Discussion on Channel Morphology in Sanmenxia Reservoir

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Abstract Since 1974, Sanmenxia reservoir is operated to store the relative clear water in non-flood season and dispose the muddy during floods. The channel adjusts itself toward the direction of equilibrium in flushing period in reservoir. This paper computes the channel-forming discharge based on the concept of geomorphic work, analyzes the relationship between the channel width and channel-forming discharge, presents the change of longitudinal profile, and discusses the index of operation mode of Sanmenxia reservoir and project that should be researched for optimizing it.

Key words: Sanmenxia Reservoir; channel morphology; channel adjustment; channel-forming discharge

1 Channel self-adjustment in Sanmenxia reservoir

The final result of alluvial river self-adjustment is to convey the incoming water and sediment, and each river is constantly adjusting itself toward the direction of equilibrium, or quasi-equilibrium [Qian, 1987]. This is known as regime concept. The status of quasi-equilibrium is corresponding to the condition of water and sediment, and it adjusts to another equilibrium state under a new condition. The river adjusts itself for adapting the variation of natural discharge and sediment load. To realize this feature of alluvial river is helpful for human being to forecast and control the development direction of the river [Xie, 1997], and it is available for management rivers. The relationship of flow and channel geometry to discharge supplied from the drainage basin is designated as river channel morphology [Qian, 1987].

The reservoir of sediment-laden river can be utilized for a long time after the sediment deposition is near equilibrium, with a main channel formed on floodplain deposits, and the capacity of it below floodplain is commonly referred as the capacity used for regulation of water and sediment. The reservoir is operated to store clear water in non-flood season and dispose the muddy during floods. For example, Xiaolangdi reservoir will use the channel storage capacity of 1.05 billion m^3 under the floodplain, of which elevation near the dam is 254m, to regulate water and sediment for long-term.

Sanmenxia reservoir is operated to store the relative clear water in non-flood season and release the muddy during floods after 1973, when a main channel, several hundreds meters in width, was also formed on the floodplain deposits below Tonggguan [Long,2004]. In 1973 through 2006, the average operation level is 316m in non-flood season], and it is 304m in flood season. Sediment is deposited temporarily in the reservoir, by storing a certain amount of water in non-flood season. Sediment load is flushed from reservoir in flood season when the operational level is set much lower. Sediemnt deposits together with the oncoming sediment load are flushed off from reservoir during flood events, and channel is formed subsequently. The channel adjusts itself toward the state of equilibrium. The differences of adjustment of alluvial river and the channel in reservoir is the period of time, when is flood season only for the latter. Therefore, there is channel morphology in Sanmenxia reservoir.

It is available for utilization and management Sanmenxia reservoir to recognize the feature of channel self-adjustment, analyze the channel-forming period and study channel-forming discharge and channel geometry.

2 Channel morphology in Sanmenxia reservoir

2.1 Channel-forming period and discharge

The fluvial processes are sameness and difference between the alluvial river and the channel of reservoirs. The sameness is that both of them will form quasi-equilibrium channel and floodplain through deposition and erosion time after time under the action of a certain water and sediment series [Han, 2003]. The difference is as following:

The rating curve for discharge of alluvial river is normal, with small average annual rate of deposition or erosion and form channel in non-flood and flood seasons, strong action of channel-forming in flood season. The rating curve for discharge of the channel is deviated due to water impounded in reservoir, with large rate of deposition and erosion in non-flood and flood season and form channel in flush time only.

Sediment is deposited in non-flood season and flood detention period in Sanmenxia reservoir, and the result of the two periods is depositing sediment in the channel only, no affect on channel-forming. Consequently the channel-forming period of Sanmenxia reservoir is flushing time in flood season.

Based on the channel-forming period mentioned above, channel-forming discharge is computed according to the concept of Geomorphic Work. The peaks of the curve, discharge versus the product of sediment discharge and discharge frequency, are chosen as channel-forming discharge, and the larger and smaller one is known as the first and second channel-forming discharge respectively. The variation of channel-forming discharge is presented in Fig. 1. The average first and second channel-forming discharge of Sanmenxia reservoir is 2800m^3/s and 1500m^3/s in 1973-2006. The first channel-forming discharges are 3160m^3/s and 2570m^3/s, and the second discharges are 2000m^3/s和 1170m^3/s in the period of 1973-1985 and 1986-2006 respectively.

The channel-forming discharge, by using the method of largest amount of sediment load, is 2540m^3/s from 1973 to 2006, 3210m^3/s in 1973-1985 and 2110m^3/s in 1986-2006.

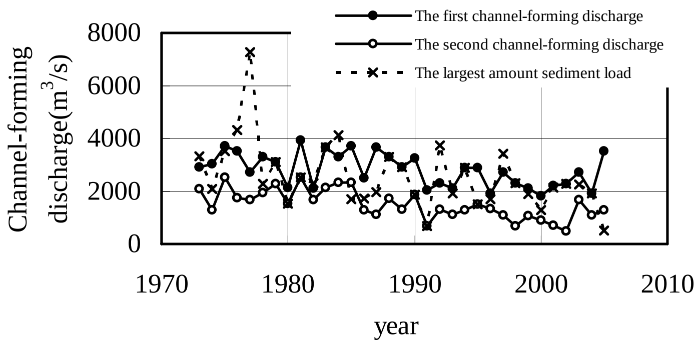

Fig. 1 Variation of channel-forming discharge of Sanmenxia reservoir

2.2 Channel width

The transverse section adjusts with the change of channel-forming discharge. The adjustment of No. Huangyu 22 in Sanmenxia reservoir is shown in Fig. 2. The channel width is 661m in 1973 and it is 364m in 2006. The average channel width is 658m from 1973 to 1985, and it is 457m from 1986 to 2006. The channel area, under

315m elevation, reduced 650 m^2 from 3510 m^2 in 1973-1985 to 2860 m^2 in 1986-2006.

The relationship of channel-forming discharge and width is presented in Fig. 3. From the figure it can be noted that channel width responds the channel-forming discharge.

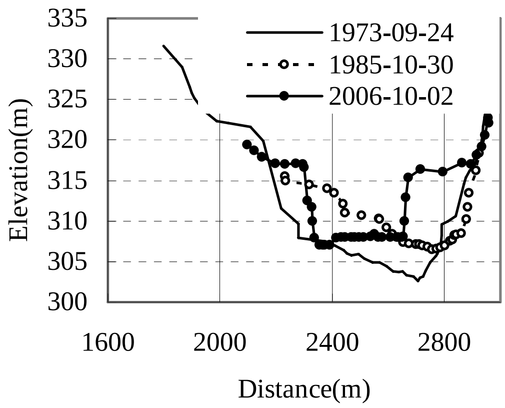

Fig. 2 Cross section of No. Huangyu 22 in Sanmenx reservoir

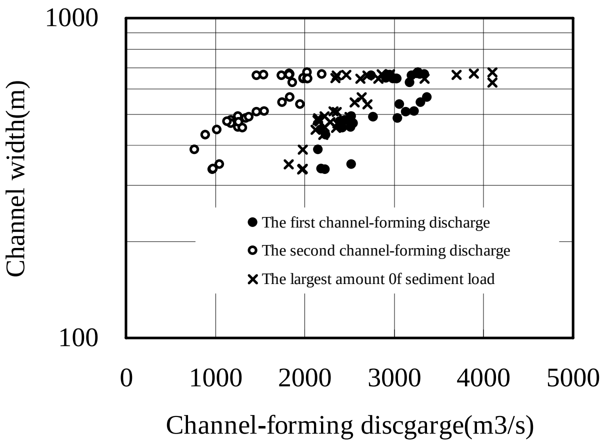

Fig. 3 Relationship of channel-forming discharge and channel width

2.3 Longitudinal profile

The adjustment of Sanmenxia reservoir longitudinal profile tends to equilibrium profile from the direction of erosion. This characteristic is different from the alluvial river, which does from alternative deposition and erosion.

The flood plain, which elevation is lower than the high floodplain formed before 1973, has been shaped consequently following the adjustment of channel. Fig 4 shows the variation of longitudinal profile of Sanmenxia reservoir. The slopes of high floodplain, floodplain, and main channel are 0.00012, 0.00019 and 0.00023 in 2006 respectively. The slope of 17km reach far from the dam is 0.00068.

The channel longitudinal profile changes following the incoming water san sediment conditions, and the profiles in 2002, 2003and 2006 are shown in Fig. 4. The slopes are 0.00022, 0.00024 and 0.00023 at the end of flood season of 2002, 2003 and 2006.

3 Discussions

3.1 Research project

It has been proved in practice the deposition formed in non-flood season can be flushed off the reservoir under the cooperative action of the erosion along the river course and the retrogressive erosion during flood events. The operation mode is appropriate for the feature of coming flow. Operation mode of the Sanmenxia reservoir in flood season to keep the reservoir sedimentation balance is valuable to study under the condition of the operation level controlled below 318m in non-flood season. The problems, as following, are significant and should be study further in the near future.

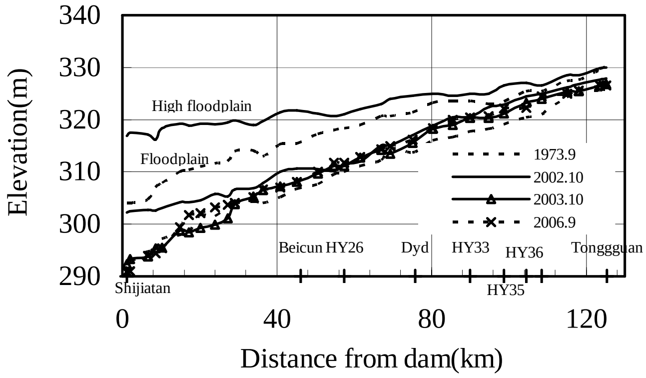

Fig. 4 Longitudinal profile of Sanmexia reservoir

(1) channel-forming period The operation level is confined at 305 in flood season and it is lower during flood events when the outlets are opened. The reach the backwater effects

(2) The channel-forming discharge of alluvial river has been studied for a long time and has been carried on. It is necessary to deal with that how to determine the channel-forming discharge in reservoir.

(3) Equilibrium longitudinal profile and transverse section The problem is not solved that what is the equilibrium longitudinal profile and transverse section and the adequate magnitude of flood and the period of flush.

3.2 Supposition for operation index

The indicator of operation mode in Sanmenxia reservoir can be divided into two kinds. One of it is water level that is used in non-flood season and the period there is no flood events in flood season, and another is discharge that is used during flood events. It is easy to operate reservoir to use these indicators.

The average annual volumes of runoff through Tongguan Station are 23.2 and 11.0 billion m^3 in flood season during the period of 1973-1985 and 1986-2006, and at the same period the average annual sediment load are 0.93 and 0.48 billion t respectively. Incoming water and sediment conditions of reservoir in different period has been changed greatly. The indicators of reservoir operation mode should not uniform for different incoming water and sediment conditions.

(1) Adjustment the operation indicator under the operation mode of 'Storing clear water and releasing the muddy'

Different indicators should be made for different annual runoff amount, such as above 20 billion m^3, 20-10 billion m^3 and less than 10 billion m^3.

(2) Operation level following the inflow discharge

Under this condition that the peak and water volume of flood in spring and July may be higher and more than it in flood season when the runoff amount of incoming is less than 20 billion m^3, the operation of reservoir should be taken to store or release water based on the magnitude of inflow discharge. For example, it is released water when the discharge is more than $1000m^3/s$ and store water when it is less than $1000\ m^3/s$.

3.3 Establishment the early-warning system of reservoir sedimentation

The cumulative deposition in Sanmenxia reservoir should be confined to some extent owing to reducing the storage capacity and influencing the adjustment of longitudinal profile blow Tongguan. In order to control the volume of sedimentation, the early-warning system of reservoir sedimentation should be established to utilize it for a long time. The flush criteria should be made and implemented when the amount of cumulative sediment deposition exceeds a critical value.

4 Conclusions and recommendations

Channel adjusts itself and toward the direction of equilibrium in Sanmenxia reservoir. The channel-forming period is in flushing operation of flood season. In period 1973-2006, the annual first and second channel-forming discharges are $2800m^3/s$and $1500m^3/s$ respectively base on the concept of geomorphic work. Channel width responds with the change of channel-forming discharge.

The channel morphology and adjustment in Sanmenxia reservoir should be carried on further study.

The early-warning system of reservoir sedimentation should be established to control the volume of deposition. The flush criteria should be made and implemented when the amount of cumulative sediment deposition exceeds a critical value.

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三门峡水库河相关系初探

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摘　要　三门峡水库蓄清排浑运用，汛期库区河道自动调整，具有冲积性河流自动调整的平衡倾向性。本文分析了水库造床期，计算了造床流量，分析了河宽与造床流量的关系、水库纵向剖面的变化。讨论了需要开展的有关研究内容，建议了调整运用指标的方向。

关键词　三门峡水库，河相关系，自动调整，造床流量

1　三门峡水库河槽自动调整

冲积河流自动调节的最终结果是力求使来自上游的水量和沙量能通过河段下泄。河流保持一定的相对平衡，这种特点称为冲积河流的“平衡倾向性”[1]。平衡状态与水沙条件相对应，在新的水沙等外部条件下，建立新的平衡。河流的自动调节作用是河流为适应外部条件而采取的一种手段，认识这一调整作用有助于预测与控制河流的发展方向[2]，更好的服务于河流治理开发。冲积河流通过自动调整作用，作为较长时期的平均情况来说，有可能处于相对平衡状态，在断面形态和纵剖面与流域因素(来水来沙及组成)之间应该存在某种定量关系，这种定量关系一般称为河相关系[1]。

多泥沙河流上修建的水库，淤积达到相对平衡，库区形成高滩深槽进入正常运用期，利用槽库容非汛期拦蓄清水，汛期利用洪水把非汛期淤积在槽库容里的泥沙冲刷出库，年内泥沙冲淤到达基本平衡，从而水库可以长期运用。如小浪底水库今后将利用坝前滩面高程 254m 以下 10.5 亿m^3槽库容长期进行调水调沙运用。

三门峡水库在 1973 年汛后形成高滩深槽[3]，并一直采用蓄清排浑运用方式运用，非汛期平均水位在 314～318m之间，多年平均 316m，汛期平均水位 301～306m之间，多年平均 304m。汛期水库水位降低，特别是洪水期敞泄排沙，库区剧烈冲刷，产生造床作用，河床形态自动调整，不但使汛期水量通过库段下泄，并力求把汛期以及非汛期的泥沙排往下游。这种自动调整作用也具有平衡倾向性。与冲积河流平衡倾向性的差异在于，冲击河流全年都处于调整期，而三门峡水库非汛期受蓄水位约束，自动调整受到限制，河槽单向性淤积，汛期排沙期是河槽自动调整作用期。水库运用年内这种周期变化，在长时段内也会形成相对平衡状态，因此，三门峡水库存在河相关系。

认识三门峡库区河槽的自动调整作用，分析库区造床期、造床流量和断面形态，可以更好地服务于三门峡水库长期利用。

2　三门峡水库河相关系分析

2.1　水库的造床期与造床流量

水库造床过程与冲积河道有许多相同之处，也有差别。相同之处是，它们都在一定来水过程与来沙过程及一定边界条件下经过反复冲淤而形成相对平衡河槽及岸边滩地。差别在于冲积性河道形成的相对河槽其水位和流量关系是相应的，全年的冲淤变幅均较小，并且全年

均有造床作用，仅仅是大流量造床作用大而已。而在水库中形成的相对河槽其水位和流量关系是不相应的，坝前水位被控制[4]。

对于三门峡水库，非汛期水库蓄水，泥沙淤积，这个阶段的作用只是淤积一些泥沙在水库中；汛期滞洪期，壅水明显，水库淤积，这一阶段对造床作用也是淤积一些泥沙在水库中；以上两个阶段相当于加大造床期的排沙量，对造床没有另外的作用。因此，对于三门峡水库，汛期降低水位排沙，除滞洪期以外的其它时段是水库的造床期。

根据以上三门峡水库造床期，利用地貌功(geomorphic work)的概念和三门峡水库出库站实测资料计算造床流量。扣除滞洪期计算汛期降低水库时间内各级流量的输沙率和频率的乘积，绘出流量与输沙率和频率乘积的关系图，曲线峰值相应的流量作为造床流量。曲线出现两个峰值，相应最大峰值的流量称为第一造床流量，相应次大峰值的流量称为第二造床流量。同时，根据三门峡水库造床期在水库的排沙期，输沙量最大的流量级对造床的作用也最强，把该流量也可认为是造床流量。图 1 是 1973-2006 年造床流量变化过程线。多年平均三门峡水库第一和第二造床流量分别为 2800m^3/s、1500m^3/s， 1973-1985 年和 1986-2006 年第一造床流量分别为 3160m^3/s和 2570m^3/s,第二造床流量分别为 2000m^3/s和 1170m^3/s。输沙量最大确定的造床流量多年平均为 2540m^3/s，1973-1985 年和 1986-2006 年分别为 3210m^3/s和 2110m^3/s。

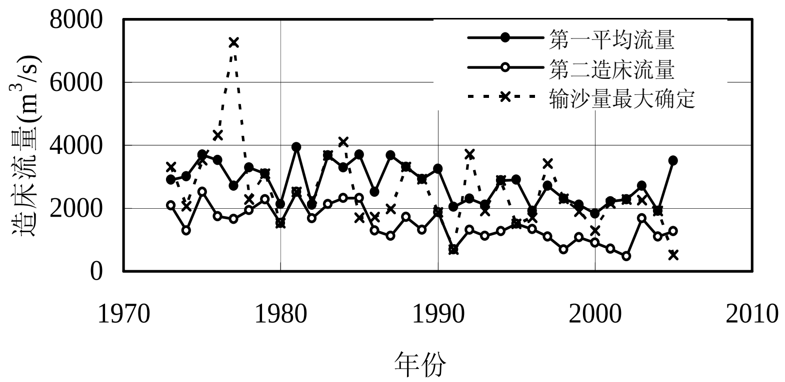

图 1 三门峡水库造床流量

2.2 河宽变化

随着造床流量的变化，河床横断面发生调整(图 2)。图 3 是库区黄淤 22 断面(距大坝河槽间距 50.6km)315m高程下面积与河宽变化。河宽从 70 年代的 600m以上到 2006 年不足 400m；1973 年汛后河宽 661m，2006 年汛后 364m；1973～1985 年平均河宽 658 m，1986～2006 年的 457m，河宽缩窄 200m以上。315m高程以下河槽面积从 1973～1985 年 3510m^{2}减小至 1986～2006 年的 2860m^2，减小 650m^2。

河宽变化是造床流量作用的结果，造床流量对河宽的影响有累积效果，河宽对 5 年滑动平均造床流量的相应关系密切(图 3)。

2.3 纵剖面变化

三门峡水库塑造纵剖面特点，一是中、下段有相当的冲淤变化，造床期大流量时不仅要冲走非造床期的淤积物，而且要冲走造床期小流量的淤积物(主要在水库下段的淤积物)，因

此，水库纵剖面的平衡是由冲刷进入平衡，即所谓的"冲刷平衡"。这与冲积河道由冲淤交替进入平衡是有差别的。

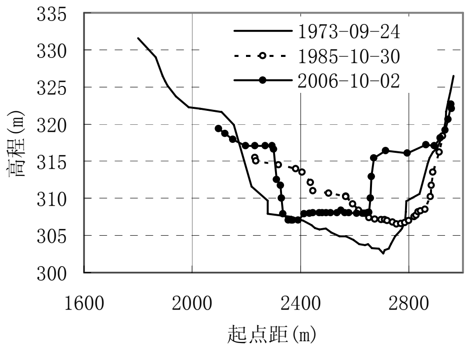

图 2　三门峡水库黄淤 22 断面

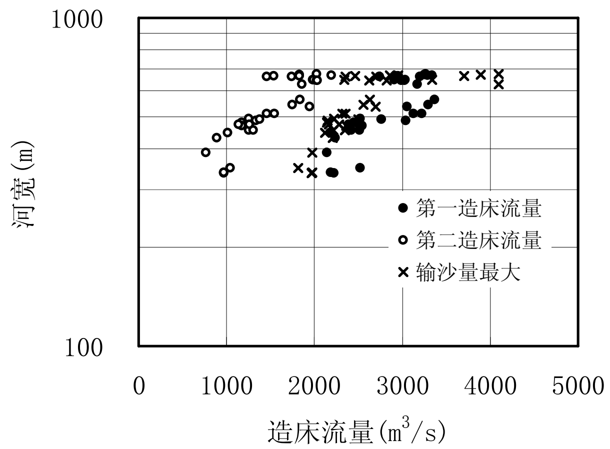

图 3　三门峡水库黄淤 22 断面河宽与造床流量的关系

三门峡水库在 1973 年形成的高滩深槽(坝前段滩槽高差在 20m 左右)的基础上，非汛期泥沙淤积，汛期河床冲刷；非汛期淤积的部位与高度受非汛期蓄水位的影响，汛期造床作用主要取决于来水来沙条件。随造床流量变化，泥沙冲淤，横断面调整缩窄(图 2)，出现比 1973 年以前形成的高滩低的滩唇，称为低滩。图 4 显示三门峡水库 2006 年汛后高滩、低滩和主槽河底纵剖面，三者潼关至坝前平均比降分别为 1.2‱、1.9‱和 2.3‱。主槽河底高程在黄淤 12 断面以下(距坝 17km)比降为 6.8‱，以上为 2.2‱。

随汛期水沙条件的变化，主槽河底高程纵剖面发生变化，2002 年、2003 年和 2006 年汛后平均比降分别位 2.2、2.4 和 2.3‱。近坝段受水库汛期控制水位影响。

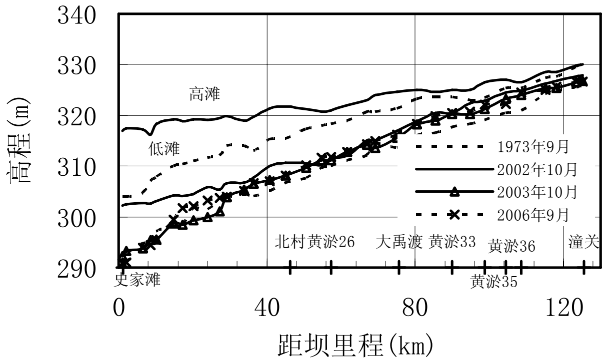

图 4　三门峡水库主槽和滩地纵剖面

3　讨论

3.1 三门峡水库需要进一步研究有关问题

三门峡水库运用的实践表明，水库蓄清排浑运用方式适应黄河的来水来沙特点，在连续枯水条件下，应继续实践和发展，为多泥沙河流的其它水库提供借鉴。围绕三门峡水库运用年内冲淤基本平衡，针对三门峡水库当前控制非汛期最高水位不超过 318m 运用，汛期如何运用才能达到主槽调整接近平衡，或者控制累积性淤积。以下问题值得研究：

(1) 造床期，三门峡水库汛期平水期控制 305m运用，流量大于 1500m^3/s敞泄，305m回水范围内的造床期如何确定，或者说 305m运用多少天内对造床作用以下不明显。(2)造床流量，对于冲积河流的造床流量，已经开展了多年的研究，虽然有几种方法计算和确定，仍有诸多需要深入研究之处；造床流量如何确定、305m回水范围以下与中上段造床流量有何不同。(3) 平衡纵横剖面，控制纵横剖面调整的造床流量，调整顺序；在枯水系列条件下，平衡纵剖面如何？汛期需要多长时间的敞泄、多大流量的敞泄，需要多大的造床流量，纵剖面可以达到获接近平衡？平衡纵剖面的坝前基准面问题。

3.2　水库运用指标设想

三门峡水库运用控制指标一是水位、二是流量，非汛期控制水位 318m、汛期 305m，汛期 1500m^3/s流量以上敞泄。这类指标方便管理，易于操作。

黄河水少沙多、水沙不平衡，年水沙条件差异巨大。1973-1985 年、1986-2006 年两个时段，潼关汛期水量分别为 232 亿m^{3}和 110 亿m^3，沙量为 9.3 亿t、4.8 亿t；平均流量为 2180m^3/s 和 1030m^3/s。针对黄河这种水沙特性，从水库长期利用角度，在对库区河道自动调整认识的基础上，制定灵活的运用指标和操作机制，在不同的来水来沙条件下，不同年份采用不同的运用指标。

(3)　蓄清排浑运用原则下调整

汛期排沙期是库区主槽的造床期，水量的多少对水库冲刷起着重要作用。对于不同量级的年水量和汛期水量，应制定不同的水库运用方案。对应汛期入库水量大于 200 亿m^3、100～200 亿m^{3}和少于 100 亿m^{3}时，分别制定不同的水库运用指标。

(4)　根据入库流量的大小决定水库运用水位

入库水量 200 亿m^{3}以下时，汛期的洪水场次和洪峰都较少，桃汛和 6 月份的洪水成为一年中最大的洪水，水库的运用应根据入库流量的大小，决定是蓄水运用还是低水位排沙运

用。

3.3 建立水库泥沙淤积预警制度

三门峡水库泥沙累积性淤积，既造成库容的减少，影响水库效益的发挥，又影响潼关以下汛期纵剖面的发展。建立水库泥沙淤积预警制度，当潼关以下泥沙累积淤积达到某一临界值时，水库应强制排沙(或敞泄排沙)，以达到控制泥沙淤积的目的。

4 结论与建议

(1) 三门峡水库河槽自动调整并具有平衡倾向性，汛期排沙期是造床期，根据地貌功的概念计算多年平均第一、第二造床流量 2800m^3/s和 1500m^3/s。造床作用具有累积效果，河宽调整相应与造床流量。

(2) 开展三门峡水库河槽调整与河相关系研究，为三门峡水库运用服务。

(3) 在保证水库年内冲淤基本平衡的前提下，三门峡水库今后应制定灵活的运用指标。建立水库泥沙淤积预警制度，制约水库泥沙淤积。

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