Analysis of turbidity currents movement in Tzengwen Reservoir

Chiun-Chau Su, Chun-Shen Chen, Chun-Hung Chen

Abstract

Tzengwen Reservoir is the biggest reservoir in Taiwan. Its present volume capacity is 510 million m^3. The desilting tunnel of Tzengwen Reservoir was finished in January, 2018. The desilting tunnel is located nearby the dam and the diameter is 10 meters. The maximum flowrate can reach to 995 m^3/s at full water level. For operating requirements, it is important to know whether turbidity currents move to the dam or not before inflow starts for each single event and estimate the time when turbidity currents move the dam. However, travelling time of turbidity currents is not known well. Here we chose Tzengwen Reservoir as a target to analysis the movement of turbidity currents. We provided simple rules with volume-based analytical method to estimate whether turbidity currents can move to the dam or not before inflow start into the reservoir and estimate the time when turbidity currents moves to the dam. The idea with volume-based analytical method is based on that turbidity currents moving to the dam need enough volume to pass through the underwater region of the reservoir to the dam. Therefore, the volume of the reservoir is important. Before each event begins, the volume of the reservoir is also different by initial water level. In our analysis, turbidity currents can move to the dam as total inflow volume is larger the volume of the reservoir at initial water level. It can be applied to estimate whether turbidity currents can move to the dam or not by rainfall forecast before the inflow start. For real-time analysis, the analysis provides two conditions to determine the time when turbidity currents move to the dam. One is the average flowrate larger than 1,500 m^3/s. The other is the inflow volume reach 0.5 times of reservoir volume at initial water level. The time when turbidity currents reach the dam usually occurs as the two conditions both are met. Average flowrate can represent hydrological factor of turbidity currents and inflow volume can represent physiographic factor of reservoirs. It shows good results for analysis of Tzengwen Reservoir. This analytical method maybe can be applied to different reservoirs by setting different thresholds of conditions.

Keywords: turbidity currents, Tzengwen Reservoir, travelling time

1 Introduction

Turbidity currents are sediment laden flow. It usually occurs in large rainfall, especially typhoon events in Taiwan. It is a threat for capacity and water supply of reservoirs, because large sediment is carried by strong flow. Desilting strategies were investigated by researchers (Morris and Fan 1998, Lee *et al.* 2010, Sumi *et al.* 2011, Lee *et al.* 2012). The turbidity currents are also called density currents by the density different to water. The turbidity currents usually submerge in reservoirs and move along bottoms. As the turbidity currents moves, the currents entrain clear water from outside and sediments fall down from currents to bottoms. These processes let the turbidity currents dilute. The turbidity currents maybe can occur in upstream of reservoirs, but not every time can keep moving to downstream of reservoirs. This phenomenon can be observed from field sample (SRWRO 2013). The movement of turbidity currents can be simulated by numerical model (Cao *et al.* 2015). Numerical simulation can estimate the travelling time of the turbidity currents. However it is time consumed and complicated. In this research, we provide a simple method to estimate where turbidity currents arrival to the downstream of reservoirs before events begin and real-time estimate turbidity currents' arrival time.

2 Background

Tzengwen Reservoir is the biggest reservoir in Taiwan. It is located in southern Taiwan (see Figure 1). Its present volume capacity is 510 million m^3. The desilting tunnel of Tzengwen Reservoir was finished in January, 2018. The desilting tunnel is located nearby the dam (see Figure 2) and the diameter of the tunnel is 10 meters. The maximum flowrate can reach to 995 m^3/s at full water level. The intake tower (red circle in Figure 2) is for the intakes of power plant and PRO. The sampling station of concentration is at intake tower. The intakes of sampling pipes were laid on the outside of the intake tower by different heights. Thus the sampling station can sample water from different level. This station is the oldest sampling station in the reservoir. So far there are several stations along the reservoir to observe the concentration along long profile of the reservoir. However the intake tower station is the oldest and has the most sampling data.

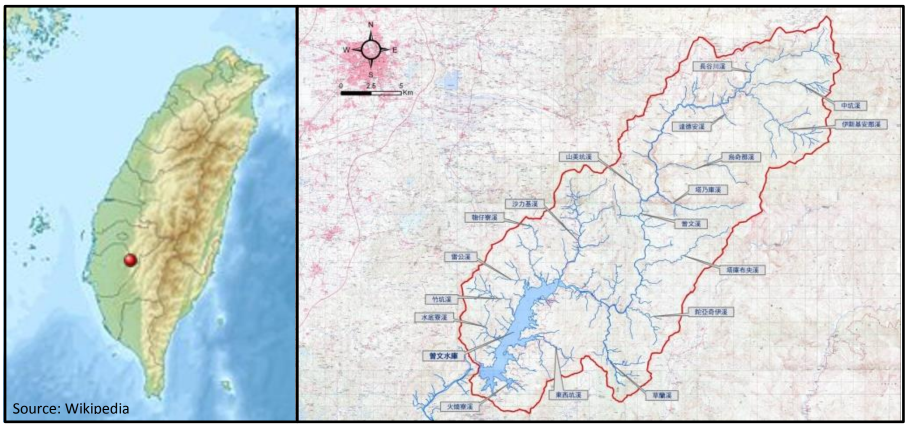


Figure 1: Location(left) and watershed(right) of Tzengwen Reservoir

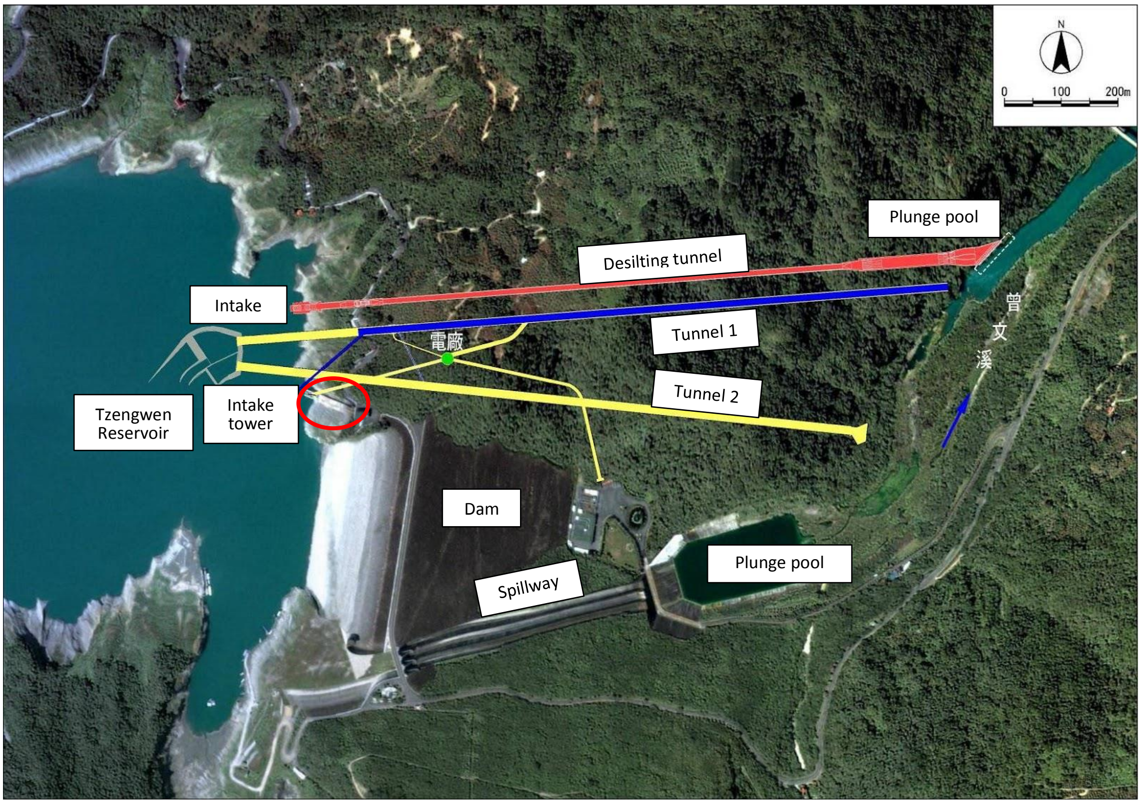


Figure 2: Structural layout of Tzengwen Reservoir

3 Estimation of turbidity currents arrival or not before events

For operation of the desilting tunnel, whether turbidity currents move to the dam or not to be sluiced is the most important thing for authority of the reservoir. Figure 3 shows the classification of turbidity currents. The x-axis is the total inflow volume of each event and the y-axis is the initial water level of the reservoir before each events. The brackets is the highest concenration sampled at the dam during each event. The intensity of turbidity currents was roughly classified by three ranges here. Green is low concentration (less than 10,000ppm), yellow is middle concentration (between 10,000 to 100,000ppm), and red is high concentration (larger than 100,000ppm). We assume turbidity currents need enough volume to keep it move to the dam, so total inflow volume is chosen as x-axis here. As total inflow is higher and the water level is lower, turbidity currents can easily move to the dam. We define the highest concentration at the dam larger than 10,000ppm means that the turbidity current reaches to the dam.

For further analysis, change initial water level to the initial volume of the reservoir and the total inflow volume was divided by the initial volume. It is easily to be found that as the volumetric ratio roughly larger than 1, turbidity currents can move to the dam. This is a simple conclusion to determine whether turbidity currents move to the dam or not by the volumetric ratio. The estimation of total inflow volume can be from rainfall forecast and the area of watershed.

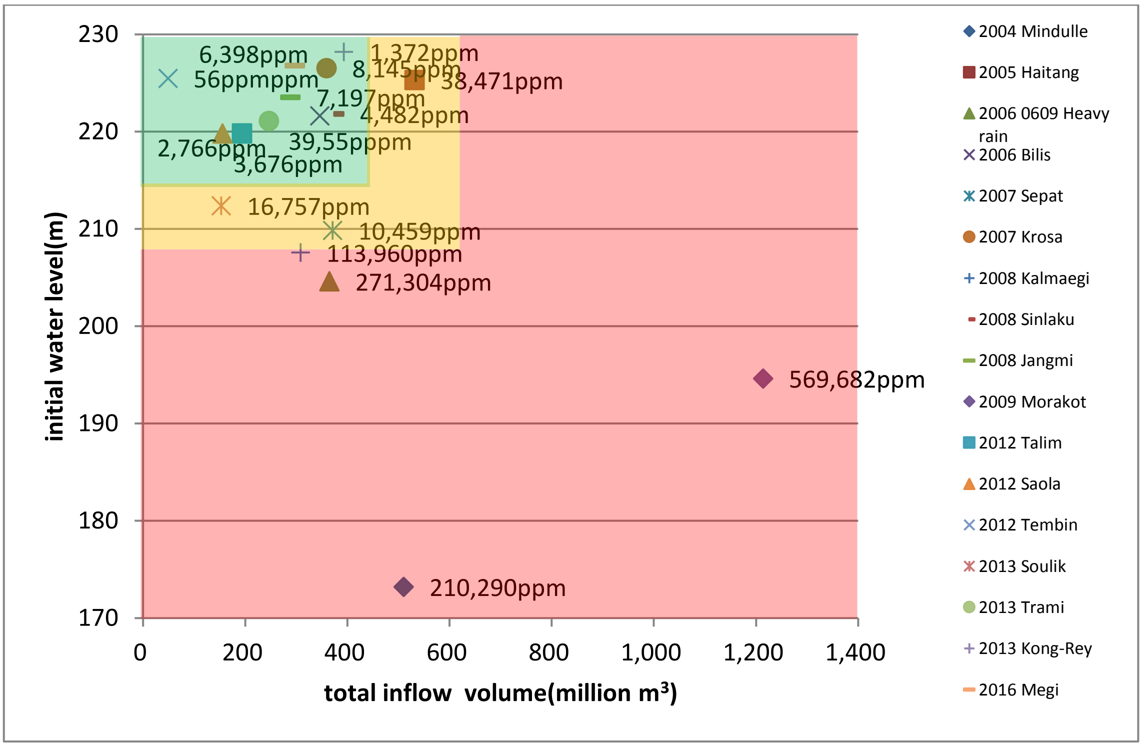


Figure 3: Intensity classification of turbidity currents in Tzengwen Reservoir

Table 1: Relationship between volumetric ratio and concentration

Item	Date	Event	Initial water level of reservoir (m)	Initial volume of reservoir (million m^3)	Total inflow volume (million m^3)	Total inflow volume/initial volume of reservoir	The highest concentration at the dam (ppm)
1	2004.07.02	Mindulle	173.2	9	510	**53.95**	**210,290**
2	2005.07.17	Haitang	225.3	573	532	**0.93**	**38,471**
3	2006.06.08	0609 Heavy rain	204.6	250	365	**1.46**	**271,304**
4	2006.07.13	Bilis	221.6	543	346	0.64	6,378
5	2007.08.16	Sepat	209.8	317	371	**1.17**	**10,459**
6	2007.10.06	Krosa	226.5	577	359	0.62	8,145
7	2008.07.16	Kalmaegi	207.6	287	308	**1.07**	**113,960**
8	2008.09.12	Sinlaku	221.8	490	374	0.76	4,482
9	2008.09.28	Jangmi	223.5	558	289	0.52	7,191
10	2009.08.06	Morakot	194.6	141	1,214	**8.63**	**569,682**
11	2012.06.18	Talim	219.8	370	194	0.52	3,676
12	2012.08.01	Saola	221.1	391	156	0.40	2,766
13	2013.07.12	Soulik	212.4	250	153	**0.61**	**16,757**
14	2013.08.21	Trami	221.1	375	246	0.66	3,955
15	2013.08.27	Kong-Rey	228.2	501	393	0.78	1,372
16	2015.08.06	Soudelor	210.9	221	164	0.75	2,241
17	2015.09.28	Dujuan	225.7	449	178	0.40	714
18	2016.09.26	Megi	226.8	482	297	0.62	6,398

4 Real-time estimation of turbidity currents arrival time

In this section, a real-time analysis method is discussed. The evens of turbidity currents arrival are still analyzed. When turbidity currents move to the dam, it usually satisfies the average discharge larger than 1 and the accumulative inflow volume is 0.5 times of the initial volume of the reservoir (see Table 2).

Figure 5 shows the hydrographs of turbidity currents moved to the dam and Figure 6 shows the hydrographs of turbidity currents didn’t move to the dam. Y-axis is the discharge, and x-axis is the ratio of the accumulative inflow volume to the initial volume of the reservoir. Instead of time, the volumetric ratio is used in x-axis. The blue line is discharge, the red line is average discharge, the horizontal dash line is the threshold as discharge is equal to 1,500cms, the vertical dash line is the threshold as volumetric ratio is equal to 0.5, and the solid line is the time when turbidity currents move to the dam (e.g. the time when sampled concentration is larger than 10,000ppm).

The time when turbidity currents arrival (solid line) usually meets the two thresholds and the trend of inflow discharge is rising.

Figure 5 shows the failure cases. It is obviously the volumetric ratio less than 0.5 or average discharge less than 1,500 m3/s for some cases. Even it meets the two thresholds. The inflow discharge is obviously decreasing from the peak of the discharge.

Figure 6 shows the real and estimated arrival time of turbidity currents. The length of line is the duration of each event. The errors are from 0 to 6 hours. Black bar means turbidity currents arrival time is later than estimation; white bar means turbidity currents arrival time is earlier than estimation.

Table 2: The key factors as turbidity currents arrival

Item	Date	Event	The highest concentration at the dam (ppm)	Initial water level of reservoir (m)	Accumulative inflow volume as turbidity arrival (million m^3)	Average discharge as turbidity currents arrival (cms)	Initial volume of reservoir (million m^3)	Accumulative inflow volume/initial volume of reservoir as turbidity arrival
1	2004.07.02	Mindulle	210,290	174.0	38	1,492	11	3.54
2	2005.07.17	Haitang	38,471	224.3	31,309	2,174	562	0.56
3	2006.06.08	0609 Heavy rain	271,304	204.6	12,982	1,717	2	52.03
4	2007.08.16	Sepat	10,459	210.8	17,127	1,487	330	0.52
5	2008.07.16	Kalmaegi	113,960	207.8	13,741	3,470	289	0.47
6	2009.08.06	Morakot	569,682	194.9	29,208	1,932	143	2.04
7	2013.07.12	Soulik	16,757	212.5	13,903	1,755	251	0.55

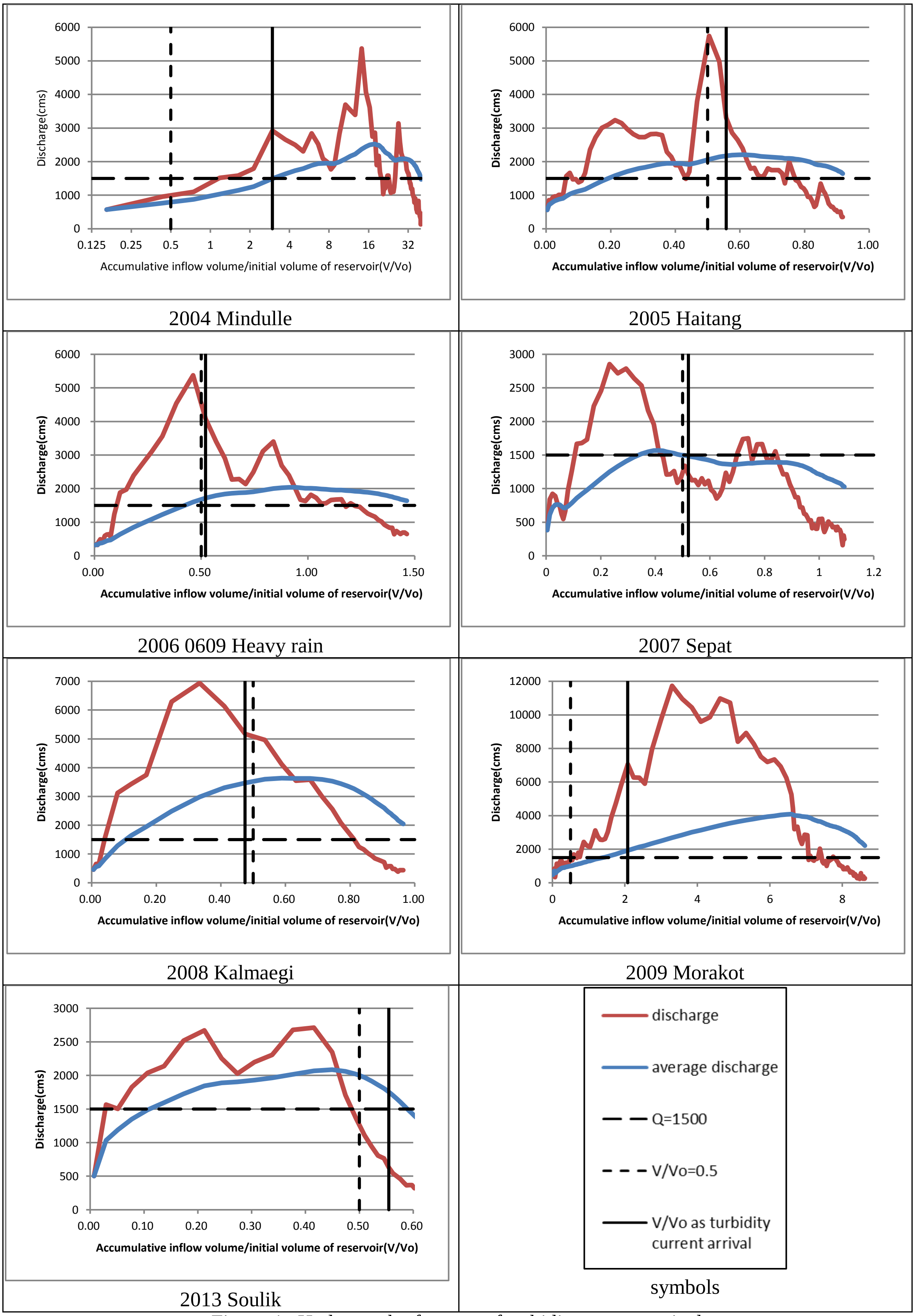


Figure 4: Hydrograph of events of turbidity current arrival

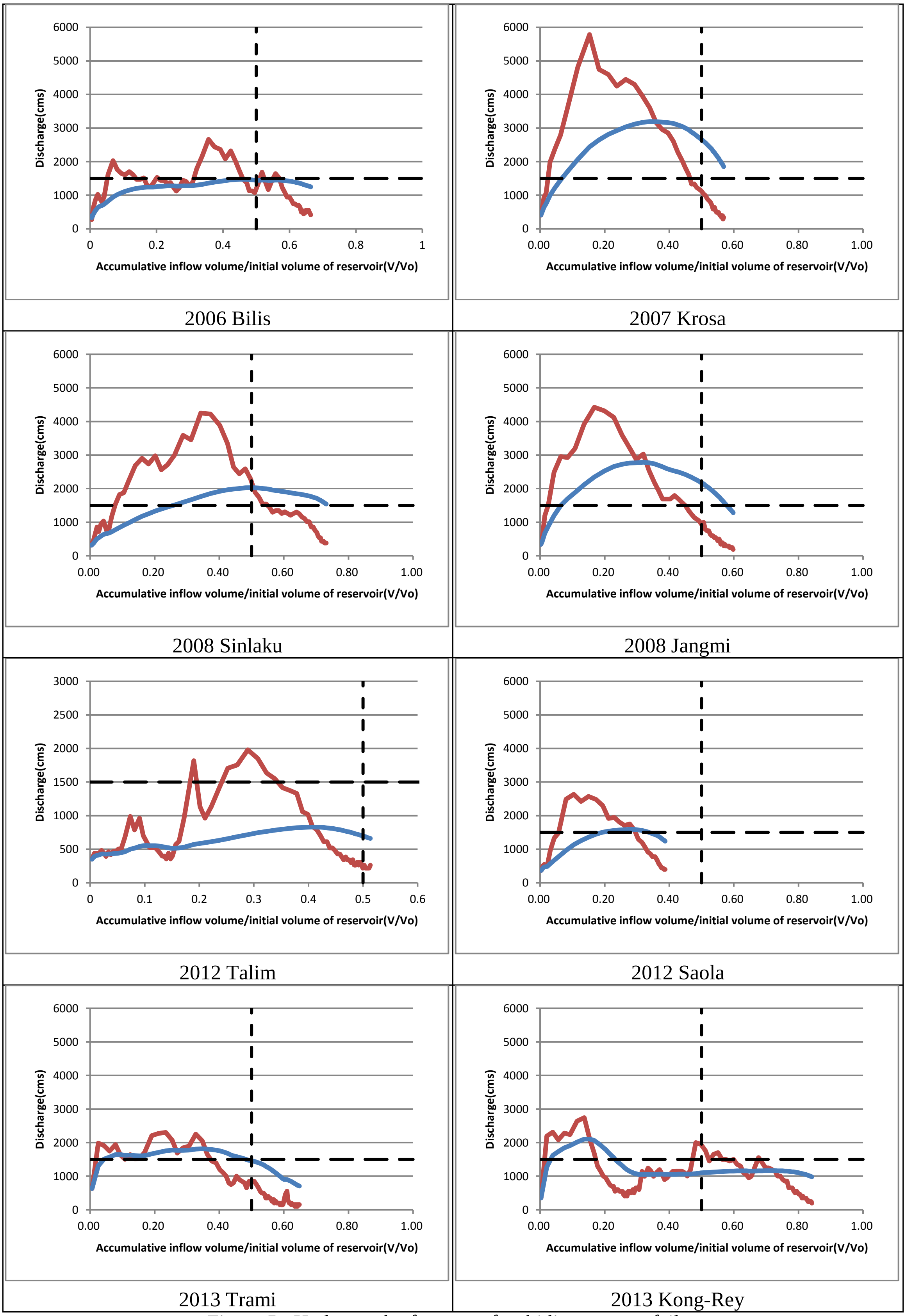


Figure 5: Hydrograph of events of turbidity currents failure

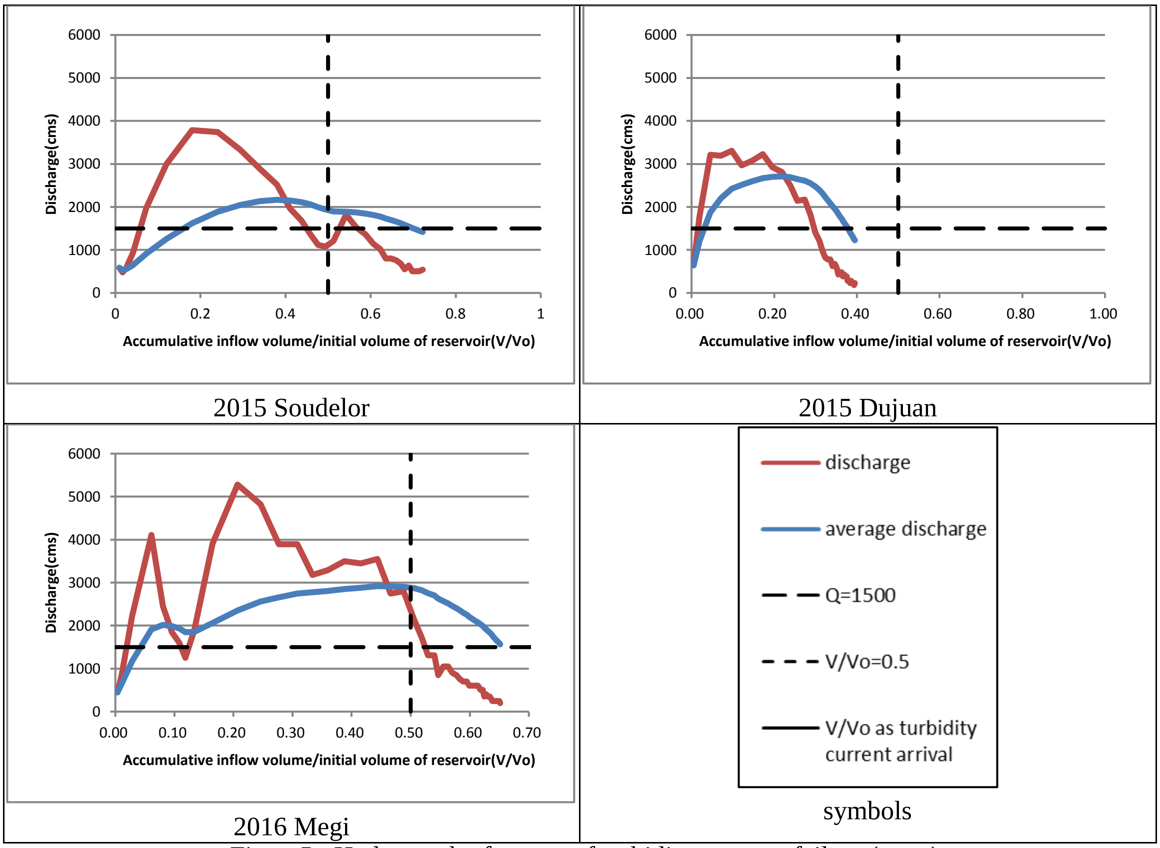
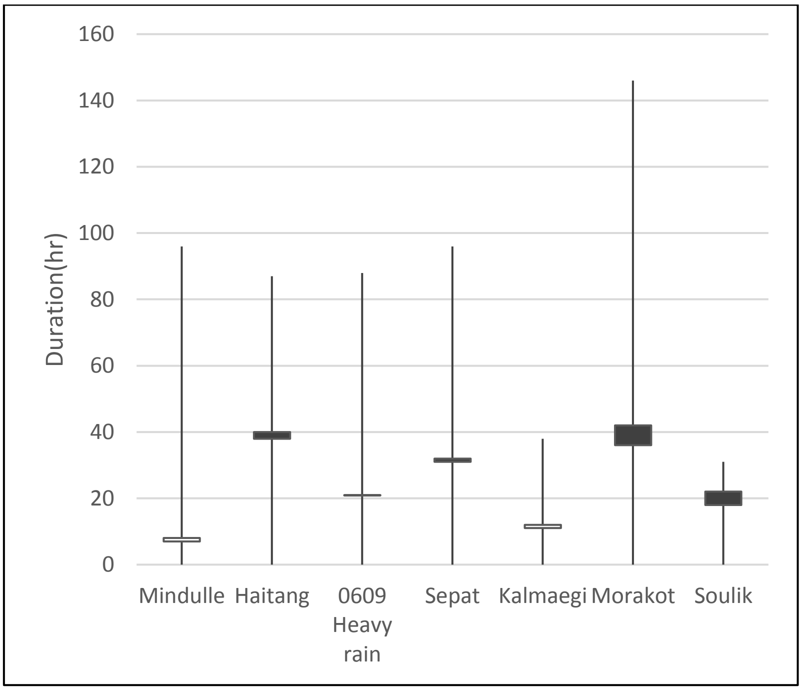


Figure5: Hydrograph of events of turbidity currents failure (cont.)



Note: black bar means turbidity currents arrival time is later than estimation; white bar means turbidity currents arrival time is earlier than estimation.

Figure 6: Comparison between predicted and real arrival time

5 Conclusions

In this research, we chose Tzengwen Reservoir as target. The total inflow volume larger than the initial volume of the reservoir can be used to estimate whether turbidity currents can move to the dam or not before events begin. For real-time analysis, the analysis provides two conditions to determine the time when turbidity currents move to the dam. One is the average discharge larger than 1,500 m^3/s. The other is the inflow volume reach 0.5 times of reservoir volume at initial water level. The time when turbidity currents reach the dam usually occurs as the two conditions both are met. Average discharge can represent hydrological factor of turbidity currents and inflow volume can represent physiographic factor of reservoirs. It shows good results for analysis of Tzengwen Reservoir. This method maybe can be applied to different reservoirs by setting different thresholds.

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