水库淤积控制

Reservoir Sedimentation Control

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1 水库淤积控制的意义和内容.

Purpose and Operation Techniques of Reservoir Sedimentation Control

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1.1 控制的意义

Significance of Reservoir Sedimentation Control

水库蓄水后，流速骤减，会使大量泥沙发生淤积。如不加控制，最终会使有效库容损失贻尽。即水库淤死，此时水库效益大幅度降低，防洪效益完全失去；发电、航运、引水等效益也大幅度降低；同时淤积向上大幅度延伸，会带来新的淹没损失；对下游河道也会有一定影响。同时还可能涉及到大坝安全。因此，如何控制水库淤积就非常重要；特别是对于多沙河流的水库。

Impounding of reservoir creates dramatically reducing of flow velocities and thereby serious consequences:

- **losing total capacity (all flood protecting capacity and most of capacities for power-generation, navigation, and water supply) ;**
- **more inundate damage caused by deposition extended upstream**
- **influence on river reach downstream reservoir**
- **safety of dam structure**

therefore reservoir sedimentation is very important, especially for hyper-concentrated river

1.2 控制的根据

Principles of reservoir sedimentation control

水库淤积控制是指利用水库与泥沙淤积规律或机械清淤，控制泥沙淤积数量和部位，使其能长期保留一部分有效库容，和避免、减轻泥沙淤积带来的负面影响。对于大的水库采用机械清淤是无济无事的，只能利用水库淤积规律，选择恰当的水库运用方式进行。

Based on characteristics of hydraulics and deposition in reservoir to control amount and location of deposition in order to preserve certain capacity for long term

Dredging can be adopted in Small reservoir sometimes

1.3 控制的内容

Operation procedures for preserving storage capacity for long term

水库淤积控制包括：库容淤积控制、库尾洪水位抬高控制、变动回水区航道条件控制、坝前泥沙与水流控制、以及下游河道冲刷控制。其中全水库的泥沙淤积控制即库容淤积控制是水库淤积控制的基础和关键。以下主要介绍库容淤积控制，即水库长期使用的运用方式。

Operation procedures including: control of

- **Storage deposition**
- **Water level rising at back water end**
- **Navigation condition in fluctuating back water region**
- **Sediment and flow routine in front of dam**
- **Degradation downstream reservoir**

Control of storage deposition is the key of reservoir sedimentation control

2. 中国在水库库容淤积控制－－水库长期使用研究方面取得的巨大成就

Development and achievements in study on deposition control and preserving capacity for long term in China

2.1　20 世纪 20 年代以前，水库淤积并未得到必要的重视

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2.1 20 世纪 20 年代以前水库淤积并未得到必要的重视

Small attention paid before twenties in last century

大都为单一兴利目标水库，对排沙有较为有利条件，泥沙淤积较轻微。如简单的滞洪水库，蓄水量很小的灌溉水库。前者利用洪峰消退后冲沙；后者可在洪水时空库迎洪）；

水库小，淤积对经济效益影响小。

淤积的问题尚未完全暴露。

- **Single-purpose reservoirs, such as for flood detention or irrigation only**
- **Small deposits**
- **Small storage capacity having small influence on economy**
- **Serious consequences not revealed**

2.2 随着综合利用水库的修建，泥沙淤积逐渐严重

Large scale reservoirs for multi-purpose creating serious deposition

20 世纪 20 年代开始，水库由单一兴利目标转为综合利用，要求常年抬高坝前水位，泥沙淤积逐渐变为严重。据上世纪七十年代统计：

美国在 20 世纪 20 年以后修建水库总库容为 $5000\times10^8 m^3$，每年淤积 $12\times10^8 m^3$，其中 1935 年以前兴建的水库中完全淤废的 10%，损失库容 1/2－3/4 占 10%。

日本水库库容大于 $100\times10^4 m^3$、坝高在 15m 以上的水库 265 座，已平均损失库容 20.6%，且 5 座已淤死。

According to data in seventies of last century

- **U.S.A. total capacity 5000x** $10^8 m^3$

  annual deposits $12x10^8 m^3$

  10% of which involved in abandoned reservoir
  10% of which involved in reservoirs with discarded capacity 1/2—3/4 of storage capacity

- **Japan 265 reservoirs with capacity larger than 100x** $10^4 m^3$ **, dam height larger than 15 m**

  20.6% capacities discarded ,
  5 reservoirs abandoned

2.2 随着综合利用水库的修建，泥沙淤积逐渐严重

Large scale reservoirs for multi-purpose creating serious deposition

前苏联中亚地区灌溉发电中小水库坝高 **6m** 以下，淤满年限一般为 **1-3** 年；**7-30m** 淤满年限一般为 **3-13** 年。

我国水库泥沙淤积也特别严重。例如山西省，至 **1973** 年全省 **43** 座大中型水库总库容 **22.3** × $10^8 m^3$，已淤积 31. 5%。陕西省 100×$10^8 m^3$ 以上水库，总库容 **15**×$10^8 m^3$，已损失 **31.6%**。

- **U.S.S.R in middle Asia**

  life span of irrigation reservoirs

  with dam height less than 6m: 1-3 years

  with dam height 7--30m: 3-13 years

- **China Serious deposition occurs**

  especially in North and West China

  In Shanxi Province 31.5% of total capacity

  22.3x $10^8 m^3$ **discarded**

  In Sanxi Province 31.6 % of total capacity

  15x $10^3 m^3$ **discarded**

2.3 对水库淤积规律的僵硬理解
Incorrect viewpoint of reservoir sedimentation

水库淤积的规律表明：只要水库有多余的库容（除河道容积外），就会使泥沙淤积；反之，要想其排出全部来沙，必须没有多余的库容，只剩下河道的容积。可见排走全部来沙与保留库容是矛盾的，不可能同时实现。从僵硬理解上述规律出发，过去国内外流行一种观点，认为水库淤死是不可避免的，于是提出了水库寿命（水库淤死的年限）的概念。上述国内外水库淤积实例，似乎也证实了这种观点

Reservoir deposits unavoidable and reservoir life span limited

Reason: income sediment passing through reservoir is contrary to surplus capacity left

i.e. either surplus capacity (except channel capacity) creates deposition

or no surplus capacity left (except channel capacity) to pass all income sediment through reservoir

2.4 水库长期使用要求的运用方式的提出
Operation scheme for preserving capacity for long term first proposed in China in sixties

针对水库淤积的严峻局面，我国政府组织了大规模的水库淤积对比研究。我国水利科研和水库管理人员，从上世纪 60 年代初即开始摸索通过改变水库运用方式，减少泥沙淤积。这种水库运用方式，就是在洪水多沙季节，降低水位排沙，汛后含沙量减少后蓄水运用。这种运用方式俗称为“蓄清排浑”。这种运用方式，在恰当条件下，可以使水库淤积平衡后，仍能保持相当一部分库容，做到长期使用

Since last sixties operation scheme has been studied to reduce deposition and sediment routine for preserving long-term capacity has been worked out, which simplified as

“ impounding clear water and discharging muddy water”

i.e. “impounding clear water for beneficial use and discharging muddy water in flood season to restore capacity”

2.5 水库长期使用的运用方式（蓄清排浑）在中国已广泛运用

Operation scheme for preserving long-term capacity applied extensively in China

我国一些水库根据各自特点，不仅通过摸索，在实践中做到了水库长期使用，而且一些水利科技工作者在一般条件下从理论上做了深入研究，论证了水库长期使用的原理，技术上的可行性，经济上的合理性，保留库容大小，运用的条件，以及它的冲淤过程等。改建后的三门峡水库、小浪底水库、三峡水库均是按长期使用水库运用和设计的。

Operation scheme for preserving long-term capacity has been applied successfully to many reservoirs such as Sanmenxia,Xialongdi, Three Gorges

Operation scheme for preserving capacity for long term deeply studied since sixties, including:

- **fundamentals, feasibility and rationality,**
- **preserved capacity,**
- **necessary conditions for preservation,**
- **process of deposition**

2.6 加拿大对“水库长期使用”的高度评价

Appraisal from CYJV(CIPM Yangtze Joint Venture)

加拿大 **CYJV（CIPM　Yangtze Joint Ventune）**在三峡工程可行性研究报告（第五卷）中写到：“指出这一点是很重要的，平衡坡降和水库长期使用的理论在中国已经发展成为一种成熟的技术，三峡工程处理全部泥沙的策略就是建立在这个基础之上。世界上没有一个国家像中国这样，在水库设计中有那样多的经验，以致使调节库容和防洪库容能无限期的保持”

“It is important to point out that the theory of equilibrium slope and of preserving the long term storage of reservoirs, upon which the entire sediment management strategy of Three Gorges Project is based, is developed in China to a fine art. No other nation in the world has as much experience designing reservoirs so their regulating and flood control storage can be preserved indefinitely”

3. 水库长期使用的原理，技术上的可行性，经济上的合理性

Fundamental principles, technical feasibility and economic rationality

1. 水库长期使用的原理
2. 技术的可行性
3. 经济上的合理性

3.1 fundamental principles for preserving capacity for long term

3.2 technical feasibility for preserving capacity for long term

3.3 economic rationality for preserving capacity for long term

3.1 水库长期使用的原理
Fundamental principles for preserving capacity for long term

按照前述，水库淤积与排走全部来沙是对立的，不可能在同一时间达到。这正是水库淤死是不可避免的观点的“根据”。

The viewpoint of reservoir life-time being limited is based on the fact that deposition and passing all sediment through reservoir are contradictory and not able to occur at the same time

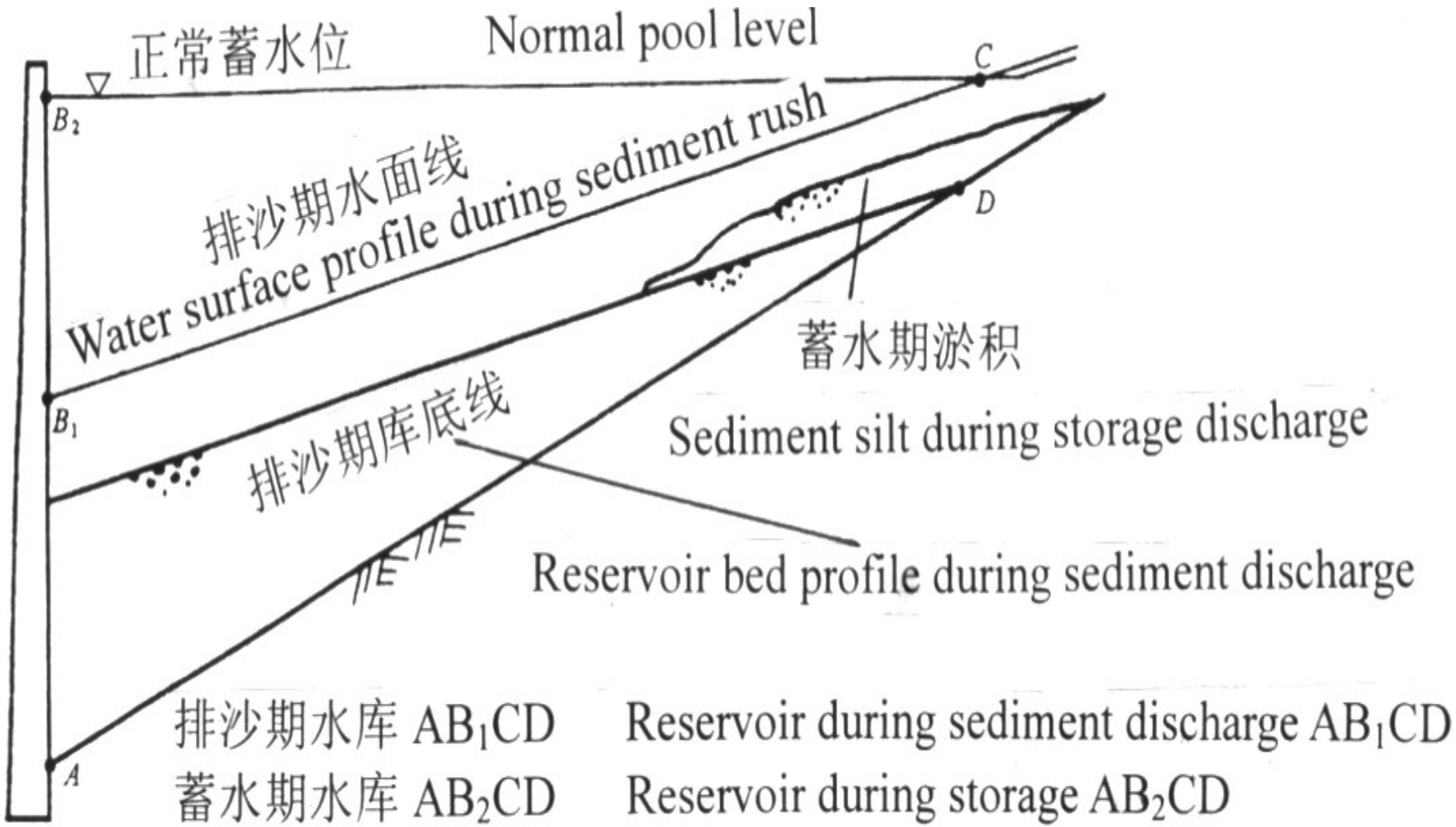
3.1 水库长期使用的原理
Fundamental principles for preserving capacity for long term

但是，如果将全年时间分成两段（或数段）（图 **1**），在来沙多的汛期，将水位降到排沙水位，此时水库已转为一个河道，没有多余的库容，故能排走全部来沙；而在汛后，来沙少的枯季，抬高坝前水位蓄水运用（此时当然会有一些淤积，但是由于来沙少，淤积数量很少，其在下一个排沙期能将其排走）。可见，长期使用的水库，没有违背水库淤积的客观规律，恰恰是利用了这种规律，将排走全年来沙与保留库容统一起来，将水库与河道统一起来

3.1 水库长期使用的原理
Fundamental principles for preserving capacity for long term

The fundamental principles for preserving capacity for long term is that the period of one year is divided into two stages (or several stages) (Fig.1): flood season and after flood season. Reservoir is treated as a river channel and a reservoir in different stages separately and in flood season the drawdown to the sluicing level turns the reservoir to be a river channel without surplus capacity, passing the income sediment with higher concentration all through the reservoir, while in dry season a higher level will be maintained to impound the reservoir for multiple-purpose utilization, and under low concentration only few sediment deposits and is scouring away in the next drawdown period.

Fig.1 Sketch of Reservoir of Long Life Span

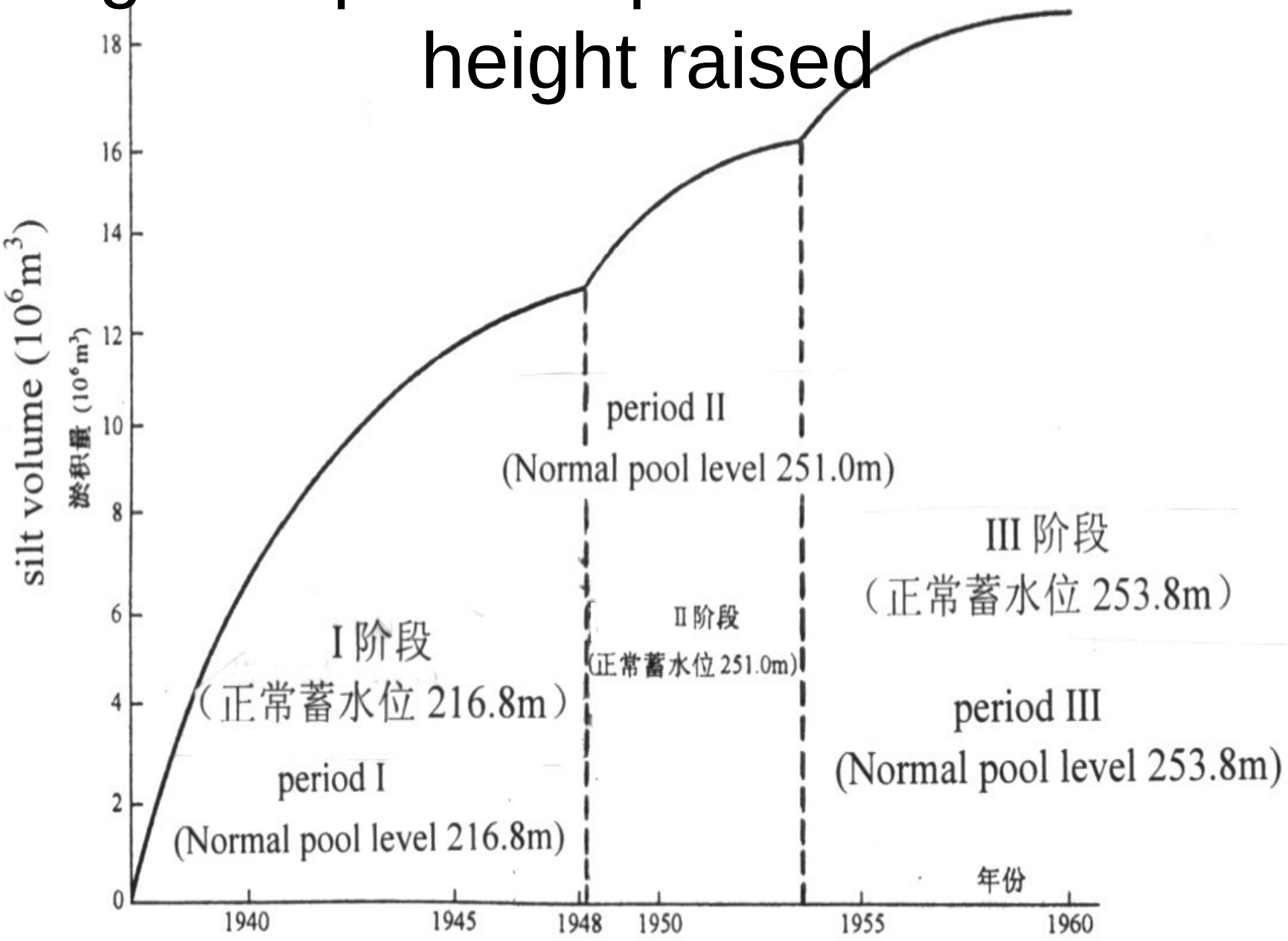


3.1 水库长期使用的原理
Fundamental principles for preserving capacity for long term

以前在对付水库淤积方面，有一种加高大坝的措施，以弥补损失的库容。这种方法只是强调了抬高蓄水位以增加库容，但是忽略了降低水位以排沙，结果加高大坝后，泥沙淤积又会迅速增加（图 2）。如前苏联格尔格比尔斯克（Гергебилыской）电站的水库曾两次抬高运用水位，但淤积进一步加重

To prolong the life span of reservoir a procedure of lifting the dam height to compensate the lost capacity has been adopted for some reservoirs. Without drawdown to pass sediment through the raised level enlarged the capacity but created deposits dramatically. (Fig.2) Gergbilseke Reservoir in U.S.S.R is a case of this kind.

Fig.2 Deposition process after dam height raised



3.1 水库长期使用的原理
Fundamental principles for preserving capacity for long term

相反，如果片面强调降低水位排沙，而在可能条件下，不抬高水位，就会使水库效益不能充分发挥。如闹德海水库以前为自由滞洪，无灌溉效益。1970 年改造后，每年汛后蓄水约 $5000\times10^4m^3$，解决了下游春灌需水。而长期使用水库，正是避免了这两种情况的片面性。

On the other hand while drawdown for passing sediment through the level should be raised to allowable height for more benefits.
Laodehai Reservoir was only for flood detention, after reconstruction in 1970 impounding 5000x$10^4\,m^3$ for irrigation after flood season.

3.2 技术的可行性
Technical feasibility for preserving capacity for long term

水库长期使用在技术上的可行性根本表现在水库能否最终平衡，或者淤积平衡后的坡降是否小于天然河道坡降。（这两者实际是一个问题的两种提法。如果最终能平衡（淤积终止），则其坡降必定小于天然坡降；反之若平衡坡降小于天然坡降，它们必定相交，淤积就会终止）。由于修建水库的山区性河道，其坡降总是明显大于水库淤积平衡的坡降（或者说水库挟沙能力有很大富裕），所以水库淤积能终止

Condition for feasibility: equilibrium slope after deposition smaller than nature river slope.

Since most reservoirs are constructed in mountain area the feasibility always exists

3.2 技术的可行性
Technical feasibility for preserving capacity for long term

据统计我国 32 座水库、日本 32 座水库、美国 27 座水库中，坡降减少 30%－50%的有 27 座，占 29.7%；减少 50%－80%的有 31 座，占 34.1%；坡降减少 80%以上的有 7 座，占 7.7%。

Among 32 reservoirs in China, 32 in Japan, 27 in U.S.

27 reservoirs (29.7% of total) with slope reduced 30%--50%

7 reservoirs (7.7% of total) with slope reduced 50%--80%

3.2 技术的可行性
Technical feasibility for preserving capacity for long term

至于有利于平衡坡降减小的具体因素还有汛期来沙比例大（我国水库一般 **7** 月至 **9** 月三个月来沙 **70.2%－96.0%**），有利于排浑；原河道坡降大（特别是峡谷河道的水库）挟沙能力富裕成份高等

Conditions for more capacity preserved:

- **more amount of income sediment in flood season for discharge muddy water(70.2—96.0% of total sediment carried from July to Sept. in China)**
- **steeper slope of nature river for surplus carrying capacity**

3.3 经济上的合理性
Economic rationality for preserving capacity for long term

在经济上的合理性表现在水库长期使用方式与其兴利目标是否一致，矛盾如何解决。

Procedures for preserving capacity for long term damage the benefits of reservoir in certain degree.
Economic rationality means to adopt measures to realize the compatibility between benefits of long term preservation and reservoir utilization

3.3 经济上的合理性
Economic rationality for preserving capacity for long term

首先，长期使用水库运用方式与防洪运用基本一致，特别是当排沙水位与防洪限制水位相同时，它可以服从防洪调度（汛期降低水位排沙，与水库防洪运用前放空库容是一致的。而在防洪蓄水时，则令其淤积，此后再排沙）。

Sediment routine for long-term preservation is the same for flood prevention, specially when flood prevention level is the same as sluicing level

3.3 经济上的合理性

Economic rationality for preserving capacity for long term

水库长期使用与发电的矛盾表现在水头变幅大，汛期为了排沙，水头较小，而在枯季水头大。但是在恰当选择机型下，通过多装机，利用汛期径流大来弥补。

Sediment routine for long-term preservation makes large variation of water head for power generation, since the head in flood season is small for sluicing. More generators of available type should be adopted to use the run-off discharge in flood season

3.3 经济上的合理性
Economic rationality for preserving capacity for long term

水库长期使用与航运的关系，从全局看也是颇为一致的，无论汛期还是枯季（枯季蓄水能增加关键时期的航深，汛期水位下降可减少变动回水区的淤积），当然由于水库变幅大，使变动回水区范围较长，对局部航道在某些时刻可能有不利影响，但是可以通过其它措施解决

Sediment routine for long-term preservation is the same for navigation.. Impounding in dry season increases navigation depth; Drawdown in flood season reduces deposition in fluctuating backwater region;Fluctuating back water area extending upstream because of large variation of pool level to create more local obstacles of navigation

4. 长期使用水库的保留库容
Preserved capacity for long term

在一定简化下，长期使用水库的最终保留库容为

$$V=\frac{m\Delta H_0^2 L}{3}+\frac{\Delta H_0 B_c L}{2}+B_c hL$$
$$=\frac{m\Delta H_0^3}{3J_c}+\frac{\Delta H_0^2 B_c}{2J_c}+\frac{\Delta H_0 hB_c}{J_c}$$

其中 V 为最终保留库容，ΔH_0 为正常蓄水位 H_n 至防洪限制水位（排沙水位）H_F 的差值，L 为水库长度，B_c 为水库平衡河槽宽度，J_c 为平衡坡降

Expressions of final capacity preserved for long term

$$V=\frac{m\Delta H_0^2 L}{3}+\frac{\Delta H_0 B_c L}{2}+B_c hL=$$
$$\frac{m\Delta H_0^3}{3J_c}+\frac{\Delta H_0^2 B_c}{2J_c}+\frac{\Delta H_0 hB_c}{J_c}$$

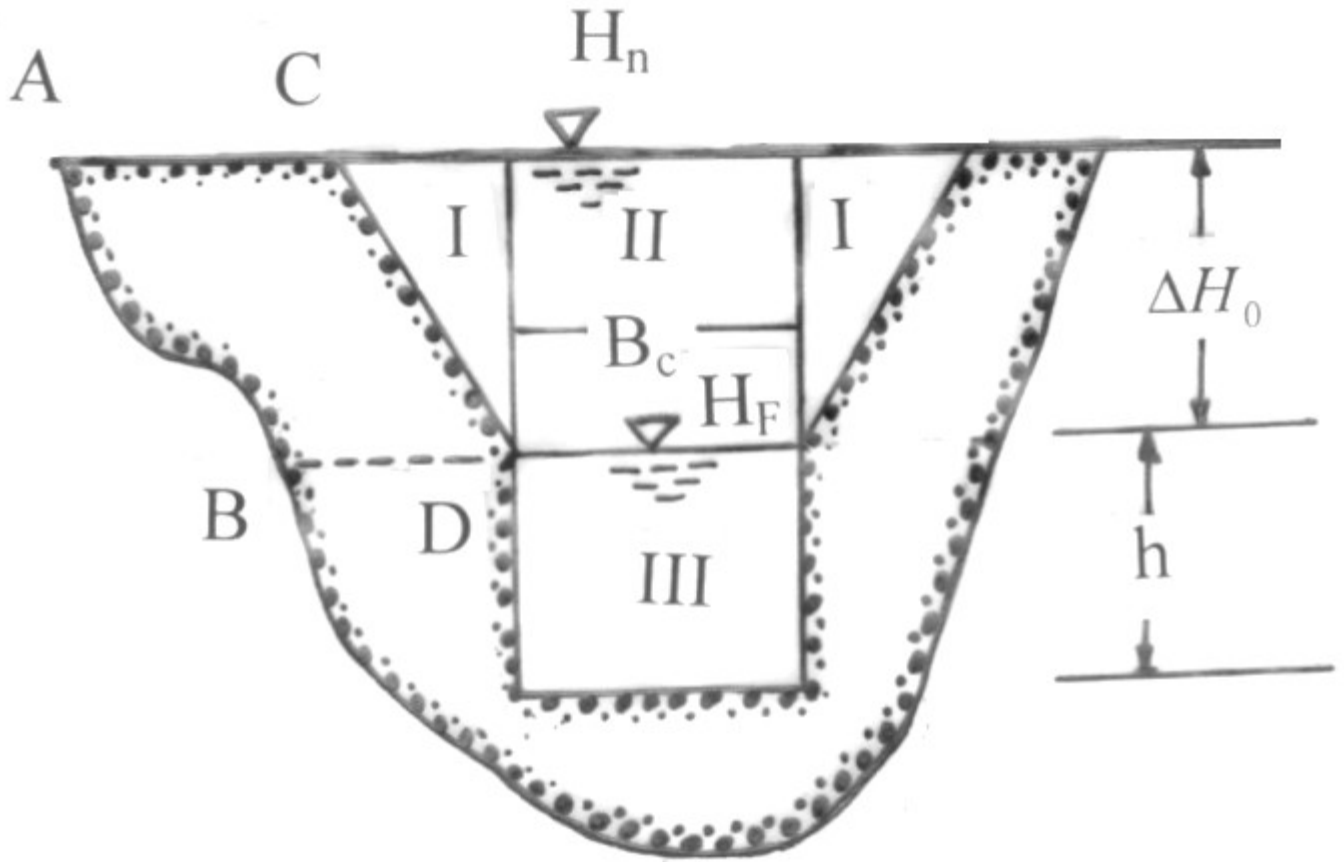
V **final capacity;**

ΔH_0 **difference between normal level** H_n **and flood control level** H_F

L **length of reservoir,** B_c **equilibrium width of reservoir deposition**

J_c **equilibrium slope**

Fig.3 Sketch of preserved capacity for long term



4. 长期使用水库的保留库容
Preserved capacity for long term

图 3 为长期使用水库淤积平衡后坝前的横断面。从式中看出，第一项为图中 I 部分对应的库容，第二项为第 II 部分对应的库容，第三项为图中第 III 部分对应的库容。式中前两项为最终保留的有效库容。一般在最终平衡之前，还有一部分滩库容（图中 ABCD 所对应的库容）可用。

从公式看出，最终保留库容与平衡后的河道宽度 B_c 成正比，与平衡坡降 J_c 成反比，还随着正常蓄水位与排沙水位之差的增加而迅速增加。

欲使最终保留库容占总库容的比例大，则应选择河道型以致峡谷型水库。

Three terms corresponding to I, II, III In Fig.3 respectively.

Before final equilibrium reached capacity of flood plain ABCD is available

Finally preserved capacity is proportional to equilibrium width and in inverse proportion to equilibrium slope and difference between normal level and sediment sluice level

River-type especially gorge-type reservoir is available for large ratio of preserved capacity to total capacity

5. 水库有足够的泄流能力，是保证水库长期使用的运用方式的条件之一

Sufficient discharge through outlets-basic conditions for preserving capacity for long term

水库的淤积纵剖面，只决定坝前水位，与泄流能力没有直接关系。但是泄流能力控制排沙期的水位，如果泄流能力不够，则往往不能保证某个控制流量（水库开始防洪蓄水的流量）下的水位达到排沙水位，从而使库水位上升，发生滞洪，加大淤积，加大坡降，也使水库淤积向上游延伸。

Sufficient discharge through outlets is in need to guarantee the preserved capacity for long term

The longitudinal profile of deposits depends on before-dam level, which related with discharge capacity of outlets.

Without sufficient discharge capacity of outlets sediment sluice level under certain flow discharge can not be assured so that pool level raised, flood retarded, deposition increased, slope enlarged and deposition extended upstream.

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Sufficient discharge through outlets-basic conditions for preserving capacity for long term

三门峡水库就是因为泄流能力不够，先后两次改建，加大了泄流能力，控制了淤积。从多年运用结果看，在丰、中水年应达到了淤积平衡。

Sanmenxia Reservoir after reconstructed twice discharge capacity of outlets enlarged, deposition under control and deposition being equilibrium

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附带指出，对一些淤死和接近淤死的水库，只要大坝工程允许，增加泄流能力，按长期使用调度可望排出一部分淤积，甚至使死库变成活库

Discarded reservoir caused by deposition able to be reused if discharge capacity is enlarged and thereby deposits from reservoir can be scoured and sediment routine is available for preserving long-term capacity