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A study of typhoons induced high serious sediment concentration deposition into a reservoir and reduced the water supply in Taiwan

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# A STUDY OF TYPHOONS INDUCED HIGH SERIOUS SEDIMENT CONCENTRATION DEPOSITION INTO A RESERVOIR AND REDUCED THE WATER SUPPLY IN TAIWAN

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**Abstract** *The Shihmen reservoir is one of the most important reservoirs in the northern Taiwan, which is a multi-functional reservoir for irrigation, water supply, hydroelectric power, flood prevention and recreation. In 2004, the inflow of Typhoon Aere brought high sediment-laden flow into the Shihmen reservoir. Such massive sediment is been carried into the Shihmen reservoir and induced serious depositional problem. Sediment concentration of the inflow water during Typhoon Aere rose up to 326,700 ppm which was far-exceeded water treatment capacity. Such high turbid concentration caused water shortage for two weeks in the Taoyuan area where 2.4 million people live. In the recent years, the measured sediment concentration near the dam site showed the evidence of turbidity current traveling from upstream of the reservoir to the dam site and made serious deposition problem. If, the turbid inflow phenomenon could be controlled and desiltation opportunity could be realized in time, the efficient desiltation operation could be established and make sure the sustainable water supply.*

## 1. INTRODUCTION

Taiwan is situated at a geographical location with special climatic condition that brings to the Island 3.6 typhoons per annum on the average. These typhoons often result in flood disasters that can cause serious damage to properties and sometimes with severe casualties. On the other hand, when typhoon or heavy rain fall occurs in Taiwan, the watershed may generate amount of sediment yield. And, land development in the watershed could accelerate soil erosion. As sediment moves into a reservoir, deposition occurs due to decrease of velocity. In general, the large size sediment may deposit quickly to form delta near the backwater region tail. The hydraulic phenomenon of delta area is similar to the shallow water of open channel. The inflow sediment presents two patterns, bed load and suspended load. The bed load may deposit at the front set of delta, and the suspended load may flow through the delta and deposit by sorting (2). When turbid inflow continues to move, the turbulence energy decreases by resistance. The inflow may plunge into the reservoir to develop turbidity current and move toward downstream. When turbidity current arrived at dam site, the flow would climb up along the dam slope. If gravity force, resistance and inertial force were equilibrium, the flow would stop to climb and started to drop. Then, the positive surge developed and moved to upstream. Finally, the reservoir would become turbid. If lower sluiceway facility could be operated in time, the turbid flow would be flush out and reduce sediment deposit. But, if the outflow discharge was insufficient, the desiltation efficiency would be discounted and the sediment would deposit. However, the research of desitation operation and positive surge in reservoir was limited (3,4,5).

This study presents the historical measurement results of sediment concentration from 2004 to 2008 in which had typhoons with heavy rainfall. The operation between water supply and turbidity current venting was preliminary discussed through field observations.

## 2. DESCRIPTIONS OF THE SHIMEN RESERVOIR

The Shihmen reservoir is a multi-functional reservoir and its functions include irrigation, water supply, hydroelectric power, flood prevention and recreation. The irrigation service area includes Taoyuan, Hsinchu and Taipei for a total of 36,500 ha, which means it is a major contributor in helping boost the agricultural productive levels in the areas serviced. The reservoir supplies water to 28 districts and 3.4 million people. This makes it a very important water source for the livelihoods of the people living in northern Taiwan. Making use of the water impoundment at Shihmen Dam, the Shihmen Power Plant generates 200 million units power annually, a vital contribution to help electric power demand and boost industrial development. The main function of Shihmen reservoir is to prevent or improve the rapid descent rates of the rivers upper tributaries, reducing the effect of peak flood cresting, and saving the areas below, such as the Taipei floodplain, from waterborne disaster (6).

The Shihmen reservoir has a natural drainage area of 762.4 $km^2$. It is formed by the Shihmen dam located at the upstream reach of the Dahan River. The Dahan River is one of the three tributaries of the Tamshuei River which flows westward the Taiwan Strait. A map of the watershed area of the Shihmen reservoir is presented in fig. 1. The Shihmen dam was constructed in 1963 is a 133.1m high embankment dam with spillways, permanent river outlet, power plant intake and flood diversion tunnels controlled by tailrace gates. The elevations of the spillway crest, permanent river outlet, power plant intake and flood diversion tunnels are EL.235 m, EL.169.5m, EL.173m and EL.220m, respectively. The total discharge of spillways is 11,400 $m^3/s$, permanent river outlet is 34 $m^3/s$, power plant intake is 137.2 $m^3/s$ and flood diversion tunnels is 2,400 $m^3/s$. With a maximum water level of EL.245 m, the reservoir pool is about 16.5 km in length and forms a water surface area of 8.15 $km^2$. The initial storage capacity was 30,912x $10^5$ $m^3$, and the active storage was 25,188x $10^5$ $m^3$. Due to a lack of sufficient desiltation facilities, incoming sediment particles have settled down rapidly along the reservoir since the dam was completed. Based on the survey data, the Shihmen reservoir has accumulated a significant amount of sediment after dam completion. The depositional pattern has become wedge-shaped since 2000. From recent survey data in 2007, the storage capacity was estimated to be 69.28% of its initial capacity. Based on the survey data, the longitudinal bed profile along the reservoir is plotted in Fig. 2. As shown in Fig. 2, the Shihmen reservoir has accumulated a significant amount of sediment after dam completion. The Fig. 3 presents the sediment size distribution and the figure shows the sediment distribution is uniform. Based on sediment size distribution, the sediment classify in reservoir is closed to silt or clay (7).

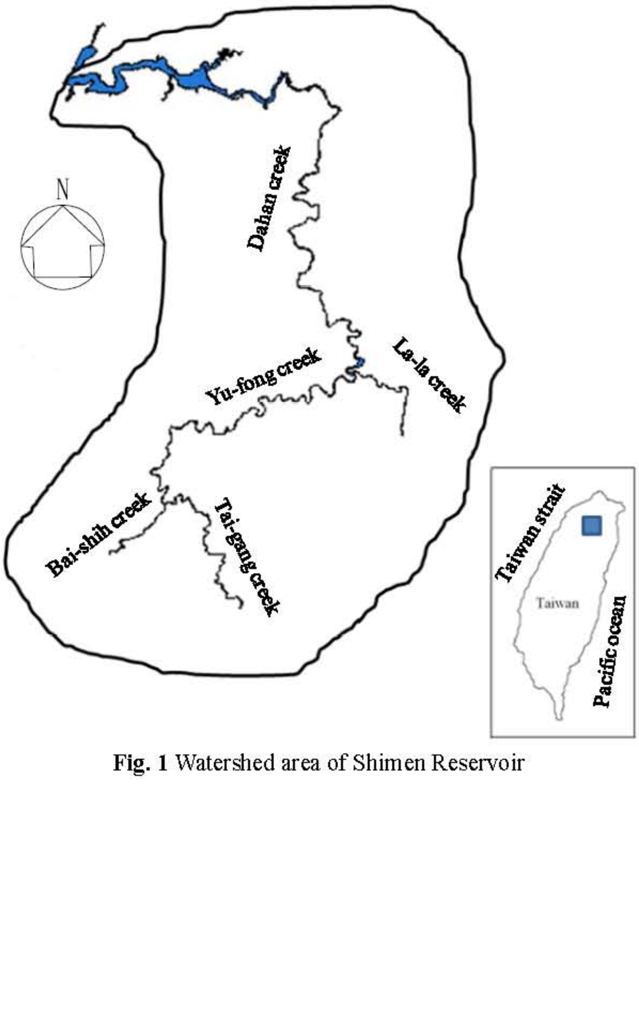


**Fig. 1** Watershed area of Shimen Reservoir

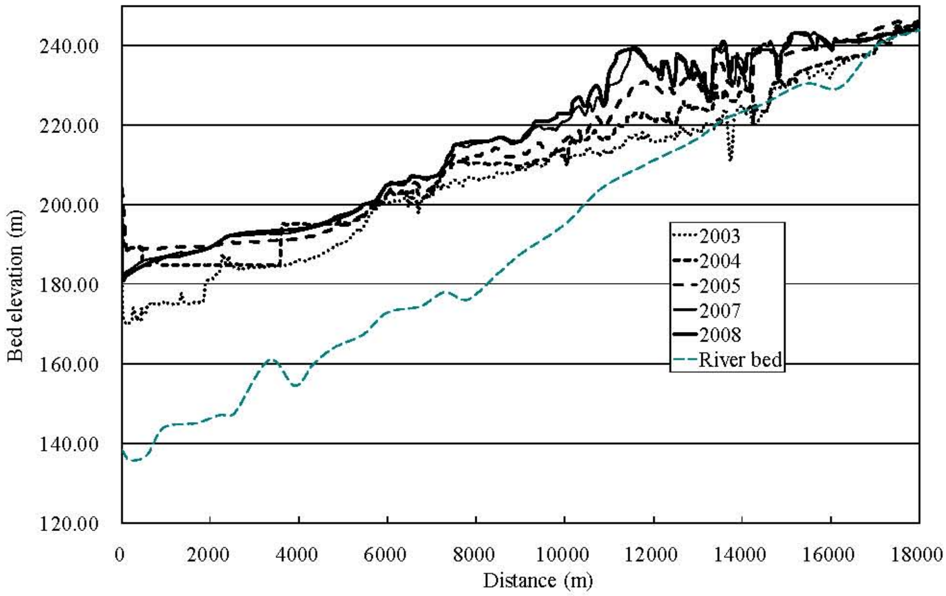


**Fig. 2** Longitudinal bed elevation of Shimen reservoir

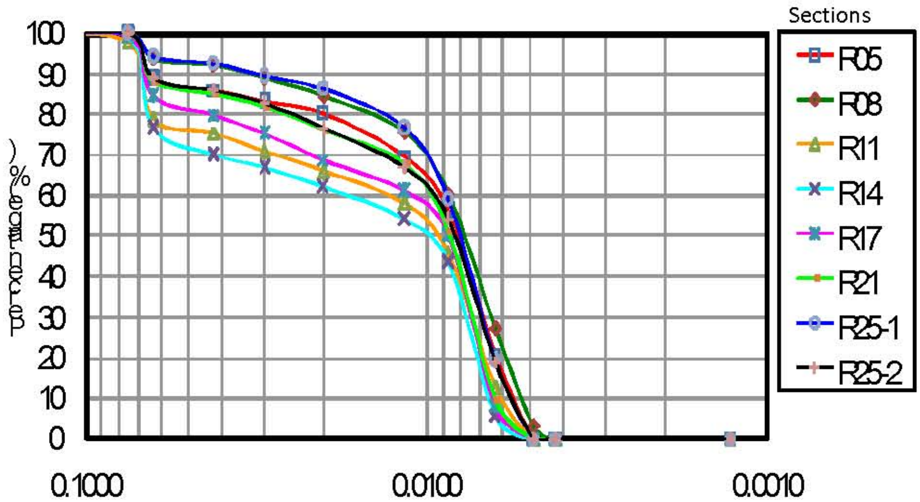


**Fig. 3** Sediment size distribution (No. is from dam to upstream)

## 3. FIELD MEASUREMENT RESULTS

In 2004, typhoon Aere attacked northern Taiwan and caused substantial losses. Typhoon Aere brought into Tamshui River Basin a total rainfall of 973mm in 4 days (about 40% of the mean annual rainfall of the Basin). The extremely heavy rainfall induced high turbidity in the runoff entering Shihmen reservoir, as shown in Fig. 4. The turbidity far-exceeded the purification capability of the water treatment plants in the downstream area. As a consequence, 2 million residents in Taoyuan County suffered from a shortage of water supply for 17 days.

The excessive rainfall induced serious landslides in an area of 265 ha in the Shihmen reservoir watershed. This generated high sediment concentration in the runoff entering the reservoir. The main composition of the geology of Shihmen reservoir watershed is shale, which can be weathered easily and is the main source of the fine-grain clay. This kind of geological composition deteriorated further the quality of stream-flow and sustained the turbidity in the reservoir for longer period of time after reservoir during the attack of Typhoon Aere. Before the attack of Typhoon Aere, retaining basins behind many sabo dams were nearly filled up to their capacity. In addition, the volume of landslide caused by Typhoon Aere far-exceeded the remaining capacity of the sediment retaining basins. The facilities to take the water from the Reservoir are located at lower levels. In the Typhoon Aere induced event, the turbidity at lower level of Shihmen Reservoir reached 326,700 ppm, which is far-beyond the maximum turbidity that water treatment plants can handle. Due to the limitation of the water conveying capacity, the water treatment plants in neighboring counties can only support limited amount of water needed. So, the high sediment concentration problem is serious, not only public water supply but also sediment deposition problem.

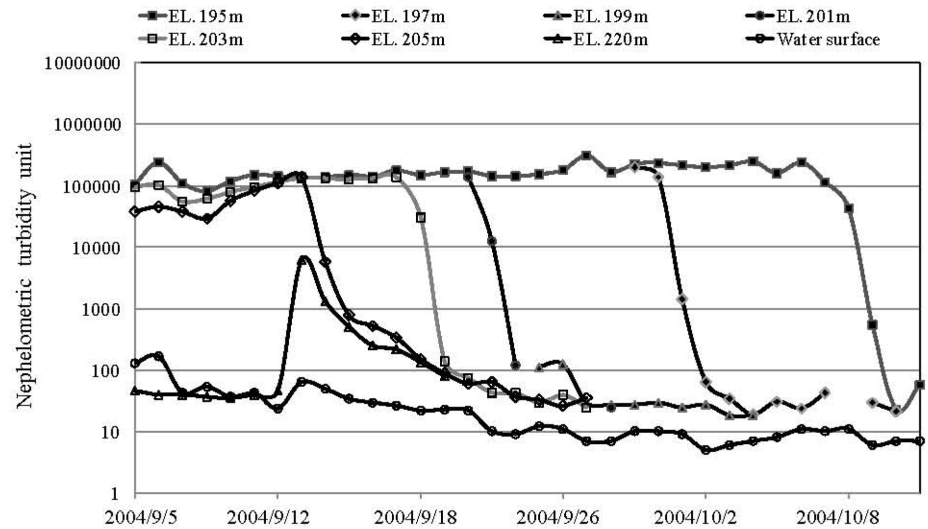


**Fig. 4** Sediment concentration hydrograph at EL. 193 near dam site of typhoon Aere

In 2005, another three typhoons attacked Shimen reservoir which included Haitang, Matsa and Talim typhoons. The maximum sediment concentration near the dam site of Haitang, Matsa and Talim typhoon were 37,530ppm, 62,505ppm and 96,400ppm, respectively. In 2007 and 2008, the maximum sediment concentration near the dam of typhoon Sepat and Jangmi were 53,547 and 36,947 ppm, respectively. They are similarly brought sediment problem and the inflow concentration exceeded water treatment capacity of the plant which can only deal with 8,100 ppm. The Fig. 5, Fig. 6 and Fig. 7 represented concentration time sequence and the concentration was significantly delaminated. Therefore, we can assume the turbidity current was flowing under the reservoir bottom. The figures also presented the deposition velocity is slow, because the concentration decreasing is about 1,350ppm per week. As the results, in 2004, the high sediment concentration problem attacked the Shimen reservoir operation seriously.

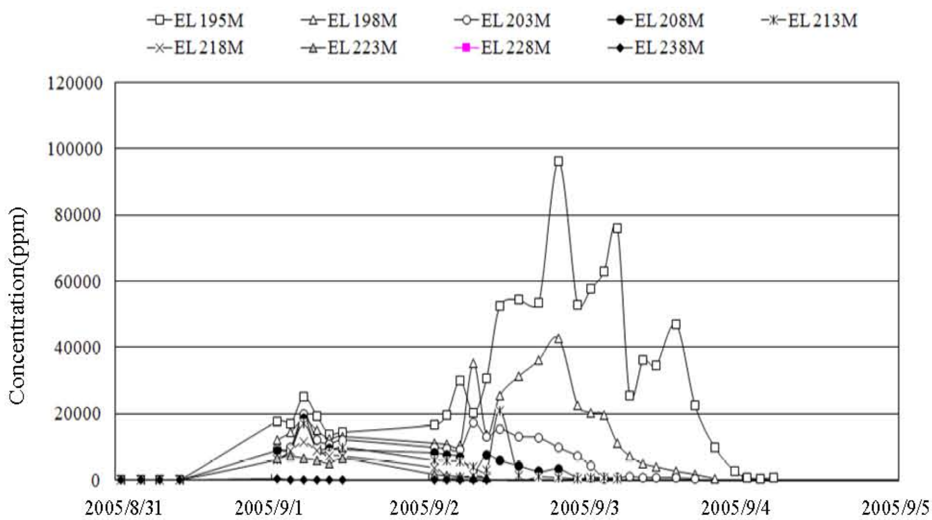


**Fig. 5** Sediment concentration hydrograph at EL. 193 near dam site of typhoon Talim

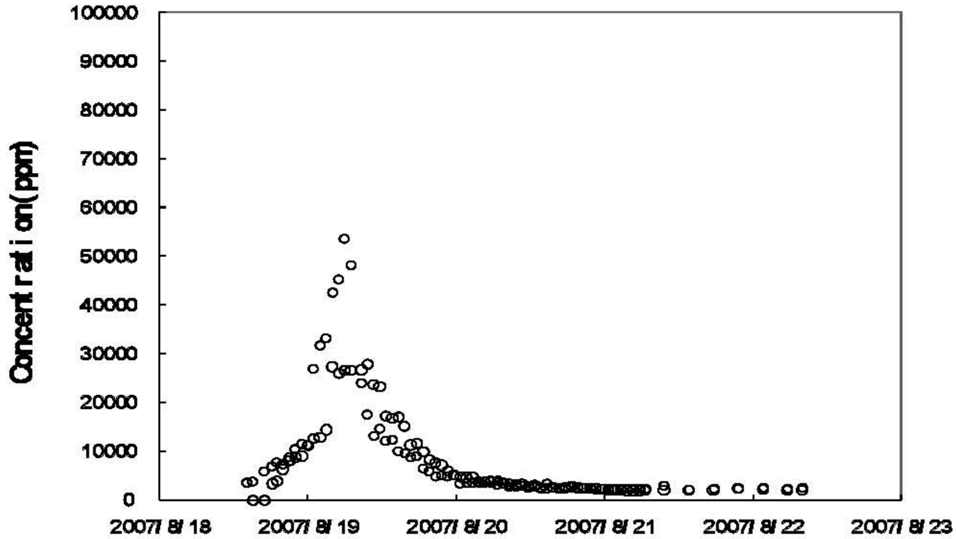


**Fig. 6** Sediment concentration hydrograph at EL. 173 near dam site of typhoon Sepat

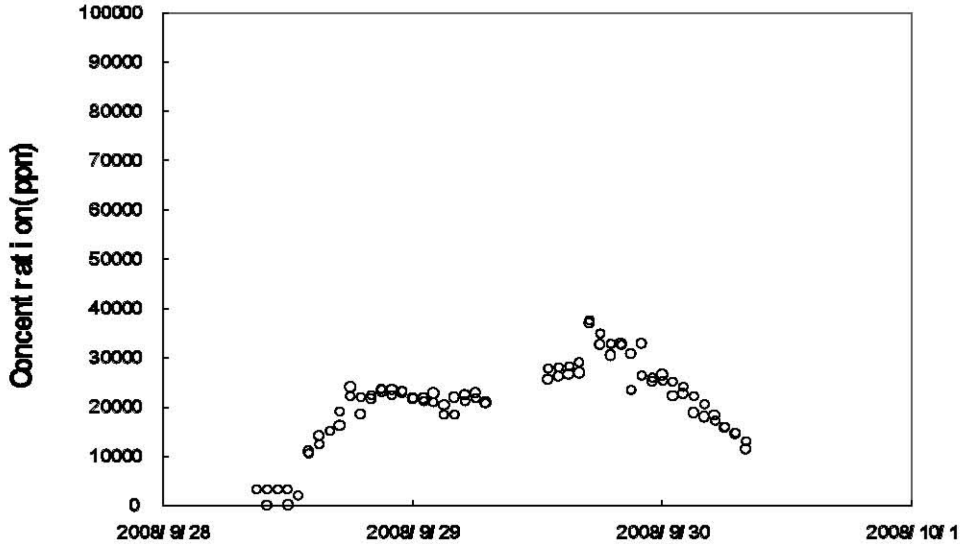


**Fig. 7** Concentration hydrograph at EL. 173 near dam site of typhoon Jangmi

## 4. CONCLUSIONS AND DISCUSSIONS

Due to high-turbid inflow problem in the Shihmen reservoir, the operation of sediment sluicing and sediment concentration monitoring are essentially important. Using the ultrasonic turbidity-velocity instrument (8) and the other measurement facilities, the sediment concentration and discharge can be monitored for real-time operations. Through numerical modeling, the turbidity current flow phenomenon also can be simulated. The real-time prediction can combine these two techniques and control the timing of water allocation for irrigation or water supply. In the resent study, ultrasonic turbidity-velocity equipment is developed to real-time field measurements of sediment concentration. Many 3D numerical models(1) and empirical formulas are adopted to predict the sediment concentration distribution near the intakes. Fig. 8 shows the relationship between intakes and turbidity current. Based on simulation results and field observations, the refined intakes can use to vent sediment and the calculated results can provide the information of operation timing for allocating public water supply (if sediment concentration 6,000 NTU) and irrigation water (if sediment concentration 10,000 NTU).

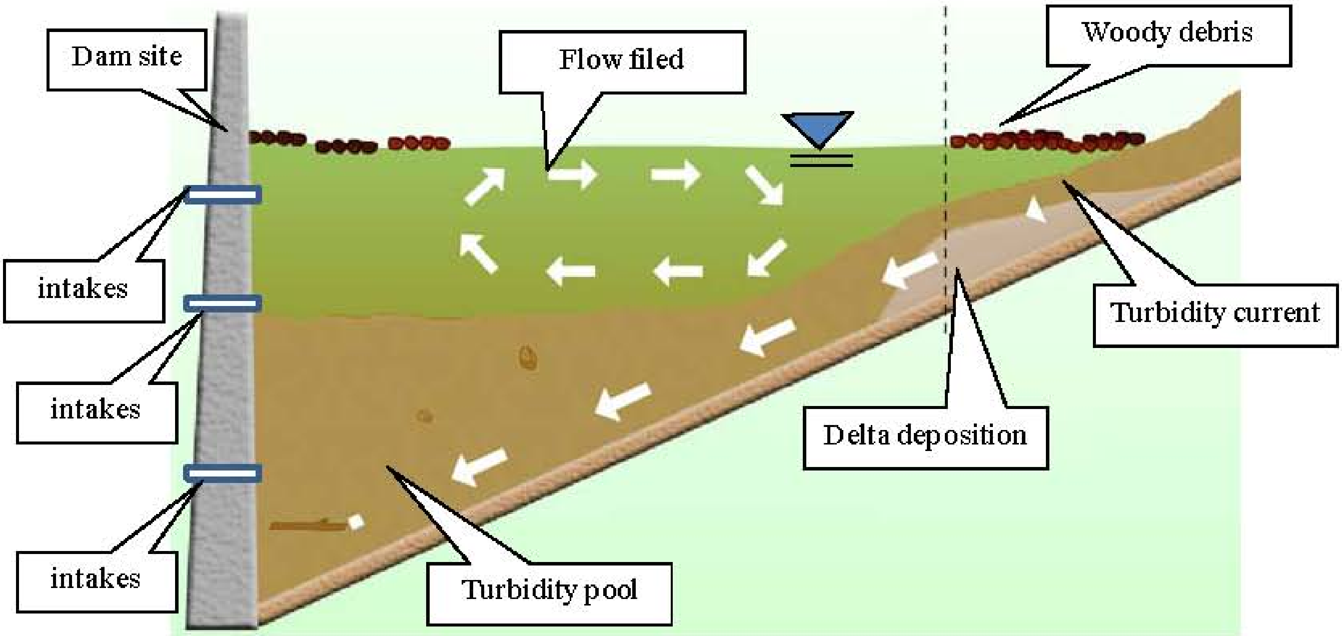


**Fig. 8** Relationship between intakes and turbidity current

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