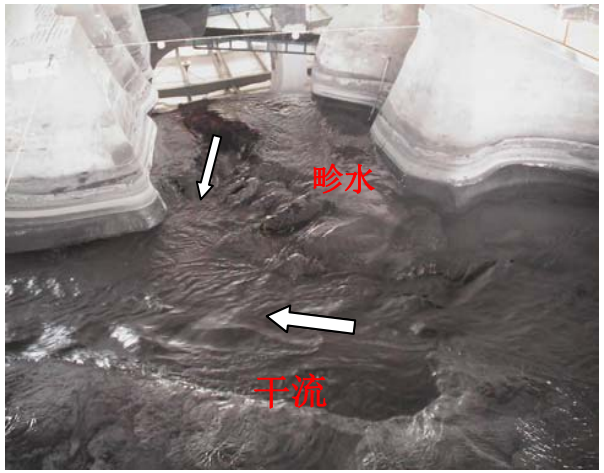
溯源冲刷向上游发 Retrogressive erosion is extending upstream.



溯源冲刷过程中多级跌水 Multistage drop water occurs.



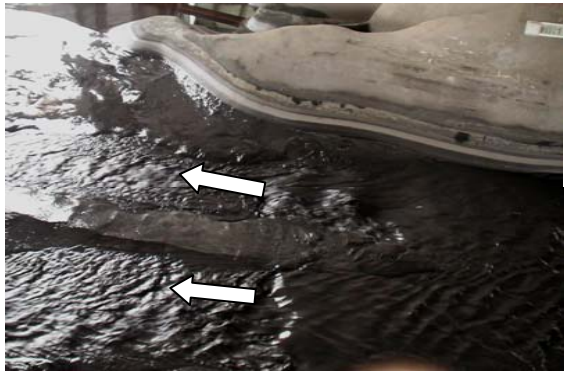
（c）支流沟口与干流冲刷跟随性强 Main stream scour is followed by scour at tributary estuary.



（b）滩地变形滞后于主槽变形，平面形态调整剧烈Beach deformation lags behind channel and plane form adjusts violently.

河槽下切后滩面滑塌After erosion of channel, beach slumps.

局部库段两股河并存 Two rivers occurs in some reaches.

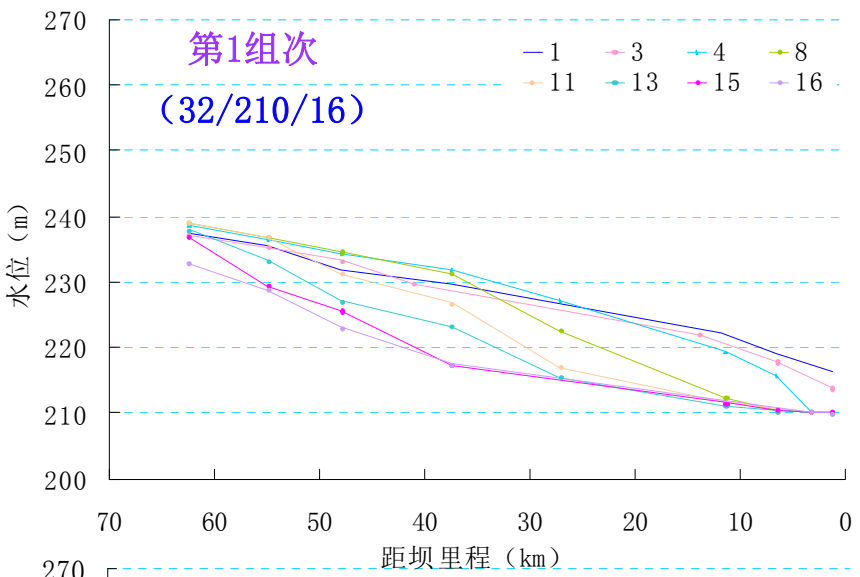


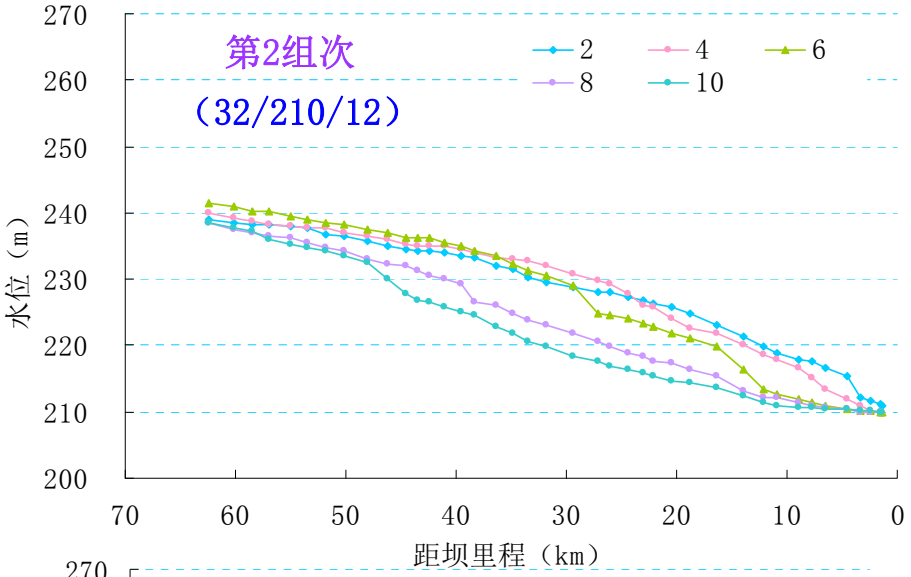
（d）高含沙水流出库 The hyper-concentrated flow discharges from reservoir.

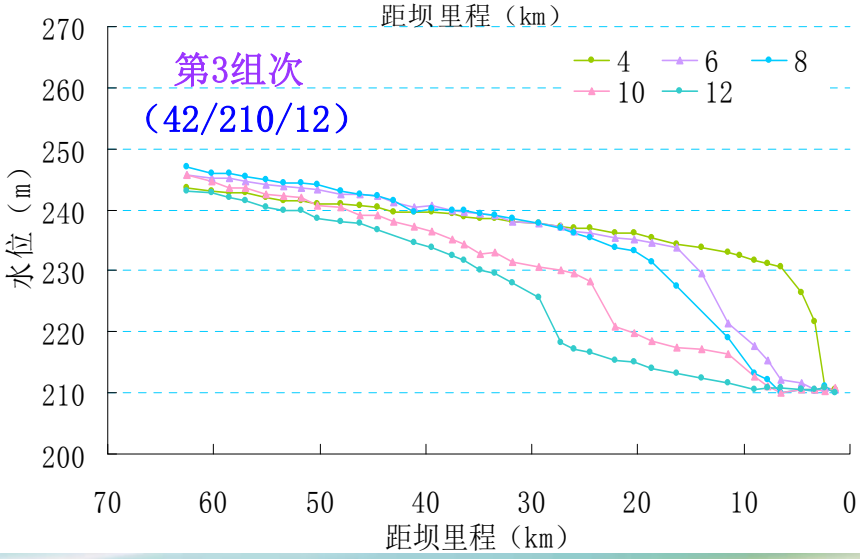
3、小浪底水库降水冲刷试验

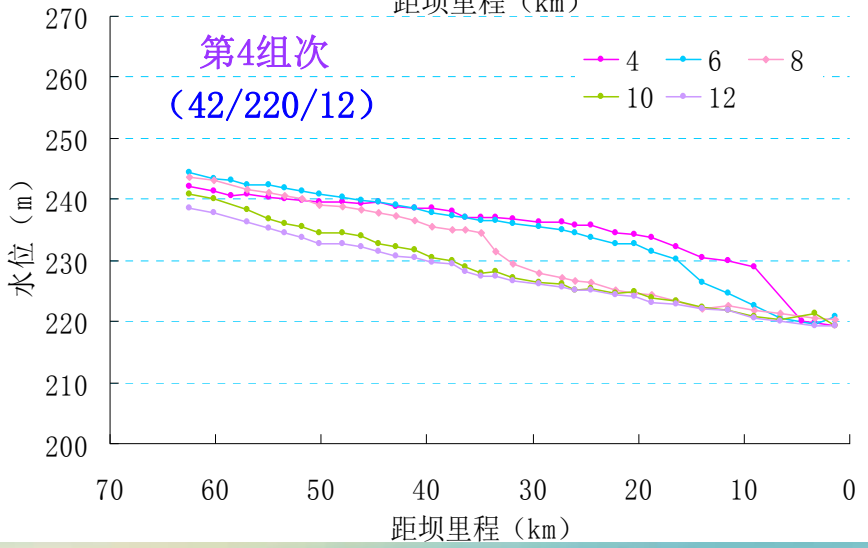
Test on precipitation washout in Xiaolangdi Reservoir

（4） 沿程水位变化过程 Change of water level





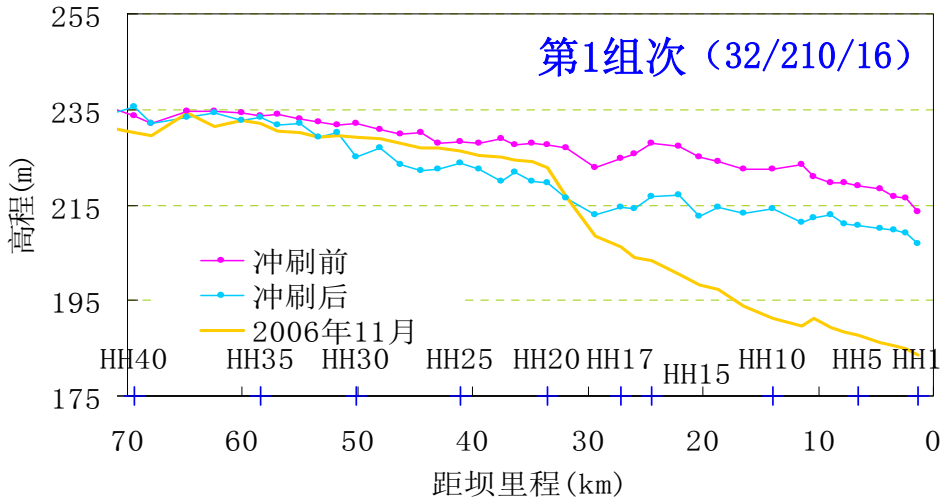


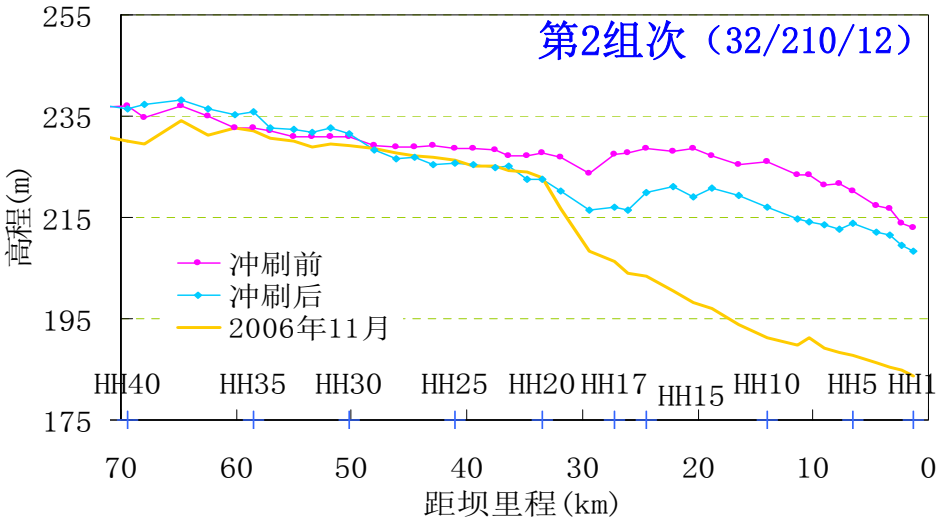


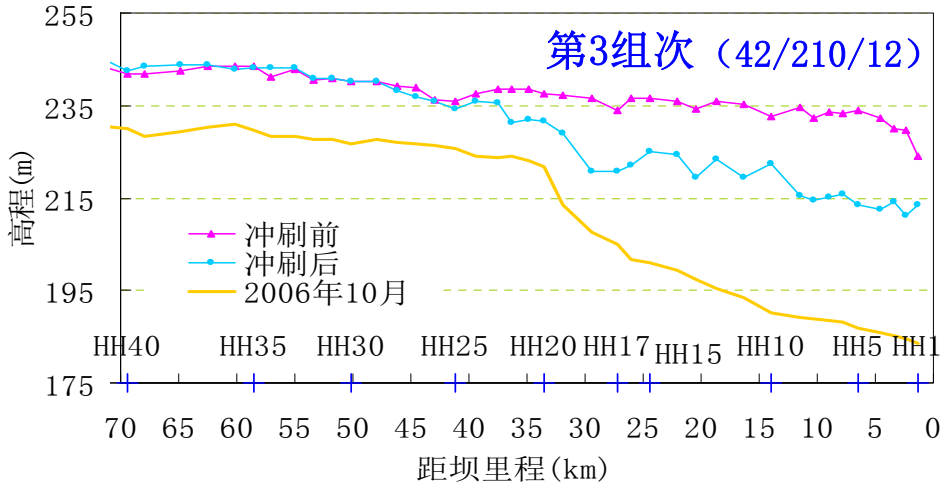
3、小浪底水库降水冲刷试验

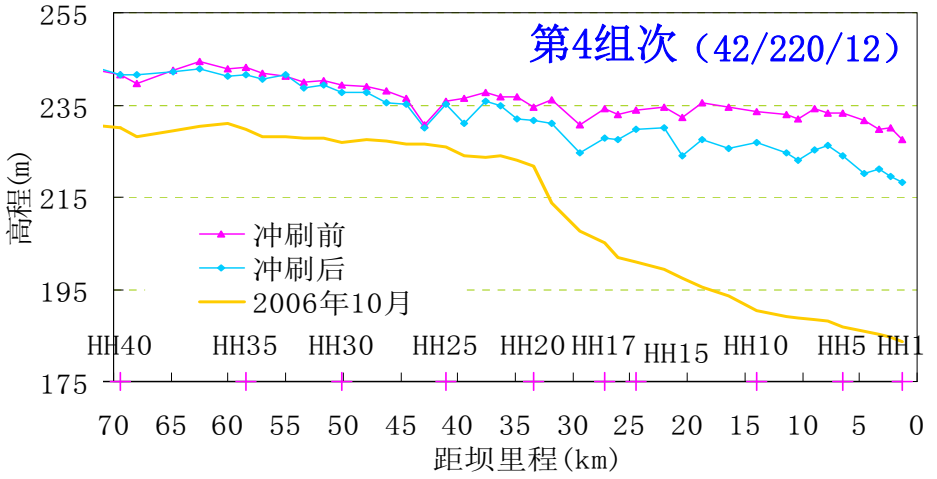
Test on precipitation washout in Xiaolangdi Reservoir

（5） 干流纵剖面变化Longitudinal profile of mainstream





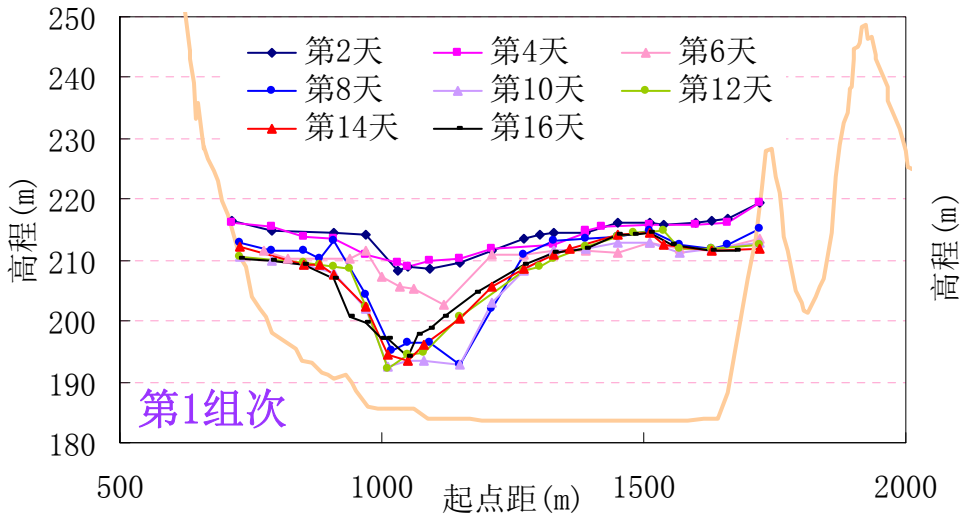


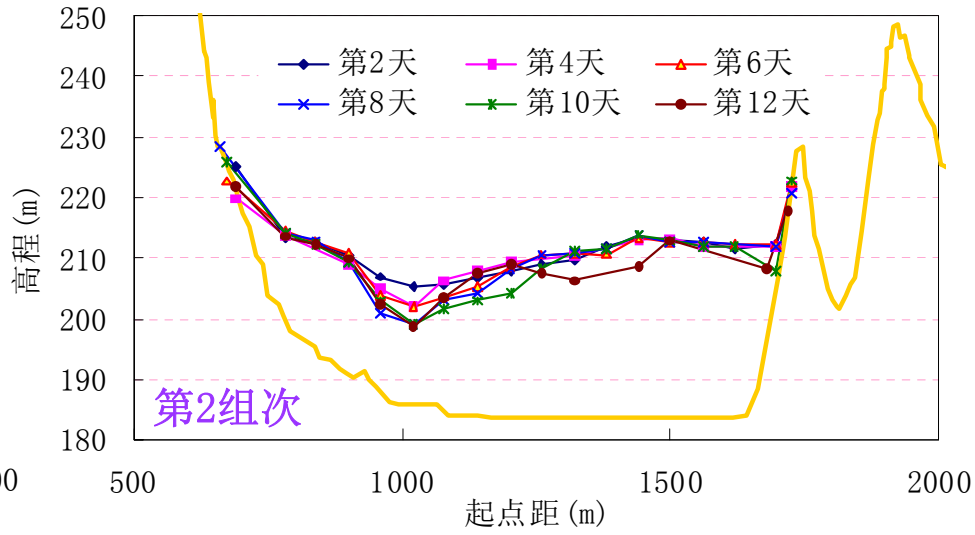


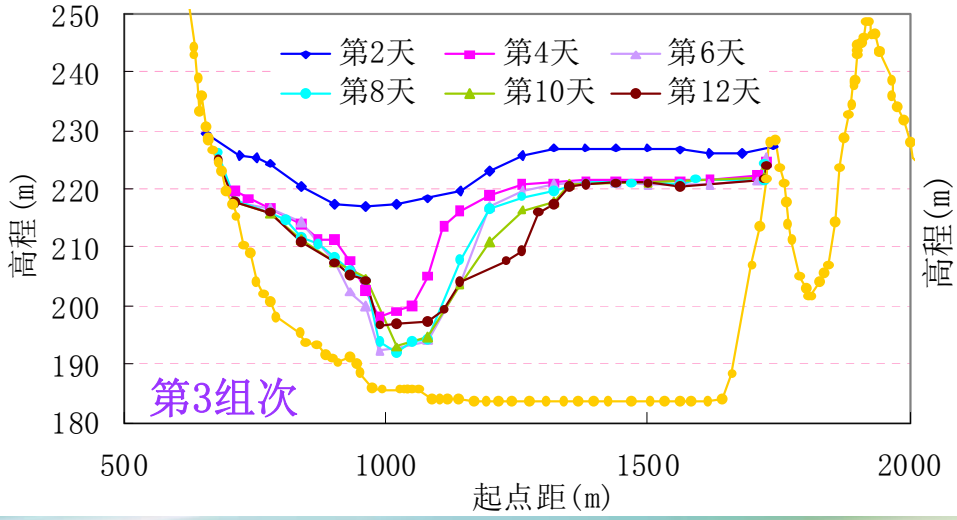
3、小浪底水库降水冲刷试验

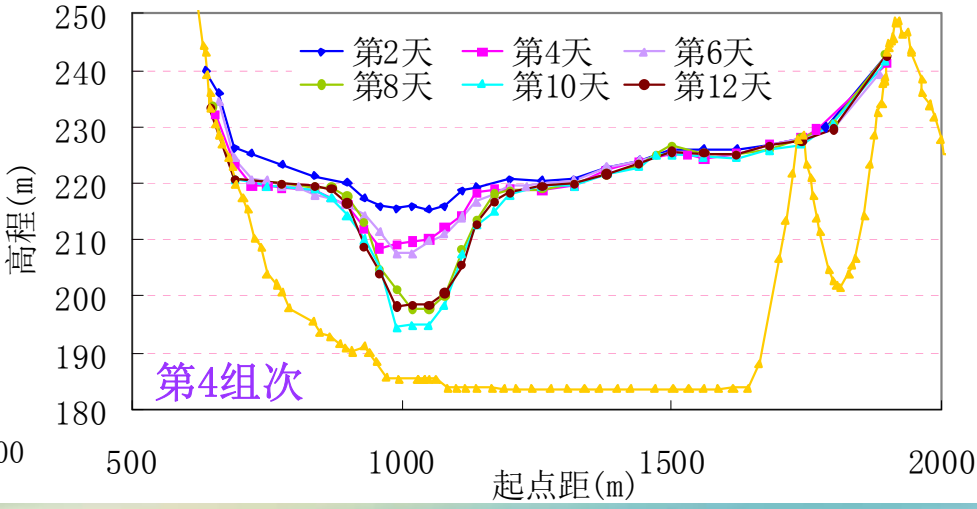
Test on precipitation washout in Xiaolangdi Reservoir

（6）干流横断面变化（HH1） Crosssection of mainstream









3、小浪底水库降水冲刷试验
Test on precipitation washout in Xiaolangdi Reservoir

（7）库区冲淤量 Scour and silting amount

库区沿程冲淤量分布计算成果表（断面法） Distribution of scour and silting amount (section method) 10^8m^3

组次 Scheme	HH10以下库段	HH10～HH18	HH18～HH24	HH24～HH31	HH31～HH38	HH38～HH50	支流	干流	合计
1	-1.37	-1.47	-0.59	-0.50	-0.01	-0.01	-0.16	-3.96	-4.12
2	-0.89	-0.82	-0.46	-0.38	0.32	0.46	-0.09	-2.11	-2.20
3	-2.89	-1.97	-0.39	-0.00	0.11	0.33	-0.35	-4.82	-5.17
4	-1.46	-0.83	-0.21	-0.20	-0.14	0.14	-0.13	-2.70	-2.83

库区冲淤量计算成果表（沙量平衡法） Distribution of scour and silting amount (Sediment balance method)

组次 Scheme	入库reservoir inflow			出库reservoir outflow			排沙比 sediment delivery rate (%)	冲淤量 Scour and silting amount (10^8t)
	水量 water (10^8m^3)	沙量 sediment (10^8t)	平均含沙量 Average sediment concentration (kg/m^3)	水量 water (10^8m^3)	沙量 sediment (10^8t)	平均含沙量 Average sediment concentration (kg/m^3)		
1	40.945	4.226	103.22	48.672	9.157	188.13	216.7	-4.930
2	22.911	4.116	140.28	28.511	6.744	236.52	163.8	-2.628
3	22.911	4.116	179.65	31.962	10.248	320.62	249.0	-6.13
4	22.911	4.116	179.65	29.023	7.433	256.10	180.6	-3.32

3、小浪底水库降水冲刷试验
Test on precipitation washout in Xiaolangdi Reservoir

（8）淤积物特性对冲刷效果影响 Enfluence of deposit characteristic on scour effect

◆由于淤积物的固结作用，在河槽下切之后，在河槽边壁仅有块状淤积物坍塌； **Because of consolidation of deposit, after channel erosions, only some block deposit on channel wall collapses.**

◆冲刷仅局限在河槽内，上溯发展速度较快。 **Erosion is limited in the channel and the velocity of retrogressive erosion is very fast.**

河槽边壁块状坍塌
Some block deposit on channel wall collapses.

河槽下切后滩面滑塌
After erosion of channel, beach slumps.

3、小浪底水库降水冲刷试验
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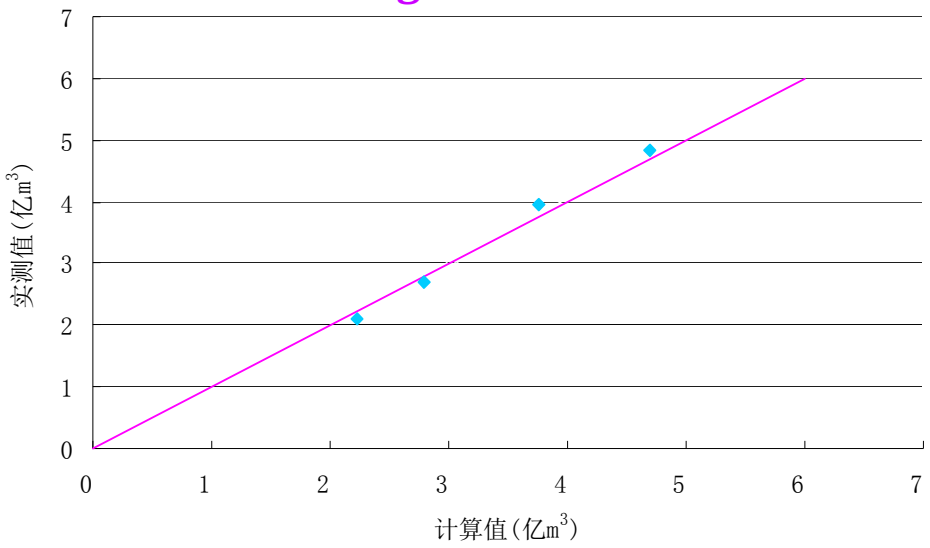
（9）合理性分析Analysis of rationality

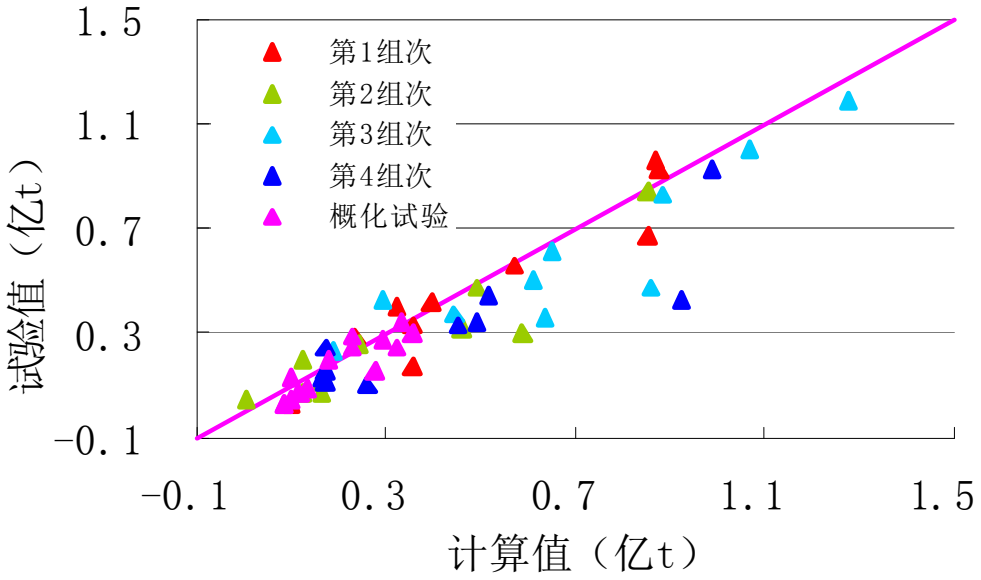
- 韩其为公式
  Qi-wei Han formula

$$W_{0,M} = \frac{QS_0 t_M}{\gamma_s'}$$

- 悬移质输沙率
  Transport rate of suspended load

$$Q_{s0}' = \Psi \frac{Q^{1.6} J^{1.2}}{B^{0.6}} \left(\frac{S_i}{Q_i} \right)^{\alpha}$$





4、结语 Epilogue

◆提出了三门峡水库不同调度条件下降水冲刷计算公式：

The formula of precipitation washout in different operation condition are put forward.

滞洪排沙期：

Period of flood detention and sediment ejection

$$Q_{s出} = 1.1 Q_{入}^{0.32} S_{入}^{0.7} J^{0.3}$$

汛前降水冲刷期：

Period of preflood precipitation washout

$$\Delta W_{s出} = 0.69 \Delta W_{入}^{0.15} \Delta W_{s入}^{0.65} \Delta W_{s}^{0.25} J_{max}^{0.68}$$

汛前调水调沙期：

Period of preflood water and sediment regulation

$$\Delta W_{s出} = 2.83 \frac{\Delta W_{入}^{1.11} J^{1.46}}{T^{1.38}}$$

◆定量给出了小浪底水库拦沙后期降水冲刷时机、方式、冲刷流量与持续冲刷历时与冲刷效果之间的关系。**The relationship between scour effect and precipitation washout timing, way, scour flow and continuous scour duration of Xiaolangdi Reservoir during later sediment retaining period are put forawrd quantitatively.**

◆应进一步深入研究溯源冲刷相似理论与模拟、淤积物干容重相似模拟等。**It is necessary to make a further study on similarity theory and simulation of retrogressive erosion, simulation dry density of deposit, etc.**


敬请指正
谢谢！
Thanks!