

A Research Overview of the Siltation Loss Controls and Capacity Recovery Processes in China's Reservoirs

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Abstract. There are many reservoirs in China with serious siltation issues which are affecting the function and safety of the reservoirs. Recently, research studies have been carried out regarding siltation loss control and capacity recovery technology due to the decreases in suitable dam sites for establishing reservoirs, and the increasingly serious siltation losses which have been occurring in the present reservoirs. The results of these studies have been of great significance to the partial recoveries of the siltation capacities of reservoirs, improvements in the respective efficiencies of the current reservoirs, and the prolonging of the service life of the reservoirs. This study presented a simple review of the previous research findings regarding the current siltation loss situations and controls, as well as the capacity recoveries which have been achieved. Also, this study proposed the urgent need for in-depth examinations to be conducted pertaining to the national investigations of the reservoir siltation status in China, as well as a review of the current mechanisms and control measures for reservoir siltation losses.

1 Introduction

China has the largest number of reservoirs among all countries of the world. There are a total of 98,002 reservoirs in China, with a total capacity of 932.3 billion m³. This is equivalent to one fifth of the country's total river runoff. China's reservoirs play important roles in providing clean energy, maintaining regional ecological balance, ensuring an adequate water supply, and mitigating flood situations. However, China is also the country with the most serious reservoir siltation issues. The average annual siltation rate of China's reservoirs is 2.3%, and the annual siltation loss capacity is equivalent to a super-large reservoir of 10 billion m³. In recent years, the reductions in China's reservoir functionality, safety and comprehensive benefits have become a bottleneck which has restricted economic and social development. Therefore, it is necessary to control the siltation of the country's valuable reservoirs, as well as to maintain the reservoir storage capacities and actively implement rescue measures for the siltation of China's reservoirs. It has become a priority to conduct partial siltation cleaning in the reservoirs and recover the storage capacities of the reservoirs in order to prolong their service life. Also, various functions which will improve and promote the sustainable use of the reservoirs should continue to be introduced.

2 Comparison the siltation situation in China and the current global siltation issues

At the present time, millions of different dams have been built around the world, which include 50,000 large dams, forming a global reservoir capacity of approximately 7 billion m³^[1]. These reservoirs have many functions, such as providing flood control, water supply sources and power generation sources. The reservoirs also have irrigation and shipping functions. All of these functions have created significant benefits for social development. However, at the current time, siltation deposition in reservoirs is a worldwide problem due to the siltation transport accompanied by the flow movements in rivers. The average service life of a reservoir is approximately 22 years, which is far less than the service life of the body of a large dam (at least 100 years). In regard to the construction processes of dams in other countries, the annual siltation transport capacity of the Nile River before the Aswan Dam was built was approximately 100 to 124 x 10⁶ tons. However, now the annual siltation transport capacity has been determined to be only 10% of the previous rate, which indicates that the siltation deposition of reservoirs is very significant. Since the establishment of the Ribarroja-Mequinenza reservoir hub on the Ebro River, 96% of the siltation from the upstream has been detained, which has not only led to the erosion and undercut of the downstream riverbed, but has resulted in the ceasing of delta silting at the mouth of river, which effectively further extended the erosion situation. The annual siltation discharge of the Colorado River in the United States was previously L50 × 10⁶ tons. However, due to water diversion from the river basins and reservoir construction processes, the siltation which enters into the sea has been greatly reduced. These findings have further highlighted that the siltation

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situations in global reservoirs have become relatively obvious. In addition, similar phenomena have occurred in the Danube (France) [2]; Rhone (Europe) [3]; Don (Russia) [4]; Niger (Africa) [5]; and Skokomish (United States) [6] Rivers, as well as China's Luan, Yangtze, Yellow, and Huaihe Rivers. The affected reservoirs throughout the world have reduced the safety of dams with rates of 0.5% to 1% siltation of their storage capacities[7]. The development of the functions and comprehensive efficiencies of the reservoirs have also been weakened. However, the annual siltation rate of the reservoirs in China has been determined to be 2.3%, which is far greater than the capacity loss rates observed in the global reservoirs. Therefore, for the majority of the reservoirs in China, their normal service life roles are being determined by the siltation deposition of the reservoirs, and not the service life of the dams.

Table 1. Regional distributions of the global capacities and siltation reservoirs (dams).

Area	Storage capacity (km ³)	Annual average silting loss rate of storage capacity (%)
World	6,325	0.5-1
Europe	1,083	0.17-0.2
North America	1,845	0.2
Central and South America	1,039	0.1
North Africa	188	0.08-1.5
South Africa	575	0.23
Middle East	224	1.5
Asia (except China))	861	0.3-1.0
China	510	2.3

3 Research progress in the functional recovery of silted reservoirs

3.1. Current status of reservoir siltation in China

According to the statistical data, the annual silt transportation of the seven major rivers in China is as high as 2.3 billion tons. It has been observed that, even though the Yangtze River has a silt concentration of only 0.54 kg/m³, the annual silt volume is approximately 500 million tons due to the large amount of water. After a reservoir is built on a river, the water level will go up, and the flow velocity will tend to decrease. Therefore, as the siltation force decreases, the siltation deposits in the reservoir will increase.

At the present time, the basic data and characteristic information of the reservoir siltation status in China has not been systematically or comprehensively mastered. According to the analyses of the related research data, the annual siltation rates of the reservoirs in China are far higher than those of other countries, and the siltation storage capacities of some of China's reservoirs have

even reached more than 30%. In 2012, the Ministry of Water Resources conducted investigations and analyses of the reservoir siltation in four typical provinces: Shanxi, Shaanxi, Guizhou and Jiangxi. The total reservoir capacity and siltation rate of Shanxi Province were determined to be 4.765 billion m³ and 34%, respectively. The total reservoir capacity and siltation rate of Shaanxi Province were determined to be 4.043 billion m³ and 34%, respectively. It was found that the total reservoir capacity and siltation capacity of Jiangxi Province were 2.955 billion m³ and 893 million m³, respectively. However, the siltation rate was observed to be only 3%. The total reservoir capacity and siltation capacity of Guizhou Province were 2.540 billion m³ and 110 million m³, respectively. However, the siltation rate was observed to be only 4.3%. Although the siltation rates in the provinces of Guizhou and Jiangxi were not found to be high, and the overall siltation rates were not large, the siltation degrees were observed to be different, and siltation problems still existed in many of the reservoirs. According to the statistical data, 6,376 reservoirs in Jiangxi Province displayed siltation problems, and 979 reservoirs in Guizhou Province displayed siltation problems. Some of these reservoirs were found to have serious siltation issues. For example, the siltation rates of the Tangbei Reservoir in Jiangxi Province, and the New Bridge Reservoir in Guizhou Province were determined to be 58.9% and 80.0%, respectively. Generally speaking, the differences in the reservoir siltation rates of the different river basins were obvious. The siltation of the Yellow River Basin located in the provinces of Shanxi and Shaanxi was observed to be relatively serious. Meanwhile, the degree of siltation in the reservoirs of Jiangxi and Guizhou Provinces were found to be much lower.

3.2 Reservoir siltation prevention methods and effects

The characteristics of reservoir, conditions of basins and other factors determine the pattern and distribution of siltation. However, these factors also determine the control methods which are put in place for reservoir siltation. Cao Huiqun [8] compiled detailed statistics regarding siltation reduction methods and their effects in 26 reservoirs in China and proposed some siltation reduction methods for reservoirs. These included methods for reducing the amounts of silt entering into reservoirs; discharging and flushing methods to remove silt deposits in reservoirs; mechanical dredging methods, and so on.

The methods of reducing the amounts of silt entering into reservoirs was found to be mainly suitable for the Yellow River, as well as other areas with serious water and soil losses. Soil erosion is the main mode of silt production, as well as the main cause of reservoir siltation in the aforementioned basins. Therefore, it is necessary to reduce the soil erosion and apply silt blocking measures through soil and water reservation practices. The applications of such measures will reduce the amounts of silt entering into the reservoirs, and

thereby lessen the overall siltation degree. Soil and water reservation practices are not only applicable to river type reservoirs, but have also been successful in lake type reservoirs. Meanwhile, the construction of silt storage dams, flood diversion, desilting, discharging silt around reservoirs and other engineering measures have previously been mainly applied in lake type reservoirs. However, water and soil conservation, silt retaining dams, and other engineering measures have high investment costs and long project implementation times. These measures have also displayed slow effects in reducing siltation, and are mainly suitable for reservoirs with relatively small watershed areas.

The methods involving the discharging and scouring of silt from reservoirs are generally suitable for reservoirs with silt discharging facilities. The effects of siltation reduction methods have been relatively good in river reservoirs. Also, hydraulic scouring methods, such as density flow, empty discharge, and transverse erosion methods, have had obvious short-term effects on siltation discharge. It has been found that for super-large river reservoirs (such as the Three Gorges, Xiaolangdi and Sanmenxia Reservoirs), clearing and draining methods are effective for the long-term maintenance of reservoir storage capacities. The Sanmenxia Reservoir showed a significant reduction in siltation after clearing and draining methods were applied. The methods involving the discharging and scouring of silt from reservoirs uses water power to directly scour the siltation which has been deposited in the reservoirs. A main channel is formed in a reservoir through the scouring process, which has obvious effects on siltation reduction, as well as a relatively low cost.

In theory, mechanical dredging methods should be applicable to various types of reservoirs, and the capacity recovery rate has been estimated to be somewhat higher. However, due to the high costs involve, these types of methods are in fact mainly suitable for medium and small-sized reservoir dredging, or the partial dredging of large-sized reservoirs. In recent years, the environmental problems of reservoirs in water source areas have become increasingly prominent. Mechanical dredging methods could potentially be used to improve the medium and small-sized reservoirs in water resource areas. However, the local dredging of large reservoirs still mainly focuses on the obstructed sections of the fluctuating backwater areas of the reservoirs. Since the main problems of the mechanical dredging methods are the high cost and secondary pollution of the deposit, an effective utilization of the silt is carried out. For example, the coarse-grained silt is used to make concrete aggregate, and the fine-grained silt is used to fire clay ceramics and porcelain bricks.

In the above-mentioned measures of storage and siltation reduction in reservoirs, both silt dredging through discharge, and silt scouring and dredging through heterogeneous flow, utilize water flow energy to discharge and dredge the incoming silt. These are not only scientific and rational reservoir operation scheduling methods, but are also the main measures used to maintain the effective capacities of China's reservoirs at the present time.

3.3 Progress achieved in the research regarding reservoir siltation control and capacity recovery

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3.3.1 Research regarding reservoir silt management

Morris (2015)^[9] pointed out that a successful reservoir silt management method was a comprehensive management method combined with silt prevention, discharging, scouring, dredging, and other siltation reduction technologies, along with monitoring and control measures. These measures mainly included the reduction of silt from the upstream areas; transfer and discharge of the silt in the reservoirs; scouring and reduction of the silt in the reservoirs; and the capacity expansion and remedial treatment of silted reservoirs, along with other measures.

3.3.2 Research regarding the maintenance and storage capacity recovery of reservoirs

The most common methods of reservoir capacity maintenance and recovery mainly include storing clear water and discharging muddy water; discharging and scouring of silt; and the discharging of heterogeneous flow, which are combined with the dispatching of water and sediment, and other hydraulic dispatching modes and artificial dredging measures.

(1) Storing clear water and discharging muddy water

At the present time, the majority of reservoirs in China have adopted operation methods involving the storage of clear water and the discharging of muddy water, in order to deal with siltation problems and strengthen the silt discharging efficiency of the reservoirs. The aforementioned methods must either discharge the silt from the reservoirs or reduce the water levels in order to fully implement the regulation and storage capacities of the reservoirs. In accordance with the observed characteristics of uneven distributions of silt from the upstream areas into the Three Gorges Reservoir during the year, the water levels during the main flood season (July to September) are maintained at a 145 m level for flood control purposes. In such cases, the flood water with large concentrations of silt can be smoothly discharged downstream. Following the flood seasons, the concentrations of silt will decrease, and the reservoir will start to store water until a normal level is reached (175 m). This is usually achieved by the end of

November for the purpose of giving full play to power generation and other efficiencies. It was observed that, during the first three years of operation of the Sanmenxia Reservoir following its establishment, siltation had rapidly formed. The average water level before the dam was between 323 m and 330 m. However, after utilizing methods of storing clear water and discharging muddy water, the area became less silted, and the capacity could be basically maintained at approximately 3.3 billion m³ after the year 2000.

(2) Discharging and scouring methods

Discharging and scouring are the most important methods of reservoir scouring, which mainly use the impacts of headwater scouring and on-way scouring during discharging processes to recover the capacities of reservoirs. A technique of scouring the silt from the previous stage has proven effective in reducing the siltation of reservoirs. The discharging and scouring of reservoirs include two situations. First, if no flooding from the upstream areas is occurring, then the capacity will be recovered by headwater scouring and the on-way scouring caused by discharging the reservoir. The discharging amounts will tend to be small at the onset, and then gradually increase. Generally speaking, due to insufficient water levels, such methods have limited scour scope and distance. Therefore, they are mainly used to maintain the scouring funnels of dams, and to resolve the siltation problems near dams. Second, when there is flooding occurring from the upstream areas, the reservoirs should be discharged in advance, and the flood conditions which are formed by storms will scour the silt and discharge it at the lower water levels. Such methods have displayed sufficient after-effect energy and good scouring efficiency, resulting in the effective capacity recovery of the reservoirs.

Previously, many research studies have been conducted regarding the headwater scouring of reservoirs, and a series of formulas for headwater scouring methods have been established. From the aspect of investigating the mechanisms of headwater scouring, Han Qiwei exported the scouring parameters for scour profiles on the basis of a hypothesis and obtained a set of detailed achievements which reflected the effects of headwater scouring in reservoirs.

It has been found that discharging and scouring methods have obvious efficiency. For example, the Sefid-rud Dam located northwest of Teheran (Iran), was constructed on the Sefid-rud River, and put into use in 1962 following its establishment. According to the siltation degrees of the Sefid-rud Dam at different times (Table 2), the initial capacity was 1.76 billion m³. However, between 1962 and 1980, serious siltation had occurred. The annual average siltation was 39.2 million m³, and the silt discharging rate was only 22%. Furthermore, the annual average capacity loss rate had reached 2.33%. Therefore, in order to reduce the siltation, a silt discharging method was adopted in 1981 for the purpose discharging and scouring the silt in the reservoir during the non-irrigated seasons. It was observed that the outflow silt concentration had been increased from 2 kg/m³ to 40 kg/m³, which greatly reduced the siltation degree of the reservoir. From 1981 to 1997, scouring

methods were implemented in the reservoir, and the reservoir's capacity was recovered to a certain extent.

Table 2. Siltation of the Cifero Reservoir at different times

time interval	Annual sediment deposition (10 ⁶ m ³)	Sand blocking rate (%)	Annual average capacity loss rate (%)
1962-1980	39.2	+78	2.3
1981-1997	-8.8	-28	-0.5
1998-2008	4.7	+58	0.27

(3) Discharging of the heterogeneous flow

When a reservoir becomes impounded, and flooding occurs causing higher silt concentrations to enter into a reservoir, the flood water will arrive at the bottom of the reservoir and move forward to the dam. This is a result of the gravity effects of the clear water of the reservoir being different from that of the flood water with higher silt concentration, and the fact that the two basically do not mix. If the gate of the bottom hole of the reservoir is opened at the time of flooding, the flood water will be discharged to the downstream through the bottom hole. Therefore, large amounts of the silt carried by the flood waters can be avoided. Basically, relatively high impound levels should always be maintained before and after the discharging of heterogeneous flow, in order that no waste water is produced. Avoiding the production of waste water not only reduces the siltation of a reservoir, but also ensures the full play of the reservoir's benefits. The water quantity conditions required for the formation of heterogeneous flow are that the flow process is large and continuous power exists. The measured data in China over many years showed that, the silt discharging rate of heterogeneous flow is far more than that of flooding with high silt concentrations. At times, the silt discharging rate of heterogeneous flow may reach higher than 90%. The average silt discharging rate of heterogeneous flow has also been observed to be more than 60%.

Furthermore, many of the previous related research studies regarding the basic theory of heterogeneous flow have made a series of achievements. For example, Wang Guangqian et al. established a basic equation for heterogeneous flow movement according to the conservation of mass and momentum on a micro-body. Fan Jiahua et al. obtained the diving conditions and a calculation method ^[10] of heterogeneous flow and outflow through measured data and laboratory experiments. Fang Chunming believed that heterogeneous flow could be successfully sneaked when the water depth of the sneak point of the heterogeneous flow was greater than the normal depth of heterogeneous flow, which confirmed that the heterogeneous flow of a reservoir is a super-saturated silt transport, and on-way siltation will inevitably happen when heterogeneous flow occurs.

(4) Combined dispatching of water and silt

The method involving the combined dispatching of water and silt is used to reduce the siltation caused by

flood waters with high sand concentrations in reservoirs. The combined dispatching of water and silt is carried out according to the dispatching rules as follows: The effective forecasting of flood waters entering into the reservoirs; discharging the flood waters near the peak of the silt concentrations; discharging the silt to the highest degree possible under the premise of ensuring the safety of the reservoir; and reducing the siltation in the reservoirs when flood waters with high sand concentrations enter into the reservoirs.

There have many research achievements for the optimized dispatching of reservoirs. Generally speaking, the optimized dispatching methods have been mainly based on water resource and power generation efficiency. However, there have only been a few research studies conducted regarding the combined dispatching of water and silt. The aim of the combined dispatching of water and silt is to reduce the siltation in the reservoirs, along with maintaining the long-term comprehensive efficiency of the reservoirs. Therefore, the siltation volumes have generally been used as the targets of the related research studies. In some studies, the proposed models have taken the effective capacities as the targets, with consideration given to the impacts of the siltation degree on the losses in the reservoirs' capacities. Other models have taken the siltation levels of the navigation obstructions in the fluctuating backwater areas to reflect the targets of the silt, with consideration given to the impacts of siltation on the navigation processes. Meanwhile, some of the other proposed models which have adopted modified capacity curves in order to consider the siltation levels. However, these models do not directly consider the targets of the silt, but indirectly reflect the impacts of the siltation degree on the optimized dispatching of the power generation of the reservoirs. Among the different models mentioned above, all of the silt targets were selected for specific problems. Generally speaking, the targets were selected to reflect the role of the comprehensive efficiency of the reservoirs.

(5) Dredging

The hydraulic discharge processes of reservoirs require the consumption of various amounts of water at different degrees. For example, in arid areas where water resources are seriously deficient, silt discharging in reservoirs is often not allowed due to water resource problems. Additionally, some reservoirs do not have silt discharge facilities, and are not likely to use hydraulic drainage methods to discharge the silt deposited in the reservoir. Therefore, hydraulic drainage methods cannot fundamentally solve the problems of capacity recovery in all damaged reservoirs.

Therefore, in the reservoirs which cannot use hydraulic drainage methods, it is generally necessary to use mechanical dredging measures to recover the reservoir storage capacity. At the present time, these types of reservoirs are dredged using mechanical dredging methods, such as dredgers and suction pumps, in order to recover the storage capacities of the reservoirs. In recent years, there have been many dredging projects carried out in rivers, reservoirs, lakes, and waterways in China. The dredging technology has been greatly developed, and the equipment capacities

have been majorly improved. Currently, the most commonly used dredging methods include the following:

(I) Land dredging

This method is suitable for dredging reservoirs with small amounts of water, or arid reservoirs during non-flood periods. An excavator is used, and the sludge is transported and excavated by pipelines, or directly poured to the shore where it is then transported by truck. The advantage of this method is complete dredging can be accomplished.

(II) Underwater dredging

This method is applicable to dredge reservoirs with water storage throughout the year. Dredging grab boats and cutter-suction dredgers are used to dig the sludge from the bottom of the rivers and load onto tugboats. The sludge is then transported to specified stacking points. This method has displayed good efficiency for medium and small-sized reservoirs. However, large-sized reservoirs have large capacities and siltation degrees. Therefore, this method has been observed to have difficulty resolving the siltation problems in large-sized reservoirs due to the large amount of dredging required, which results in high costs for the mechanical dredging and rapid siltation processes. However, it has been common to adopt partial mechanical dredging methods in large-sized reservoirs. For example, the Three Gorges Reservoir was dredged in the fluctuating backwater areas in order to solve the problems of the silt which had been deposited in the channel.

4 Research prospects

With the rapid development of China's social economy, and population's increasing demands for the ecological safety of the nation's river basins, the following research projects will be required to be carried out according to China's current reservoir siltation degrees and research status.

(1) Investigations and analyses of China's reservoir siltation situation

A systematic investigation of the degrees of siltation in China's reservoirs is lacking at the present time. According to the statistical data of reservoir siltation in the 20th century, the siltation loss rates of China's reservoirs is 2.3%, which obviously does not conform to the present situations of reservoir sedimentation in China. Therefore, it is urgent that a reservoir siltation survey be systematically carried out in order to fully grasp the status of reservoir siltation in China. The most commonly used method for investigating the capacities of reservoirs is topographical surveying. However, there are many reservoirs in China, and terrain surveying processes entail large workloads and high costs. Therefore, it has become very urgent to determine an effective and rapid research method for surveying China's reservoir capacities. On this basis, the classification of reservoirs is made according to different indicators through the investigations of reservoir siltation degrees, and the understanding the characteristics of the basins, capacities, siltation volumes, and speed of the different typical reservoirs. This improved understanding

will allow for various measures of siltation control and dredging in the different types of reservoirs to be implemented, and the specific circumstances within the different types of reservoirs can be considered.

(2) Examination of the siltation mechanisms and control measures for the different types of reservoirs

Reservoir siltation control measures not only refer to the controls put in place after the balance of siltation is achieved, but also includes the entire utilization process of a reservoir. During the initial stage, low water levels can be used to regulate the siltation degree. During the middle stage, dispatching, discharging by heterogeneous flow, muddy reservoir discharging, and other technologies can be utilized to reduce the siltation levels. Meanwhile, during the later stage, the emptying of the reservoir and removal of silt through digging and other measures can be adopted to maintain a certain degree of effective storage capacity in the reservoir. The purpose of reservoir siltation control is to delay the dredging times and reduce the dredging frequencies, so that a reservoir can maintain a certain effective storage capacity for a long period of time. Reservoir siltation control measures include the following: The reduction of the amounts of silt entering into the reservoir by means of water and soil conservation and silted dam; The utilization of dispatching the silted position during the initial stage in order to reduce the accumulated silt in the reservoir as much as possible; The implementation of storing clear water and discharging muddy water methods in order to reduce siltation; The use of silt discharging by heterogeneous flow; The implementation of open discharging methods to pull out the silt, as well as the discharging of silt by flooding and muddy water in the reservoirs, and the combination of hydraulic discharging, silt resource utilization, mechanical dredging, and other measures. This study recommends conduct further research into the applicable conditions of the various silting control measures, as well as examining the effects of these methods on silt reduction.

(3) Examination of the dredging measures for the different types of silted reservoirs

For heavily silted reservoirs, proper dredging is an effective measure for the partial recovery the storage capacities of reservoirs. There are currently many siltation technologies available for use in reservoirs. In principle, these include hydraulic natural scouring, artificial mechanical dredging, and small engineering measures, which are relatively mature technologies. The mechanical dredging technologies include dredgers, jets, pneumatic pumps, siphons, and so on. Meanwhile, the small engineering measures may contain a series of measures, such as the side discharge of silt; beach flushing through high channels; silt transportation by pipelines; silt loosening by blasting, and so on. The hydraulic and natural scouring methods can be used to dredge entire reservoirs, and the methods of artificial and mechanical dredging are often used for partial dredging. However, the small engineering dredging measures have displayed good siltation reduction efficiency under the effective coordination of water flow conditions. Some of the aforementioned measures can be used in various reservoirs. However, some measures are only suitable

for medium and small-sized reservoirs. Therefore, it is necessary to further examine the different types of reservoir dredging measures, as well as the application conditions and efficiencies of the different measures, in order to determine which type of dredging measure should be implemented in the different reservoirs, the coordination processes of the utilization of the reservoir dispatching, and so on.

(4) Examination of the silted reservoir capacity recovery and maintenance processes

It has been found that siltation will generally occur after reservoir dredging, and rapid siltation will greatly reduce the dredging efficiency. Therefore, the determination of effective measures for maintaining the dredged capacity for long periods of time should be an important research focus in the future. It will be necessary to examine the position, time, frequency, and scale of reservoir dredging, and determine a rational operation method to maintain with dredged capacities of the reservoirs.

(5) Discussion of the management experiences of silted reservoirs

The siltation problems of silted reservoirs in China are expected to be systematically resolved if an evaluation system for the effects of silted reservoirs is established based on the functions and recovery measures required for the various reservoir types. In order to effectively address the current siltation problems of China's reservoirs, the implementation of scientific and rational governance measures should be combined with the theoretical results of relatively mature and advanced siltation situations, including the effective functional evaluations and recovery strategies used in reservoirs throughout the world during the actual management processes of reservoir siltation situations.

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