

## TYPHOONS' EFFECTS ON LONG-TERM WATERSHED SEDIMENT MANAGEMENT IN SHIHMEN RESERVOIR IN TAIWAN

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### ABSTRACT

Serious siltation in reservoirs generally results from natural collapse and anthropogenic activities. Taiwan has been experiencing severe sediment problems with the intense transient flows result from the steep terrain and torrential rains. Facing the growing difficulty of finding new water resources, and the potential consequence of severe water shortages, Taiwan definitely has to prolong the utility of existing reservoirs, and to keep the stable quality of water supply. Although reservoirs may be dredged to prolong their life spans and treated to improve their quality, it is far better to achieve these ends through effective watershed sediment management. In order to assess the effectiveness of reservoir management plans and conservation works, this study adopts the concept of completeness ratio to represent the sedimentation reduction and increases in lifespan of reservoir. Besides, we analyze the typhoons' effects on long-term watershed sediment management.

**Keywords:** Sediment management, Sedimentation reduction, Reservoir Watershed, Typhoon, Completeness Ratio.

### METHODOLOGY

Both the sedimentation records and watershed conservation works to the Shihmen reservoir from 1964 to 2006 are collected for further analysis. It induces severe sediment problems in the Shihmen reservoir that torrential rains accompanying the typhoons. After long-term watershed sediment management, the annual sediment yield in the Shihmen reservoir is reduced from  $4.0 \times 10^6 \text{m}^3$  to  $1.4 \times 10^6 \text{m}^3$ , but approximately  $20 \times 10^6 \text{m}^3$  after Typhoon Aere (08/23/2004 ~ 08/26/2004). This study defines the completeness ratio as the management effectiveness index, representing the interaction between calculated sediment yields and actual amount, and the effects due to typhoons are discussed. Diagrams are also used to explain both the tendency of completeness ratio over the years and the relationship between completeness ratio and management funds.

### COMPLETENESS RATIO

This study has based on completeness ratio (*CR*) as its evaluation indicator, which is mainly to render the evaluation work of completeness ratio can be extended from one single works to

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the entire project of the watershed so as to effectively expand the aspect of effectiveness evaluation of sediment control (Chen and Lai, 2004). The estimation equation of completeness ratio as follows:

$$CR = \frac{Q_{so} - Q_s}{Q_{so} - Q_{sp}} \times 100\% \quad (1)$$

In the Eq. (1),  $Q_{so}$  is sediment yield before erosion control;  $Q_{sp}$  is reasonable sediment yield; and  $Q_s$  is sediment yield after erosion control.

As learned from equation (1), numerator, sediment control effectiveness, is of the difference of values of sediment yield before and after the management, and what it stands is of the sediment-prevention with erosion control measures. And the denominator in equation (1), sediment goal, is of the difference of value of sediment yield before management and reasonable sediment yield, and it stands for the amount of sediment to be administered. In a word, completeness ratio is of the comparison value of sediment control effectiveness against sediment control goal, and it is of the efficiency that can help prevent sediment loss as evaluated after erosion control works.

The completeness ratio equation (1) as defined in this study can also explain its connection with sediment management by means of the indicating chart (figure 1). The equation considers not only the sedimentation reduction because of the sediment control works or management, but also reasonable sediment discharge that various planning objectives permit. Accordingly, all projects can set up different management goals and reasonable sediment discharge, such as making sediment yield get back to the situations that never undergo sediment disaster or artificial development.

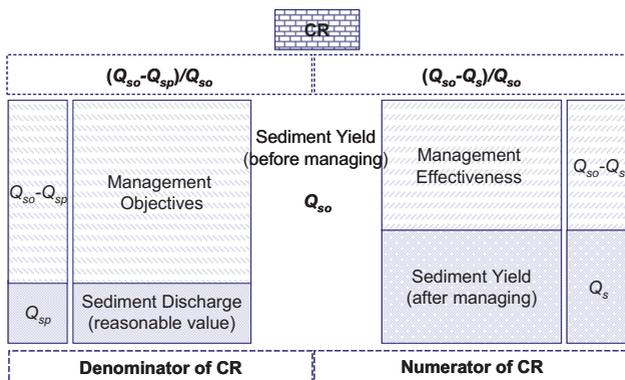


Fig.1 Schematic diagram of the completeness ratio

## EVALUATION FOR SEDIMENT IN SHIHMEN RESERVOIR

Shihmen Reservoir is the first multiple function reservoir in Taiwan as it can irrigate, generate power, provide water to the public, flood prevention, and sightseeing, and it has operated for 40 years since its completeness in May 1963. Shihmen Reservoir has, based on the “20-years plan of watershed governance for Shihmen Reservoir,” stipulated five-phase

(each phase lasts for 4 years) of governance plan. After governance for a long period of time, the amount of sedimentation has gradually lowered. Based on the sedimentation data of the reservoir, the sediment deposition averages at 4.02 million m<sup>3</sup> from 1963 to 1972 every year, while has come down yearly since 1972. Until 2003, the annual amount of sedimentation stays at 1.40 million m<sup>3</sup> every year. However, since typhoons and disasters have frequented Shihmen Reservoir more than often, typhoon Aere and Masha especially, the problem of reservoir sedimentation is so serious that the accumulated yearly amount of sedimentation for these years has increased from 1.4 million m<sup>3</sup> to 2 million m<sup>3</sup>. As a whole, the total amount of sedimentation from 1963 to 2005 amounts to 86.36 million m<sup>3</sup>, while a few of the major typhoons brought out about as much as 72.31 million m<sup>3</sup>, showing how great the amount of sedimentation typhoons can bring about to Shihmen Reservoir.

The accumulated sediment control effectiveness of Shihmen Reservoir for a long period is mainly that each phase of the sediment management project can be facilitated and soil and water conservation work realized. Furthermore, the construction of check dams in the watershed can also prevent debris flow and stabilize hillslope or river-bed effectively. For years, many check dams in the tributaries have been constructed, aside from several large-scale check dams as Yising dam, Jung-Hua dam and Baling dam are built in the upstream. Presently, there are as many as hundred of check dams within the watershed, and the amount of sediment prevented is mostly from large-scale check dam (height of above 10 meter), which amounts of 24 and the total sediment prevented amounts to approximately 36 million m<sup>3</sup>.

## **SEDIMENTATION REDUCTION AND MANAGEMENT EFFECTIVENESS**

Sedimentation of reservoir is one of important benchmarks indicting the sediment control effectiveness in watershed. With the long-term sediment management and treatment of watershed, current sedimentation of the reservoir can be regarded as the sedimentation after management. Such actual amount of accumulated sedimentation will be reckoned as the “actual sediment yield”, and the curve of “actual sediment yield” will also be regarded as the curve after management. Relative to the “actual sediment yield”, the curve without management can be reckoned as the “calculated sediment yield”. The calculated sedimentation of the reservoir can be regarded as the sedimentation without management and such calculated amount of accumulated sedimentation will be reckoned as the “calculated sediment yield”. The difference of accumulated sedimentation between the two scenarios (management and without management) can represent the effectiveness of sediment management in the watershed over a long period of time.

To investigate the substantial effectiveness of long-term management in the watershed, this study makes use of the difference of accumulated sediment under the scenarios of management and without management for years to indicate the long-term sediment control effectiveness. As of such, the information on the actual sediment concentration in Hsiayun hydrological station is compiled from 1963 to 1971, and used to find out its average in order to avoid over-estimation of sediment concentration without management. Thus, the sediment concentration of runoff is 1615 ppm, and this value multiplied by the runoff amount of past years is the “calculated sediment yield”.

## TYPHOONS' EFFECTS ON LONG-TERM SEDIMENT MANAGEMENT

In order to effectively extend the estimation of sediment control effectiveness as well as to investigate the sediment effectiveness brought along with major typhoons, this study regards the historical average value of “calculated sediment yield” as representative within the next few years. As for the amount of “actual sediment yield”, the average value of annual sedimentation of reservoir at 2 million m<sup>3</sup> is adopted and the sediment control effectiveness in Shihmen Reservoir can be calculated (figure 2). The decreasing effectiveness of reduced sedimentation explains that the excellent result of long-term management is greatly affected by typhoons. Heavy rainfall and typhoons bring about the sediment disaster and prominently reduce the management effectiveness. Furthermore, the effectiveness of management, difference in accumulated sedimentation between “calculated sediment yield” and “actual sediment yield”, reaches 80 million m<sup>3</sup> before typhoon Aere. The effectiveness of 80 million m<sup>3</sup> lengthen the life-span of reservoir by 60 years, meanwhile, the deposition of all check dams in Shihmen Reservoir reaches 40 million m<sup>3</sup>, amounting to 50% of the effectiveness, not to mention the marginal effectiveness. The sedimentation of reservoir has gradually slowed down with construction of large-scale check dams and held until the check dams are fully filled (figure 3). So the construction of these large-scale check dams is the groundwork for the management effectiveness of Shihmen Reservoir. However the effectiveness of check dams become insignificant after being filled up so that the management effectiveness do not show prominent effect, in the wake of the increasing sedimentation of Shihmen Reservoir by heavy rainfall and typhoons after 2005.

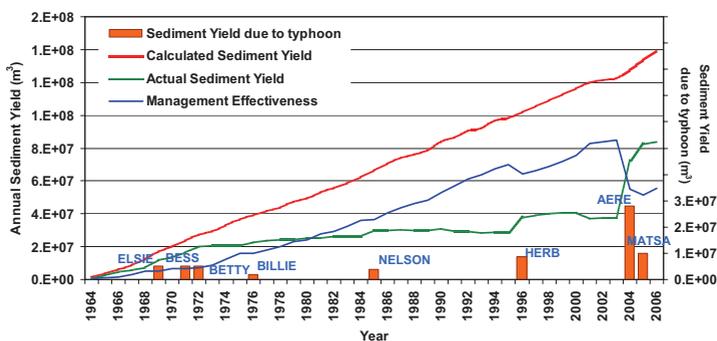


Fig.2 The relation between typhoons and effectiveness of the long-term management

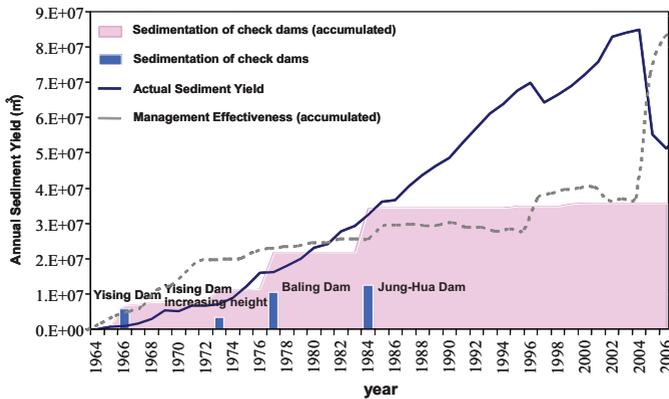


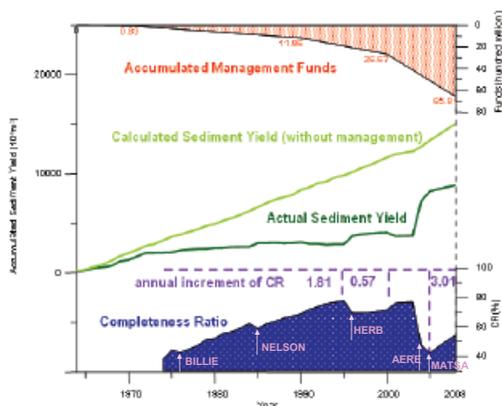
Fig.3 The relation between check dams and effectiveness of the long-term management

### RELATIONSHIP BETWEEN MANAGEMENT EFFECTIVENESS AND FUNDS

This study, based on long-term management effectiveness and the projects of the Soil and Water Conservation Bureau in Shihmen Reservoir, considers the estimated sediment-reduction amount and management expense for the coming two-phase management plan in subsequent 6 years. Then, the change status of historical completeness ratio of Shihmen Reservoir can be estimated, and so as the evolutionary trend of future completeness ratio after the implementation of projects in the future. The connection between management expense and completeness ratio can also be investigated, while the reasonable sediment yield is  $400,000\text{m}^3/\text{yr}$  (50% of the anticipative sediment yield before the reservoir built). And the sediment yield after management is assumed to recover to  $1.4\text{ million m}^3$  before typhoon Aere so as to explain the long-term management effectiveness and the implementation effects of subsequent plans.

As indicated with the calculation results found in figure 4, the average value of yearly completeness ratio reaches 60% as shown from the statistics of management effectiveness every year before 2006. And such value is considered as the judgment criteria as how good the management work in Shihmen Reservoir watershed is conducted, while the completeness ratio that reaches 60% is reckoned to have achieved favorable management effectiveness (Chen *et al.*, 2007). If not, special expense and manpower have to be invested to continuously implement conservation project. Besides, figure 4 has also elaborated the accumulation of prominent management effectiveness in the past with each of the conservation projects and realization of management measure so that the completeness ratio does not only exceeds 60%, sometimes even reaches 80%. Nonetheless, the completeness ratio has dropped with increased amount of sedimentation because of several serious typhoons, especially the critical sediment disaster created by typhoon Aere. It has thus ended up serious sediment loss in the watershed that existing management scale simply can't cope with it effectively. As a result, the completeness ratio drops to about 40%. If such ratio is based on with "Special Act Governing the Management of Shihmen Reservoir and Its Catchment Area" (Soil and Water Conservation Bureau, 2006) included for consideration, the completeness ration can be enhanced to 54% during the first phase (year 2006- year 2008) as evaluated by this study, and

enhanced to 62% during the second phase (year 2008 – year 2011) so that the sediment control in watershed can be gradually restored to previously favorable condition.



**Fig.4** The relation between management effectiveness and management funds

For the time being, the sediment control amount in the first-phase management works is estimated at 10.5 million cubic meters as planned, and the expense of management amounts NT\$3.914 billion. Besides, the annual increase value of completeness ratio between year 2005 to year 2008 is of the highest (3.01), seconded by year 1974 to year 1995 (1.81), and tailed by the year 1996 to year 2000 as of the smallest (0.57). As can be seen, though the completeness ratio during the period remains low as of the effects from typhoon Aere during the project implementation of conservation management in the watershed in the first-phase, its amount of annual increase is of the highest among others. Also, the annual increase of management expense between year 2005 to year 2008 is found to be most prominent (NT\$1.305 billion), and if it is exchanged to the effectiveness of completeness ratio as can be enhanced by the expense between year 2005 to year 2008 remains the lowest (value of comparison being 0.23). However, it is close to that of the result between year 1996 to year 2000 (value of comparison being 0.31). As can be learned, whenever there is extremely sediment-related disaster it would take greater amount of management expense and time than previous year before watershed can be restored to its previous completeness status.

## RESULTS AND CONCLUSIONS

This study has analyzed the sedimentation records to explain the increase in lifespan of reservoir and adopted the completeness ratio to represent the sedimentation reduction and management effectiveness. Results show that the increase of the Shihmen reservoir’s lifespan is about 60 years for the reason of the effectiveness of both the long-term reservoir management plans and watershed conservation works. Total quantity of sedimentation reduction is about  $80 \times 10^6 \text{ m}^3$  before 2003; meanwhile, the deposition of check dams is around  $40 \times 10^6 \text{ m}^3$ . The check dams in watershed, those large-scale check dams especially, are the groundwork for the management effectiveness of Shihmen Reservoir. This study is also trying

to find more efficient ways of utilizing available data to explain typhoons' effects on long-term watershed sediment management, and the completeness ratio is an answer and important benchmarks. The completeness ratio can explain both the tendency of sedimentation reduction over the years and the relationship between management effect and management funds. Additionally, the completeness ratio of Shihmen reservoir is not only soaring as time goes on but also descending during typhoon events. According to the variations based on the sediment yield and typhoon events, the results also interpret the rising on the completeness ratio with the increasing investment on the management.

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