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# PROBLEMS OF RESERVOIR SEDIMENTATION IN CHINA

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**ABSTRACT:** As there are many heavily sediment-laden rivers in China, with high sediment concentration and a large quantity of sediment load, the sedimentation problems of the reservoirs built on those rivers are so serious that the amount of sediment deposited in the reservoirs is great and the rate of sedimentation is accelerated. According to the statistics, up to the end of 1981, a total amount of $11.5\times10^9 m^3$ of sediment were accumulated in those reservoirs, i.e. 14.2% of the total designed capacity were lost. The average annual loss in storage capacity reached 2.3 percent, being the highest in the world. Silting of impounding lakes not only has an effect on the benefits of the reservoirs and seriously threatens the life of reservoirs, but also results in many environmental problems which were not fully estimated in the planning of the reservoirs. In this paper, the situation of reservoir deposition in China are described from the following aspects: 1) the characteristics of hydrology and sediment of the rivers; 2) the seriousness of reservoir sedimentation in China; 3) problems caused by reservoir deposition; 4) the methods of minimizing sediment deposition, etc.
**KEY WORDS:** reservoir sedimentation, rivers with heavy sediment load, impounding clear water and releasing muddy water, measure of minimizing sediment deposition

Since the founding of the People's Republic of China, 84 000 reservoirs of different kinds have been constructed in China with a total storage capacity of 450 billion $m^3$. These reservoirs play a tremendous role in the development of industry and agriculture of the country. Nevertheless, many rivers have high concentration and huge discharge of sediment, the reservoir sedimentation problems are very serious. Severe deposition in the reservoir not only affects the function of the reservoir, but also causes a series of socio-environment problems, which calls for Chinese scientists and technicians to pay high attention to and make great efforts on the methods of minimizing sediment deposition. Through handwork for 30 years, the Chinese scientists and technicians gradually have a better understanding of the characteristics of sedimentation and erosion in a reservoir and have obtained the ways to tackle the reservoir sedimentation.

# I. THE HYDROLOGICAL AND SEDIMENTARY CHARACTERISTICS OF RIVERS IN CHINA

## 1. High Sediment Concentration and Heavy Sediment Load

Many rivers in the northern China originate in or flow through the regions of the Loess Plateau.

In these regions the soil is loose and storms often occur in flood season, thus, the sediment concentration of rivers is high. From the comparison of some rivers in China and in other countries, some rivers in the northern China rank the first as for sediment concentration and amount of sediment loads (Qian *et al.*, 1980).

## 2. The Annual Runoff and Sediment Load Concentrated in Flood Season

In the northern China, it is arid in winter, and rainfall caused by rainstorms is mainly concentrated in flood season, so the runoff and sediment load of rivers are mainly concentrated in flood season. Table 1 shows the reservoir inflow of runoff and sediment load during flood season on some Chinese sediment laden streams, as a percentage of the total amounts of the year.

Table 1 shows that 90% of the annual sediment load comes from flood season, whereas only 60% of annual runoff took place in the same period.

Table 1 Reservoir inflow of runoff and sediment during flood season as a percentage of the total amounts of the year

| | Liujiaxia | Sanmenxia | Guanting | Naodehai | Heisonglin | Zhenziliang | Fenhe | Hongshan | Average |
|---|---|---|---|---|---|---|---|---|---|
| Runoff (%) | 58 | 61 | 56 | 62 | 45 | 48 | 61 | 70 | 57.6 |
| Sediment load (%) | 90 | 91 | 86 | 90 | 98 | 97 | 96 | 95 | 92.8 |

# II. SERIOUSNESS OF RESERVOIR SEDIMENTATION IN CHINA

## 1. A Large Amount of Sediment Deposits in the Reservoirs

Based on the data of 236 reservoirs in China, up to the end of 1981, the total amount of sediment deposited in these reservoirs were 11.5 billion $m^3$, accounting for 14.2% of the total storage capacity. About 0.8 billion $m^3$ of reservoir capacity lost annually.

2. Rapid Rate of Reservoir Deposition

According to the statistics, the annual average rate of reservoir capacity loss is 2.3%. Table 2 shows the situation of some large and medium-sized reservoirs in China, most of which are large reservoirs. In fact, sedimentation of some medium- and small-sized reservoirs are more serious.

Table 2 Sedimentation in some reservoirs in China

| Reservoir | Drainage area ($km^2$) | Design capacity (million $m^3$) | Years surveyed | Total deposition (million $m^3$) | Percentage of design capacity lost to sedimentation |
|---|---|---|---|---|---|
| Sanmenxia | 688400 | 9640 | 1960- 1989 | 5690 | 59.0 |
| Hongshan | 24486 | 2560 | 1960- 1987 | 670 | 26.2 |
| Guanting | 47600 | 2270 | 1953- 1994 | 630 | 27.8 |
| Fenhe | 5268 | 721 | 1960- 1989 | 330 | 45.8 |
| Liujiaxia | 172000 | 5720 | 1968- 1989 | 1410 | 24.7 |
| Danjiangkou | 95217 | 16000 | 1968- 1986 | 1130 | 7.1 |
| Cetian | 16900 | 200 | 1960- 1983 | 205 | 102.5 |
| Zhenziliang | 1840 | 36 | 1959- 1973 | 29 | 80.6 |
| Naodehai | 4501 | 168 | 1963- 1986 | 2 | 1.2 |
| Gongzui | 76400 | 357 | 1967- 1987 | 206 | 57.7 |
| Bikou | 27600 | 521 | 1976- 1986 | 218 | 41.8 |
| Shimen | 3861 | 105 | 1973- 1988 | 28 | 26.7 |
| Hongsiba | 121 | 34 | 1960- 1986 | 7 | 20.6 |
| Wangyao | 820 | 203 | 1972- 1990 | 77 | 37.9 |
| Fengjiashan | 3232 | 389 | 1971- 1990 | 63 | 16.2 |
| Miaogong | 2400 | 183 | 1960- 1989 | 97 | 53.0 |
| Dongxia | 552 | 77 | 1959- 1983 | 41 | 53.2 |
| Shixiakou | 3048 | 175 | 1959- 1988 | 35 | 20.0 |
| Changshantou | 14174 | 348 | 1960- 1986 | 47 | 13.5 |
| Wenyuhe | 1876 | 105 | 1959- 1988 | 20 | 19.0 |
| Bajiazui | 3522 | 496 | 1958- 1990 | 249 | 50.2 |
| Yangmaowan | 1100 | 120 | 1970- 1990 | 17 | 14.2 |
| Zhaikou | 903 | 185 | 1970- 1990 | 8 | 4.3 |
| Luhun | 3492 | 1320 | 1960- 1983 | 62 | 4.7 |

## III. PROBLEMS CAUSED BY RESERVOIR SEDIMENTATION

1. Loss of Storage Capacity Resulting in the Reduction of Benefits of Reservoirs

The storage capacity of a reservoir is the basic condition for multi-purpose benefits. Because of sediment deposition the storage capacity of a reservoir reduced, so the original beneficial goals of the reservoir can not be fully realized. In order to reduce the rate of sedimentation to prolong the life of a reservoir, some reservoirs have to change their mode of operation from impounding water all the year round to storing the clear water and discharging the muddy water. Following such a mode of operation, although the multi-purpose benefits of a reservoir are reduced from the consideration of long term usage of the reservoir, it is worthwhile.

## 2. Headward Extension of Backwater Deposits Resulting Loss in Increase duce to Flooding and Immersing

In general, the deposition in a reservoir occurs within the range of backwater, but for those reservoirs constructed on loaded rivers, as a result of heavy deposition, the deposits not only accumulate in the range of backwater, but also extend beyond it. This phenomenon is the so-called headward extension of backwater deposits. For example, in the Hongshan Reservoir on the silt loaded river——the Laoha River in Northeast China(Jiang *et al*., 1992) (Fig. 1), the maximum water level of the reservoir is 437.99 m a.s.l., a horizontal length of backwater relevant to the level is only about 36 km, but now the distance between the deposit terminal and the dam is 61 km. The elevation of the river bed at the deposit terminal is up to 457.5 m a.s.l., 19.5 m higher than the maximum pool level.

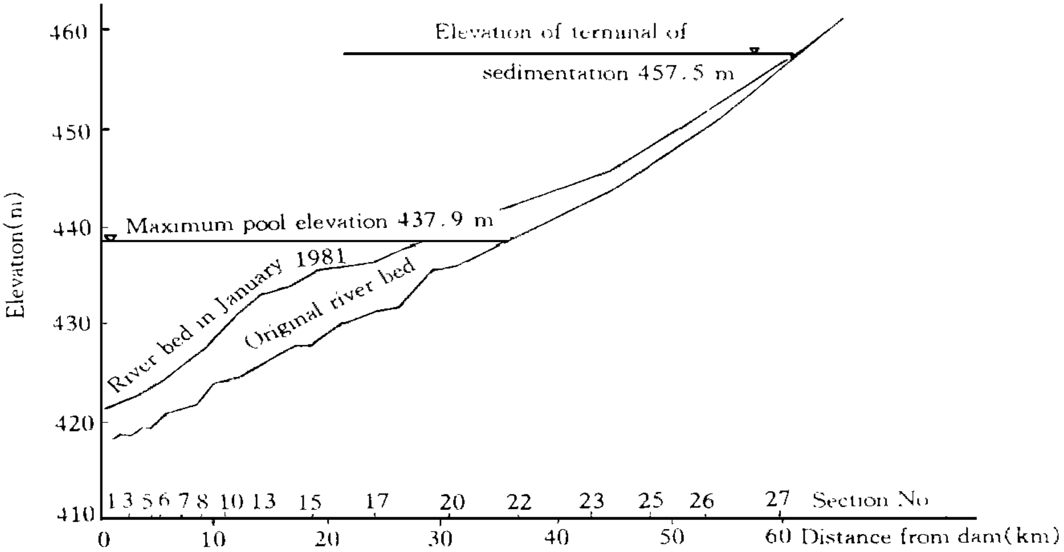



Fig. 1 Longitudinal profile of Hongshan Reservoir

Both the local river bed and the ground water table may be raised by the headward extension of backwater deposits. Taking Guanting Reservoir as an example, the terminal of deposition extended upward by 10 km, the groundwater table was raised by 3– 4 m and the area of local salinealkalinized land has been expanded 14 times than before(Zhang *et al*., 1985).

3. Pollution of Water Quality

Because of the reduction in self-purifying power due to sluggishness of flow in the reservoir, the water is also polluted by sediment adsorbing pollutant.

According to the observations in Guanting Reservoir, some toxic substances, such as large phenol, arsenic, and chromium, can be absorbed and transported by sediment particles and a large higher amount of toxic matter has been found in the bodies of fishes, which results in the fish yield reducing.

4. Adverse Impact on Navigation

After the lowering of water level in low-flow season, sand dunes with considerable height may form in the reach of fluctuating backwater, bringing serious trouble to navigation.

5. Effect on Downstream Channel of the Reservoir

After a reservoir is constructed on a sediment-loaded river, the natural conditions of flow and sediment in the downstream channel are changed. The erosion or siltation of the river bed downstream of the reservoir depends on the function of regulation of the reservoir. Taking Sanmenxia Reservoir as an example, in the first stage, i. e., the period of impounding (Sept. 1960 to Oct. 1964) the clear water was released from the reservoir, causing the serious erosion in the lower reaches of the Huanghe (Yellow) River. In the second stage, i. e., the period of flood detention and sediment releasing (Nov. 1964 to Oct. 1973), because of the insufficient discharging capacity of the outlet, the peak discharge was retarded during a flood period, and the incoming sediment would be released by a low flow. As a result, a huge amount of sediment deposited in the main channel of the lower reaches of the Huanghe River. In the third stage, i. e., the period of impounding the clear water and releasing the muddy water (Nov. 1973 to present), after the reconstruction of the reservoir was completed, the releasing capacity of the project was expanded, so the flood detention would not occur in the reservoir. Thus, the outflow was competent to transport the sediment outflow, and the deposition in the channel downstream of the reservoirs would be reduced.

## IV. MEASURES FOR REDUCTION OF RESERVOIR SEDIMENTATION

1. Retaining the Sediment in the Upper Reaches to Decrease the Oncoming Sediment Load

To reduce the oncoming sediment load of reservoirs is one of the essential measures for preventing or mitigating the reservoir sedimentation. The practical experience indicates that if the watershed is not very large, the effects of soil conservation on reducing sediment can be obtained in a short time. Taking Hongshan Reservoir as an example (Jiang *et al.*, 1990), in the 1960s and 1970s the average annual rainfall in the watershed of the reservoir was closed to the long-term average rainfall of 464.3 mm, but the sediment load was quite different, it was 5734 $\times 10^4$ t in the 1960s and decreased to 1989 $\times 10^4$ t in the 1970s, only 35% of the former.

The reason for the reduction of incoming sediment load is mainly the store effects of the water conservation works in the upper reaches. During the period from the 1960s to the 1970s, the irrigation area in the watershed and the storage capacity of reservoirs were increased, and the warping with turbid flow was widely used in the most part of the irrigation area, which resulted in the effects of retaining silt remarkably (Fig. 2). The same achievement was also obtained in Guanting Reservoir.

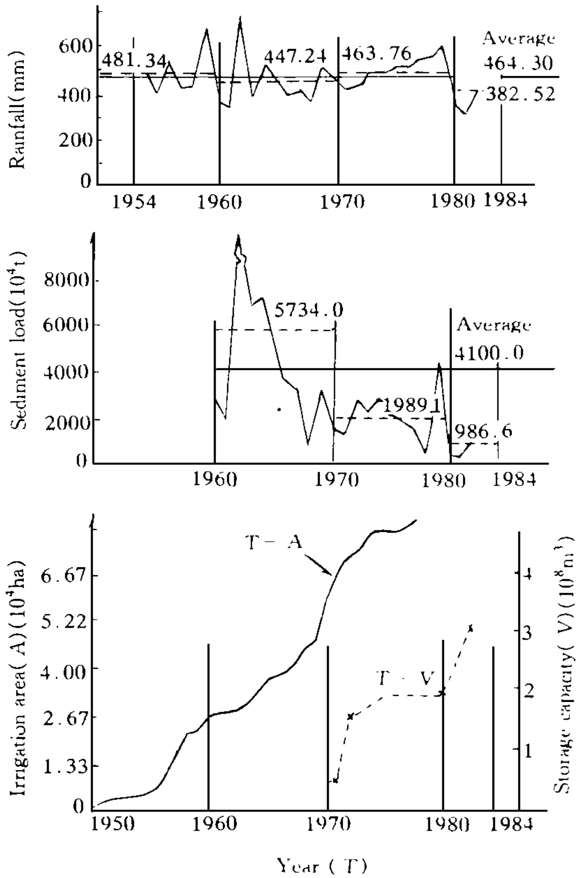



Fig. 2 Coordinated hydrographs for the basin of Hongshan Reservoir

## 2. Optimizing the Planning and Design

The experience from the Chinese practice indicates that the regulation both runoff and of sediment has to be considered in the planning and design of a reservoir built on silt-laden river.

The annual average rate of reservoir sedimentation ($R_s$) is used as an index to express the seriousness of the deposition. $R_s$ is related to the operation mode of the reservoir, the annual average incoming sediment load and the initial storage capacity of the reservoir. Based on the analysis of field data from parts of the storage reservoirs in China, a empirical formula has been obtained as follows (Fig. 3) (Jiang, 1980).

$$R_s = 0.0002G^{0.95}(V/F)^{-0.8}$$

where, $G$ ——the average modules of erosion of the watershed (t/km$^2$. a); $V$ ——the original storage capacity of a reservoir (m$^3$); $F$ ——catchment area of a reservoir (m$^2$).

From Fig. 3, it can be seen that, generally, $V/F$ shouldn't be less than 0.1 m$^3$/m$^2$. Otherwise the average annual rate of reservoir sedimentation would be larger than 2%. In this case the facilities of sediment releasing should be taken into consideration in the planning of the reservoir.

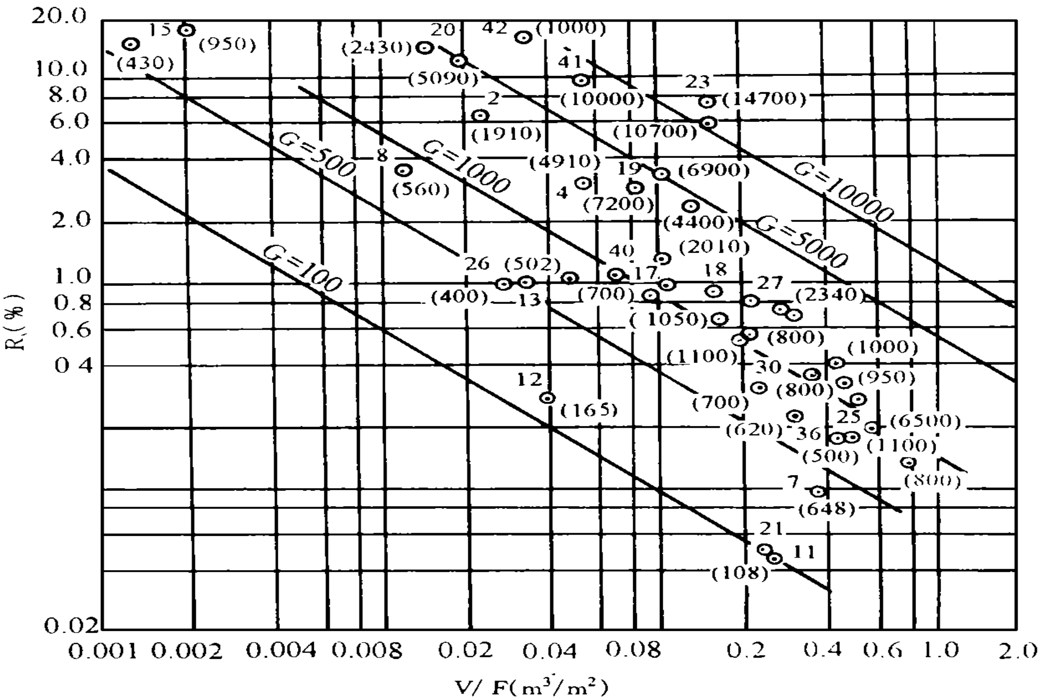



Fig. 3 Relationship between the loses rate of storage capacity and characteristics of reservoir
(The numbers beside the point in this figure are the serial number of reservoirs and the parenthetical numbers are the average modules of erosion of the watershed of a reservoir)

3. Choosing Proper Mode of Reservoir Operation

For the reservoir built on silt-laden river, to select a proper mode of operation and to reasonably manage the reservoir plays an important role in the reduction of sediment deposition and in the development of multiple purpose benefits. Many reservoirs in China took the operational mode of storing flood water during the initial stage of operation, and then, because of the seriousness of silt deposition, it was forced to change the operation mode to "storing clear water and sluicing muddy water".

Table 3 shows the relationship between the rate of annual depletion of reservoir storage capacity and the characteristic value of reservoir volume *C* (ratio of annual sediment load and the storage capacity of a reservoir) of a part of reservoirs in China. It can be seen that if the value of *C* is 0.04– 0.05, the rate of annual depletion of reservoir storage capacity is 2%, so as for the reservoir constructed on the silt-laden stream, if its value of *C* is more than 0.04, the operational mode should be better taken as "storing clear water and discharging muddy water".

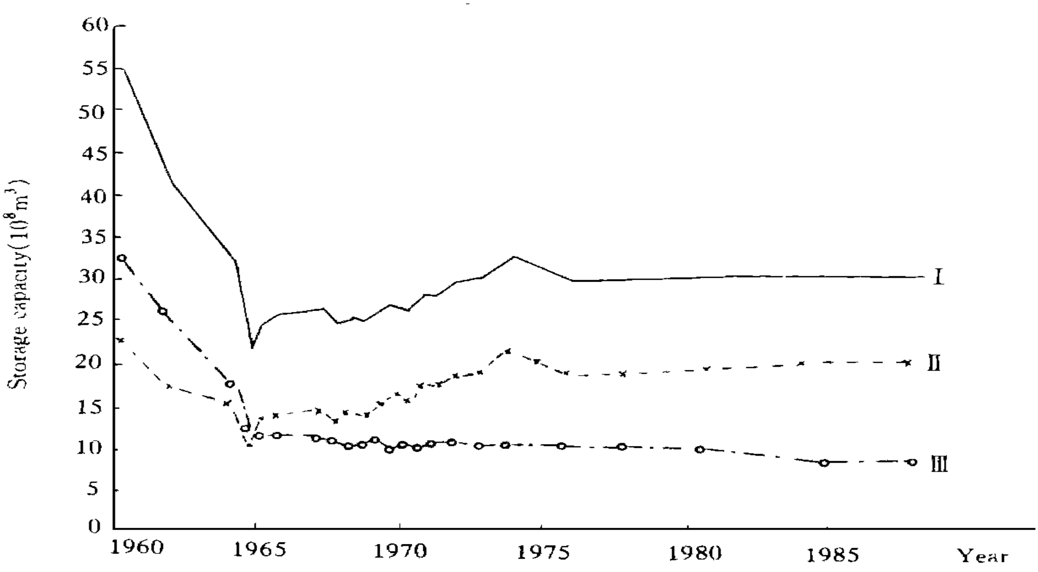
If the operational mode of storing clear and discharging muddy is adopted, the sediment load deposited in the reservoir in dry season can be flushed out of the reservoir in the flood season. Thus, the balance of erosion and siltation might be achieved every year. Such results have

Table 3 Variation of the annual average rate of storage capacity depletion under the different modes of reservoir operation

| Reservoir | Design capacity ($10^6 m^3$) | Annual sediment load ($10^6$) | $C=$ ③/② ($t/m^3$) | Rate of storage capacity depletion (%) | Fixed number of years (a) | $R_s=$ ⑤/⑥ (%) | Mode of reservoir operation* |
|---|---|---|---|---|---|---|---|
| ① | ② | ③ | ④ | ⑤ | ⑥ | ⑦ | ⑧ |
| Sanmenxia | 16200 | 1600 | 0.099 | 14.6 | 1.5 | 9.70 | A |
| | | | | 1.5 | 18.0 | 0.08 | B |
| Zhenziliang | 36 | 9.4 | 0.260 | 36.0 | 3.0 | 12.00 | A |
| | | | | 23.0 | 10.0 | 2.30 | B |
| Heisonglin | 8.6 | 0.7 | 0.083 | 20.2 | 3.0 | 6.70 | A |
| | | | | 12.00 | 11.0 | 1.10 | B |
| Honglingjin | 16.6 | 0.6 | 0.036 | 14.0 | 5.0 | 2.80 | A |
| | | | | 1.8 | 7.0 | 0.26 | B |
| Dongxia | 37 | 2.5 | 0.067 | 54.4 | 17.0 | 3.20 | A |
| | | | | −3.0 | 7.0 | −0.42 | B |
| Jinping | 12 | 1.3 | 0.108 | 7.5 | 3.0 | 2.50 | A |
| | | | | 1.2 | 8.0 | 0.15 | B |

* A is storing water throughout the year. B is storing clear water and discharging muddy water.

been realized in Sanmenxia and Heisonglin reservoirs. Fig. 4 shows the change of storage capacity of Sanmenxia Reservoir. It can be seen that before the reconstruction in 1964, the volume of the reservoir decreased rapidly due to the serious silt deposition. After the reconstruction




I. Total storage II. Storage above the main channel III. Storage over flood-plain

Fig. 4 Change in storage capacity below an elevation of 330 m in Sanmenxia Reservoir completion, when scour occurred during every flood season, the volume of the reservoir not only have not depletion again but also have some recoverage.

## 4. Removing Sediment by Machine

In some arid or semiarid regions in China, the rivers have no water in dry season, but in flood season, the flood usually carries a large amount of sediment entering the reservoir. For these reservoirs the operation of lowering the pool level for removing sediment is not allowed. In this case, the dredging measures should be adopted as a main way to recover storage capacity. According to the dredging ways, the device of dredging can be divided into mechanical dredger and hydraulic suction dredger. One of the hydraulic dredgers is called siphon dredging device. It fully uses the hydraulic head difference between the upstream and downstream levels of the dam as the source of motive power without any additional power, it has been widely used in the small reservoirs in north China.

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