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Simulation of Saguling Dam Break Using the HEC-RAS Software

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Abstract: The Saguling dam is built on the cascade system of the Citarum river. The Saguling dam is located upstream of the system over the Cirata and Jatiluhur dams. Besides having the many benefits (irrigation, recreation, flood control, water storage, etc.), the Saguling dam saves the risk of big dangers in the case of the failure. The general failure or dam break reason of the Saguling dam can happen due to the internal and external factors. The internal factor is an occurrence of breach in the dam body that causes the process of piping in the top, center and low part of the dam body. Another internal factor is the mal-function of the spillway if the water discharge is too much. The external factor is the big flood discharge that can cause the overtopping. This research intends to conduct the simulation of dam failure or dam breaks in the Saguling dam. The methodology consists of data collection for the material of dam break analysis 2D like hydrology data, digital map, and technical data of dam. Then, the collected data was analyzed using the HEC-RAS software. Considering the possibilities of failure risk of Saguling dam, the simulation analysis of dam failure or dam break was performed for some scenarios and their impacts on the downstream part of the dam. The results show that the Saguling dam with the overtopping scenario has the worse impact than the piping scenario with the maximal inundation area and the possibility area of 19.39 km^2. The simulation of the Saguling dam failure or dam break produces the flood discharge whose flow will reach the Cirata reservoir in 3 hours.

Keywords: dam, failure, dam break, simulation, piping, overtopping.

使用HEC-RAS软件模拟 萨古灵溃坝

摘要：萨古林大坝建在柑桔河的梯级系统上。萨古林大坝位于西拉塔和贾蒂卢赫大坝上方的系统上游。除了有许多好处（灌溉、娱乐、防洪、蓄水等）外，萨古岭大坝还可以在发生故障的情况下避免巨大的危险。萨古岭大坝的一般故障或溃坝原因可能是由于内部和外部因素造成的。内部因素是坝体发生破口，导致坝体顶部、中部和下部布管过程。另一个内部因素是溢洪道的故障，如果排水量过多。外在因素是大洪水造成的超限。本研究旨在对萨古岭大坝的溃坝或溃坝进行模拟。该方法包括水文数据、数字地图和大坝技术数据等二维溃坝分析材料的数据收集。然后，使用HEC-RAS软件分析收集的数据。考虑到萨古岭大坝发生溃坝风险的可能性，针对部分情景及其对大坝下游的影响，进行了溃坝或溃坝的模拟分析。结果表明，覆顶情景的萨古岭大坝的影响比淹没面积最大、可能面积19.39平方公里的管道情景的影响更差。萨古林大坝溃坝或溃坝的模拟产生了洪水，其流量将在3小时内到达 西拉塔 水库。

关键词：大坝，失效，溃坝，模拟，管道，超限。

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1. Introduction

A reservoir usually functions as a storage that is used for raising the water level [1]-[2], and the dam body acts as a barrier to the seepage of the water downstream and as a buffer for the water storage. If the reservoir has the multipurpose functions that are for irrigation, water supply, flood control, hydroelectrical power, and fishery, we can imagine the significance of the reservoir functions for human life [3]-[4]. The dam break will threaten the human life and goods and the spread of the flood wave since there are general facility structures, human residential and agricultural areas in the downstream of the dam. This is due to the less minimum knowledge about the inundation depth of the flood and the travel time [5]. Flood behavior of dam break has a special characteristic due to the potential energy because of the elevation difference between downstream and upstream of the dam that will cause the high flow velocity and sudden outflow from storage to the downstream of the dam [6]-[7]. The important parameters, which affect the flood greatly due to the dam break include the travel time of the flood wave, travel time of the flood peak, and the flood peak depth [8]. Flood routing very necessary for analyzing these three parameters [9, 10].

The Saguling dam is located in the West Bandung Regency, West Java Province, and at an elevation of 643 m over the sea. By the cascade system, the Saguling dam is one of the three reservoirs that dam the flow of the Citarum river located in the most upstream and then followed by the Cirata and Djuanda (Jatiluhur) dams located at the bottom. The inundation area of the Saguling reservoir is about ± 5,600 ha with the volume of initial storage 875 million m^3 during the first operation in 1986.

The area of the Saguling watershed is about 2,283 km^2, the average yearly rainfall is estimated lower being 1,702 mm/year. Based on a previous study, the design flood that can happen in the Saguling watershed for 1,000 years is about 5,585.7 m^3/s; however, the maximum flood, or Q_{PMF} (probable maximum flood), can be about 8,099.7 m^3/s).

As this dam is located in the most upstream in the cascade dam system of the Citarum river, it has one of the main functions, such as the stability and safety guards of the dam structure under it. In the case of the failure or dam break in the Saguling dam, the downstream dams will have the same risk directly because the water flow as the result of the Saguling dam break is directed into the dams under it.

The potency of flood discharge (Q_{PMF}) and the large reservoir volume can cause the dam break disaster. Therefore, it is necessary to simulate the Saguling dam break and analyze its impact in the downstream.

2. Materials and Methods

2.1. Study Location

The research location is in the Saguling dam that is built on a section of the Citarum river. Administratively, the Saguling dam is located in the Saguling village, Saguling district, West Bandung Regency, West Java Province. The owner of Saguling dam is PT PLN (Persero) and the Manager of Saguling Dam is PT Indonesia Power UPB Saguling.

The development process of the Saguling dam was in progress from 1980 until 1986. The dam construction (embankment) is in the Saguling dam, the Saguling district. However, this dam drowns 49 villages. About 12,000 households were moved, part of them followed the transmigration project. The designed life time of the dam is about 60 years, i.e., until 2044.

The Saguling dam is built for the electrical energy interest. In the beginning stage, the installed electrical energy generation has the capacity in the amount of 700 MW. In the course of time, the electrical capacity increased to 1,400 MW, it is due to the increasing demand for electricity. The Saguling dam functions as a fishery, irrigation, agro-aqua-culture, and tourism facility. Figure 1 presents the Saguling dam and reservoir.

Fig. 1 The Saguling dam and reservoir

2.2. Dam Break

Dam break can become a great disaster if it happened. The material loss will be experienced from this event, it can lead to fatalities. The population and all forms of assets in the dam downstream will suffer due to the event. The routine and periodical maintenance that is well carried out by the dam manager can minimize the occurrence of disaster.

Considering the dam break in general, the earthen dams can be classified into three groups by the dam break reason as follows [3]:

2.2.1. Hydraulic Break

Hydraulic break generally happens when the water flow around the dam is uncontrolled. The flow will be erosive in the dam body and foundation. The earthen dam is very susceptible to the hydraulic break incident because the soil can be eroded although the velocity is low. The erosion of the earthen dam due to the big enough rainfall is shown in Figure 2.

Fig. 2 Dam erosion due to the rainfall

2.2.2. Seepage Break

The seepage generally happens in all dams, its velocity must be controlled. The seepage can happen through the dam body and the dam foundation. If the seepage is uncontrolled, the water can get away because of the piping break.

2.2.3. Structure Break

The structure break involves the dam or foundation breach or break. It is mainly dangerous for the big dam or the dam that is built from the low strength material like clay and sandy soil. The crack forms that can cause a dam break are illustrated in Figures 3 and 4.

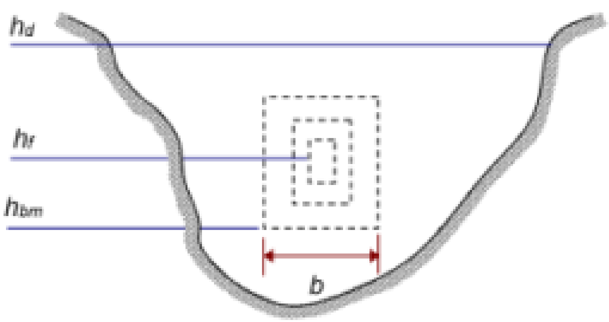

Fig. 3 The structure breach due to the piping [11]

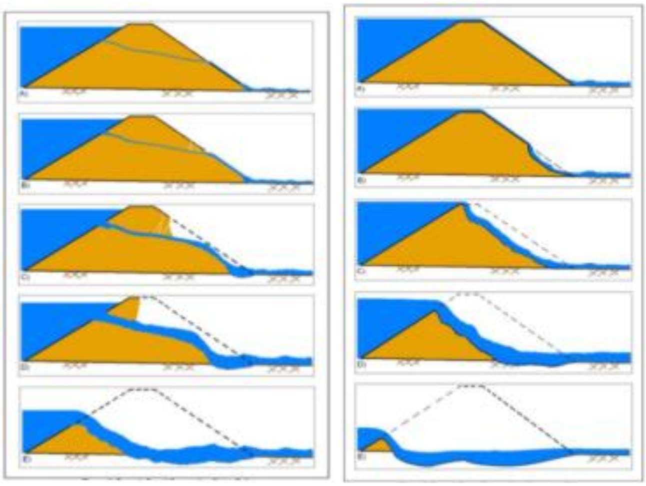

Fig. 4 The mechanism of cracking due to the piping (A) and overtopping (B) [12]

2.3. HEC-RAS Simulation

Dam body or foundation break causes the uncontrolled reservoir water discharge in the large volumes. The dam breaks in this research were simulated using the HEC-RAS software. The required data include the input of dam break analysis 2D, hydrological data, digital map, and the dam technical data with the following details:

1. *Digital map data*

The digital map is the Digital Elevation Model (DEM) map, water catchment area (DTA) in the reservoir, and the boundary of inundation potency due to the dam break.

2. *Technical data of the Saguling dam*

The required technical data of the dam include the dam peak thickness, the reservoir storage capacity, and the elevation of the flood water level.

3. *Hydrological data*

The required hydrological data include the design flood during a certain period. This research uses the maximum design flood hydrograph or Q_{PMF} (Probable Maximum Flood).

The HEC-RAS simulation used the analysis results of hydrograph outflow from the dam and flood routing downstream of the hill. The dam break process begins by the breaching, which is a hole formed during the dam breaking. The breaching is determined by two ways: overtopping and piping. Breaching in this modelling uses the scenario of overtopping and upper, middle and lower piping. The breaching is modelled as the breaching of seepage hole of the trapezoid shape.

3. Results and Discussion

3.1. Data Input

Data inputs for the Saguling dam break simulation are as follows:

The digital map data

Digital maps include the Saguling reservoir area map and map of the Saguling dam downstream of the

Cirata reservoir from the DEMNAS website with the m format (*.tiff). Figure 5 presents the digital map of the Saguling dam break.

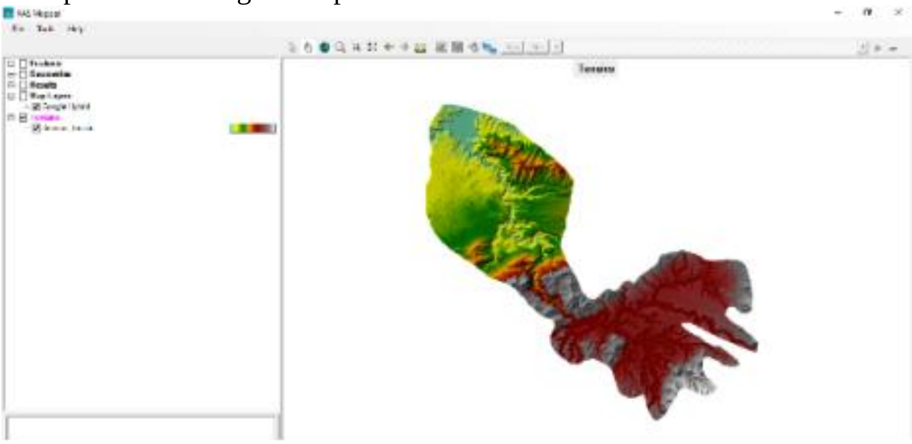

Fig. 5 Digital map of Saguling dam break simulation

3.2. Technical Data of Saguling Dam

The required technical data for the Saguling dam break simulation have some boundary conditions as follows:

- Weir width = 10 m (filed data)
- Weir length = 260.81 m (adjusted to the of BC line connection)
- Weir top elevation = 650.5 m- (field data)
- Center station break structure = 150
- Final bottom width of the failure structure = 50 m
- Final bottom elevation of the failure structure = 623 m
- Left side slope of the failure structure = 1
- Right side slope of the failure structure = 1
- Break weir coefficient = 1.44 (default)
- Breach formation time = 1 hour
- Failure mode = Overtopping
- Trigger failure at water surface elevation = 650.5 meter (adjusted to the peak elevation)

However, for piping scenario, there are some differences as follows:

- Failure mode = Piping
- Piping coefficient = 0.5 (default)
- Initial piping elevation = 640 m → the upper piping scenario
- Initial piping elevation = 630 m → the middle piping scenario
- Initial Piping elevation = 623 m → the lower piping scenario
- Trigger failure at water surface elevation = 645 m (data of flood water level)

Data of hydrology

The hydrology data used in this simulation process are maximum design flood hydrograph or Q_{PMF} (Probable Maximum Precipitation). Table 1 presents the design flood hydrograph-Q_{PMF} of the Saguling dam.

Table 1 Design flood hydrograph - QPMF of Saguling dam

	(hour)	QPMF (m³/s)	(hour)	QPMF (m³/s)	(hour)	QPMF (m³/s)	(hour)	QPMF (m³/s)
1	0.00	0.00	17.00	6,783.70	35.00	2,041.88	53.00	499.09
2	1.00	1.871	18.00	6,448.84	36.00	1,893.04	54.00	460.63
3	2.00	272.34	19.00	6,109.19	37.00	1,754.28	55.00	425.08
4	3.00	1,357.42	20.00	5,770.31	38.00	1,625.04	56.00	392.23
5	4.00	2,904.14	21.00	5,436.40	39.00	1,504.77	57.00	361.87
6	5.00	4,432.55	22.00	5,110.60	40.00	1,392.92	58.00	333.83
7	6.00	5,714.21	23.00	4,795.17	41.00	1,288.98	59.00	307.92
8	7.00	6,688.90	24.00	4,491.70	42.00	1,192.44	60.00	284.00
9	8.00	7,371.61	25.00	4,201.27	43.00	1,102.83	61.00	261.91
10	9.00	7,803.87	26.00	3,924.52	44.00	1,019.70	62.00	241.52
11	10.00	8,032.22	27.00	3,661.77	45.00	942.601	63.00	222.70
12	10.34	8,071.38	28.00	3,413.08	46.00	871.15	64.00	205.33
13	11.00	8,099.75	29.00	3,178.35	47.00	804.94	65.00	189.30
14	12.00	8,043.43	30.00	2,957.30	48.00	743.62	66.00	174.50
15	13.00	7,893.74	31.00	2,749.56	49.00	686.84	67.00	160.86
16	14.00	7,675.30	32.00	2,554.67	50.00	634.29	68.00	148.27
17	15.00	7,407.71	33.00	2,372.13	51.00	585.67	69.00	136.65
18	16.00	7106.46	34.00	2201.39	52.00	540.70	70.00	125.94

3.3. The simulation Process

The simulation process for the Saguling dam break has four scenarios: overtopping, upper piping, middle piping, and lower piping. All scenarios are simulated during 70 hours (simulation time) with the output result as the inundation map and relation curve between the maximum water level elevation and channel bed elevation at this point.

3.4. The Simulation Result Output

The results of the inundation area simulation produced from the four scenarios are given in Table 2.

Table 2 Maximal inundation area of Saguling dam break simulation

Condition	Inundation area	
Overtopping	m^2	km^2
Upper piping	19,388,625,9	19.39
Middle piping	17,347,946.58	17.35
Lower piping	17,339,975.93	17.34

Based on Table 2, it can be concluded that considering the impact of inundation due to the Saguling dam break, the worst scenario is under the overtopping condition with the total inundation area of 19.39 km^2. The simulation results showed the maximum inundation that might happen in three hours after the Saguling dam break. This indicates that at that time the maximum water discharge will reach the Cirata dam. Therefore, it is possible for the Cirata dam to experience a break at that time (3 hours) after the Saguling dam is broken. Figure 6 describes the maximum inundation, the process of flood flow due to the Saguling dam break under the overtopping conditions and how the flow reaches the Cirata reservoir. The details of each scenario regarding maximum water-level elevation are presented in Tables 3-6 and Figures 7-10.

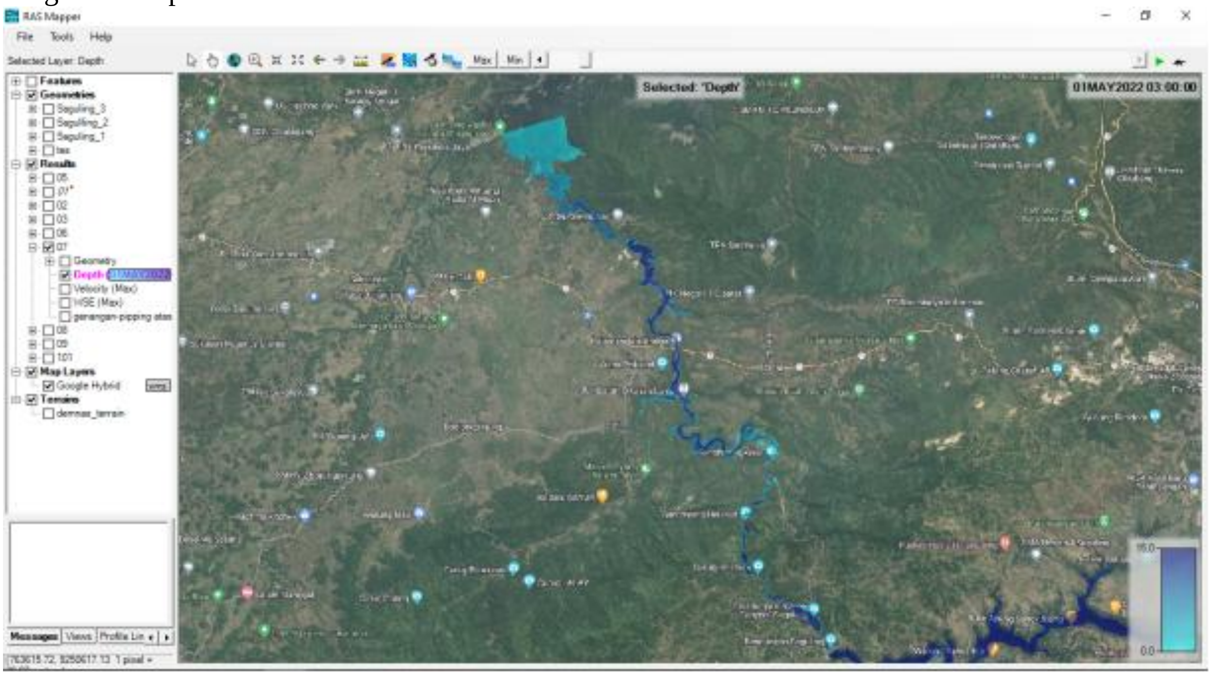

Fig. 6 Flow process toward the Cirata reservoir after the Saguling dam break

Table 3 Maximum water-level elevation of the Saguling dam by overtopping scenario

No	Station	Elevation of channel bed (m)	Elevetion of max water (m)	No	Station	Elevation of channel bed (m)	Elevetion of max water (m)	No	Station	Elevation of channel bed (m)	Elevasi muka air (max) (m)	No	Station	Elevation of channel bed (m)	Elevasi muka air (max) (m)
1	0.00	611.23	612.80	28	1601.66	531.14	564.00	55	5204.36	364.43	388.73	82	11251.64	220.36	236.51
2	1.25	610.71	612.80	29	1700.65	528.80	563.99	56	5301.39	380.58	388.59	83	11508.90	220.09	236.11
3	9.97	607.39	612.79	30	1800.54	536.39	563.95	57	5411.76	368.07	368.07	84	11753.39	216.84	235.59
4	29.67	601.76	612.78	31	2002.19	542.50	563.35	58	5607.52	342.46	346.06	85	12251.82	211.09	235.19
5	41.14	600.22	612.78	32	2101.91	540.64	561.24	59	5712.76	332.01	346.25	86	12507.11	211.40	235.09
6	60.90	599.44	612.78	33	2302.29	521.20	551.73	60	5900.85	325.11	342.02	87	13000.53	212.81	234.91
7	71.03	598.72	612.78	34	2400.91	507.81	546.98	61	6006.47	339.05	339.05	88	13250.66	214.40	234.79
8	80.65	597.96	612.80	35	2500.08	511.99	543.36	62	6101.82	319.95	325.91	89	13500.53	211.00	234.75
9	90.90	597.26	612.81	36	2601.42	526.18	539.76	63	6207.94	297.97	317.48	90	13750.70	212.44	234.70
10	120.16	596.34	612.82	37	2800.31	540.93	540.93	64	6400.20	282.86	304.29	91	14511.83	213.43	233.68
11	140.81	597.01	612.82	38	2901.70	540.41	540.41	65	6501.36	282.87	295.48	92	15000.18	211.01	233.11
12	159.68	597.76	612.83	39	3005.60	518.56	529.17	66	6604.34	282.73	293.32	93	15502.35	212.25	232.92
13	181.28	599.07	612.84	40	3102.96	506.01	512.67	67	6703.92	300.36	300.36	94	16005.15	213.19	232.73
14	201.86	598.24	612.87	41	3200.25	491.88	512.67	68	6803.21	275.91	285.74	95	16503.61	214.54	232.34
15	250.43	594.32	611.72	42	3403.08	512.49	512.50	69	7001.92	269.41	277.23	96	17502.99	208.59	231.57
16	276.46	596.59	610.22	43	3502.93	475.00	475.00	70	7200.47	254.34	271.71	97	18021.13	212.00	231.05
17	352.39	603.15	606.75	44	3603.92	441.80	455.58	71	7603.28	254.12	268.28	98	19009.13	209.00	229.79
18	403.24	597.67	604.79	45	3802.28	414.94	450.09	72	8015.74	243.78	252.80	99	20015.85	211.00	229.28
19	452.92	595.33	602.69	46	3901.12	427.91	450.09	73	8206.64	235.64	249.25	100	20502.70	209.00	229.02
20	500.63	593.58	599.69	47	4006.60	438.98	450.09	74	8409.11	236.31	246.59	101	21023.03	211.00	228.97
21	551.46	592.07	595.72	48	4100.18	417.63	442.11	75	8602.54	238.37	243.65	102	21506.15	213.00	228.92
22	801.76	542.00	576.07	49	4400.62	425.38	443.40	76	9250.52	225.15	239.04	103	23000.36	189.75	200.31
23	901.83	539.63	567.50	50	4501.25	430.96	441.02	77	9500.43	230.02	238.47	104	23502.70	188.36	199.58
24	1005.33	544.34	563.97	51	4601.14	429.60	429.60	78	9750.95	225.72	238.52	105	24002.37	189.92	199.09
25	1203.54	531.14	564.05	52	4805.47	378.75	391.71	79	10254.02	220.11	238.31	106	25003.64	190.00	195.91
26	1300.39	527.95	564.04	53	4910.66	367.56	388.61	80	10508.11	222.08	238.29	107	25503.87	190.00	195.00
27	1501.11	535.44	564.05	54	5100.52	370.45	388.97	81	11005.93	221.14	237.46	108	26241.85	188.00	191.80

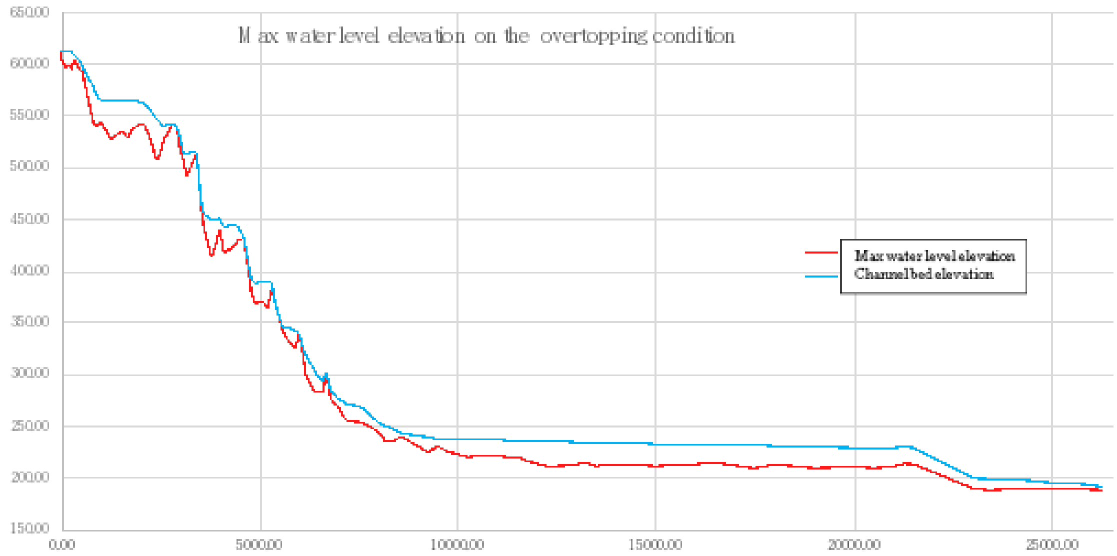

Fig. 7 Maximum water-level elevation due to the Saguling dam break under the overtopping conditions

Table 4 Maximum water-level elevation due to the Saguling dam break according to the upper piping scenario

No	Station	Max water level elevation (m)	Channel bed elevation (m)	No	Station	Max water level elevation (m)	Channel bed elevation (m)	No	Station	Max water level elevation (m)	Channel bed elevation (m)	No	Station	Max water level elevation (m)	Channel bed elevation (m)
1	0.00	612.76	611.23	28	6253.72	315.90	295.27	55	13033.06	234.91	213.89	82	19746.60	229.50	209.84
2	100.41	612.78	596.56	29	6501.36	295.56	282.87	56	13267.86	234.79	214.10	83	20017.83	229.29	211.00
3	250.43	611.69	594.32	30	6756.56	287.36	284.10	57	13530.23	234.76	211.25	84	20267.59	229.09	210.00
4	352.39	606.79	603.15	31	7001.92	277.34	269.41	58	13745.69	234.71	212.67	85	20545.78	229.01	209.00
5	506.62	595.94	593.35	32	7246.52	271.53	251.64	59	14001.83	234.52	211.05	86	20761.05	228.99	209.00
6	753.14	579.56	546.55	33	7508.65	270.32	255.07	60	14256.71	234.28	210.26	87	21000.26	228.97	210.75
7	1011.42	564.12	544.53	34	7755.67	262.07	253.27	61	14530.60	233.66	214.31	88	21261.18	228.95	211.00
8	1250.49	564.15	528.69	35	8027.67	252.41	242.18	62	14749.46	233.33	211.06	89	21532.77	228.93	213.00
9	1530.58	564.14	535.47	36	8254.81	248.86	236.99	63	15006.06	233.11	211.01	90	21739.38	228.95	213.52
10	1757.65	564.09	533.01	37	8510.32	245.02	233.05	64	15254.96	232.98	211.01	91	22037.75	225.71	225.71
11	2004.86	563.45	542.36	38	8750.77	242.65	231.29	65	15480.91	232.93	212.02	92	22261.98	201.43	191.00
12	2245.90	554.32	540.56	39	9054.29	240.64	229.00	66	15763.79	232.81	213.67	93	22569.19	200.90	191.82
13	2501.90	543.39	512.35	40	9256.86	239.02	225.00	67	16003.58	232.74	213.28	94	22795.23	200.55	190.03
14	2742.37	538.89	527.28	41	9513.82	238.44	230.44	68	16264.83	232.64	214.65	95	23010.27	200.30	189.41
15	3005.90	529.25	518.59	42	9749.30	238.53	225.76	69	16517.83	232.32	214.86	96	23271.01	200.03	188.00
16	3253.31	512.77	493.29	43	10003.99	238.49	224.00	70	16753.99	232.18	214.36	97	23508.57	199.57	188.19
17	3502.93	475.00	475.00	44	10254.02	238.32	220.11	71	17039.93	232.09	214.02	98	23753.48	199.31	188.00
18	3750.92	453.20	417.26	45	10539.06	238.29	223.96	72	17288.69	231.84	213.96	99	24053.14	198.98	190.00
19	4006.69	448.58	439.00	46	10750.21	238.24	222.51	73	17514.06	231.57	208.42	100	24302.94	198.70	190.00
20	4255.23	442.39	398.84	47	11000.01	237.50	221.18	74	17751.74	231.41	210.00	101	24500.79	198.56	190.90
21	4517.90	439.24	434.04	48	11251.64	236.52	220.36	75	18004.68	231.07	212.15	102	24758.56	196.83	192.00
22	4750.82	398.86	378.92	49	11506.47	236.12	220.19	76	18252.51	230.69	210.26	103	25007.94	195.90	190.00
23	5004.05	389.36	373.90	50	11754.59	235.60	216.79	77	18588.33	230.22	212.00	104	25265.86	195.45	189.00
24	5252.88	388.76	369.71	51	12001.51	235.25	212.80	78	18759.37	230.02	210.01	105	25519.79	194.94	190.00
25	5505.15	347.67	346.50	52	12251.82	235.20	211.09	79	19025.06	229.78	209.00	106	25755.69	193.69	190.00
26	5749.99	345.87	330.63	53	12507.11	235.10	211.40	80	19258.70	229.65	207.00	107	26007.37	192.85	189.00
27	6040.66	333.19	331.36	54	12742.42	234.99	213.62	81	19537.60	229.58	207.00	108	26241.85	191.80	188.00

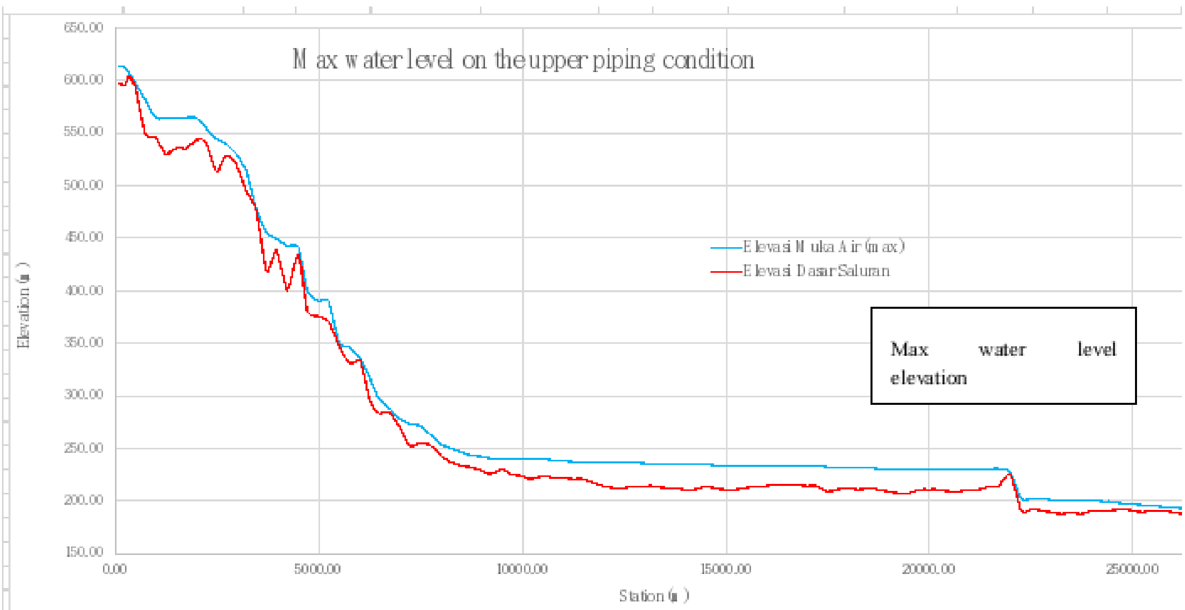

Fig. 8 Maximum water-level elevation due to the Saguling dam break according to the upper piping scenario

Table 5 Maximum water-level elevation due to the Saguling dam break according to the middle piping scenario

No	Station	Water level elevation (m)	Channel bed elevation (m)	No	Station	Water level (m)	Channel bed (m)	No	Station	Water level (m)	Channel bed (m)	No	Station	Water level (m)	Channel bed (m)
1	0.00	612.79	611.23	28	6521.61	295.03	280.89	55	13241.30	234.80	215.25	82	20045.64	229.25	210.48
2	113.58	612.80	596.32	29	6773.41	285.57	278.46	56	13506.37	234.75	211.45	83	20288.07	229.08	210.00
3	250.43	611.71	594.32	30	7007.86	277.00	268.79	57	13757.13	234.70	212.06	84	20560.32	229.01	209.00
4	512.61	595.81	593.00	31	7239.94	271.48	251.35	58	14024.59	234.50	211.41	85	20756.78	228.99	209.00
5	754.70	579.41	546.37	32	7532.03	269.76	255.17	59	14262.17	234.27	210.20	86	21064.35	228.97	211.00
6	1018.32	564.05	544.81	33	7753.29	262.11	253.32	60	14497.12	233.70	212.35	87	21259.06	228.95	211.00
7	1265.91	564.05	528.44	34	8035.70	252.04	241.19	61	14757.82	233.31	211.00	88	21514.45	228.92	213.00
8	1503.42	564.06	535.40	35	8242.59	248.92	236.84	62	15031.19	233.08	211.00	89	21513.98	228.92	213.00
9	1758.21	563.99	533.05	36	8502.24	245.12	233.00	63	15254.96	232.98	211.01	90	21761.04	228.96	214.77
10	2004.86	563.36	542.36	37	8745.15	242.66	231.49	64	15516.55	232.91	212.37	91	22019.20	225.99	225.99
11	2256.94	553.86	536.23	38	9045.86	240.69	229.01	65	15769.68	232.80	213.80	92	22267.85	201.41	191.00
12	2516.32	542.53	517.04	39	9250.52	239.04	225.15	66	16005.15	232.73	213.19	93	22504.76	200.98	192.00
13	2756.86	538.28	530.28	40	9454.73	238.60	228.69	67	16254.07	232.64	214.83	94	22752.36	200.60	190.38
14	3005.60	529.18	518.56	41	9768.69	238.54	225.00	68	16520.18	232.31	214.91	95	23011.40	200.30	189.37
15	3259.55	512.68	493.89	42	10025.73	238.43	223.20	69	16767.15	232.17	214.45	96	23281.83	200.01	188.00
16	3502.93	475.00	475.00	43	10242.24	238.32	220.07	70	17048.91	232.07	214.03	97	23532.75	199.52	188.73
17	3749.02	450.10	417.60	44	10533.70	238.28	223.78	71	17260.97	231.86	214.00	98	23781.92	199.30	188.00
18	4031.72	450.10	439.52	45	10766.02	238.14	222.10	72	17520.81	231.56	208.32	99	24118.72	198.92	190.99
19	4255.23	442.12	398.84	46	11017.78	237.42	220.76	73	17762.05	231.39	210.00	100	24318.93	198.66	190.00
20	4510.66	439.97	433.09	47	11251.64	236.51	220.36	74	18089.61	230.96	213.00	101	24540.60	198.45	191.00
21	4750.82	398.77	378.92	48	11538.23	236.08	220.06	75	18284.57	230.68	210.00	102	24757.15	196.84	192.00
22	5004.05	389.27	373.90	49	11755.61	235.59	216.76	76	18503.97	230.32	212.00	103	25027.91	195.83	190.00
23	5252.88	388.69	369.71	50	12039.89	235.24	212.03	77	18745.49	230.03	210.39	104	25285.14	195.45	189.00
24	5527.41	347.19	345.15	51	12254.64	235.19	211.15	78	19043.32	229.77	208.16	105	25537.39	194.87	190.00
25	5758.77	345.64	329.49	52	12506.66	235.09	211.40	79	19260.63	229.65	207.00	106	25799.73	193.48	190.00
26	6014.44	337.82	337.82	53	12784.98	234.95	213.42	80	19562.23	229.57	207.01	107	26064.11	192.51	189.00
27	6242.64	316.31	296.32	54	13072.95	234.89	215.24	81	19743.12	229.50	209.91	108	26241.85	191.80	188.00

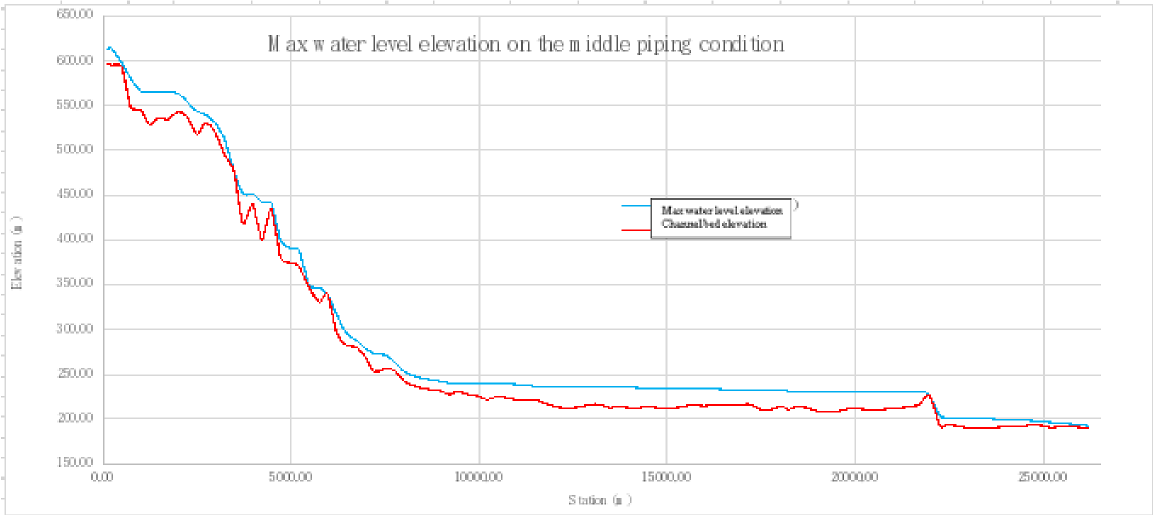

Fig. 9 Maximum water-level elevation due to the Saguling dam break according to the middle piping scenario

Table 6 Maximum water-level elevation due to the Saguling dam break according to the lower piping scenario

No	Station	Max water level elevation (m)	Channel bed elevation (m)	No	Station	Max water level elevation (m)	Channel bed elevation (m)	No	Station	Max water level elevation (m)	Channel bed elevation (m)	No	Station	Max water level elevation (m)	Channel bed elevation (m)
1	0.00	612.79	611.23	28	6281.18	314.42	291.12	55	13031.73	234.90	213.88	82	19782.44	229.48	209.13
2	53.58	612.76	599.64	29	6523.91	294.99	280.87	56	13271.09	234.78	214.05	83	19986.07	229.32	211.00
3	100.41	612.81	596.56	30	6787.89	286.12	276.85	57	13524.35	234.76	211.22	84	20256.12	229.09	210.00
4	250.43	611.70	594.32	31	7048.98	276.02	261.04	58	13763.56	234.69	211.67	85	20495.30	229.02	209.00
5	500.63	599.68	593.58	32	7271.44	271.37	251.58	59	14011.66	234.51	211.14	86	20793.82	228.99	209.00
6	754.70	579.41	546.37	33	7507.32	270.26	255.03	60	14250.17	234.28	210.30	87	21052.12	228.97	211.00
7	1005.33	563.97	544.34	34	7759.69	261.82	253.23	61	14531.42	233.65	214.32	88	21279.52	228.95	211.00
8	1258.75	564.04	528.48	35	8022.15	252.56	242.75	62	14754.91	233.31	211.02	89	21599.54	228.91	213.01
9	1517.00	564.05	535.32	36	8252.72	248.83	236.95	63	15006.32	233.11	211.00	90	21776.48	228.96	214.76
10	1765.58	563.98	533.46	37	8502.24	245.12	233.00	64	15262.80	232.98	211.02	91	21991.37	226.14	226.14
11	2008.17	563.35	542.43	38	8768.55	242.53	230.97	65	15516.55	232.91	212.37	92	22251.08	201.46	191.00
12	2264.63	553.55	532.85	39	9024.92	240.84	229.08	66	15757.90	232.80	213.55	93	22554.57	200.91	191.96
13	2512.14	542.78	515.57	40	9262.40	238.99	225.11	67	16051.85	232.72	211.75	94	22773.79	200.57	190.18
14	2751.60	538.46	529.01	41	9514.42	238.43	230.47	68	16273.54	232.63	214.34	95	23041.08	200.27	189.31
15	3031.06	519.85	519.85	42	9744.95	238.51	225.95	69	16545.88	232.27	215.01	96	23290.67	199.99	188.00
16	3259.55	512.67	493.89	43	10026.95	238.43	223.17	70	16748.67	232.17	214.44	97	23532.75	199.52	188.73
17	3521.65	466.83	466.83	44	10289.35	238.31	220.36	71	17029.82	232.09	214.01	98	23834.84	199.29	188.00
18	3750.92	450.10	417.26	45	10558.79	238.28	223.36	72	17292.69	231.83	213.91	99	24009.42	199.07	189.99
19	4007.41	450.10	439.08	46	10760.42	238.14	222.08	73	17537.84	231.54	208.38	100	24266.03	198.72	190.94
20	4277.82	442.11	393.65	47	11010.19	237.45	220.87	74	17744.95	231.41	210.03	101	24520.34	198.51	191.00
21	4517.90	439.14	434.04	48	11278.45	236.49	220.90	75	18021.13	231.05	212.00	102	24788.25	196.69	192.00
22	4763.89	396.46	378.47	49	11534.40	236.08	220.00	76	18250.39	230.69	210.38	103	25051.89	195.75	189.97
23	5034.20	389.20	380.20	50	11753.39	235.59	216.84	77	18505.11	230.32	212.00	104	25237.33	195.48	189.00
24	5248.68	388.69	369.13	51	12004.09	235.24	212.90	78	18738.66	230.04	210.89	105	25549.13	194.83	190.00
25	5513.76	347.42	345.21	52	12253.69	235.19	211.16	79	19031.15	229.77	208.96	106	25774.56	193.60	190.00
26	5764.18	345.56	328.95	53	12518.77	235.09	211.18	80	19275.11	229.64	207.01	107	26034.38	192.68	189.00

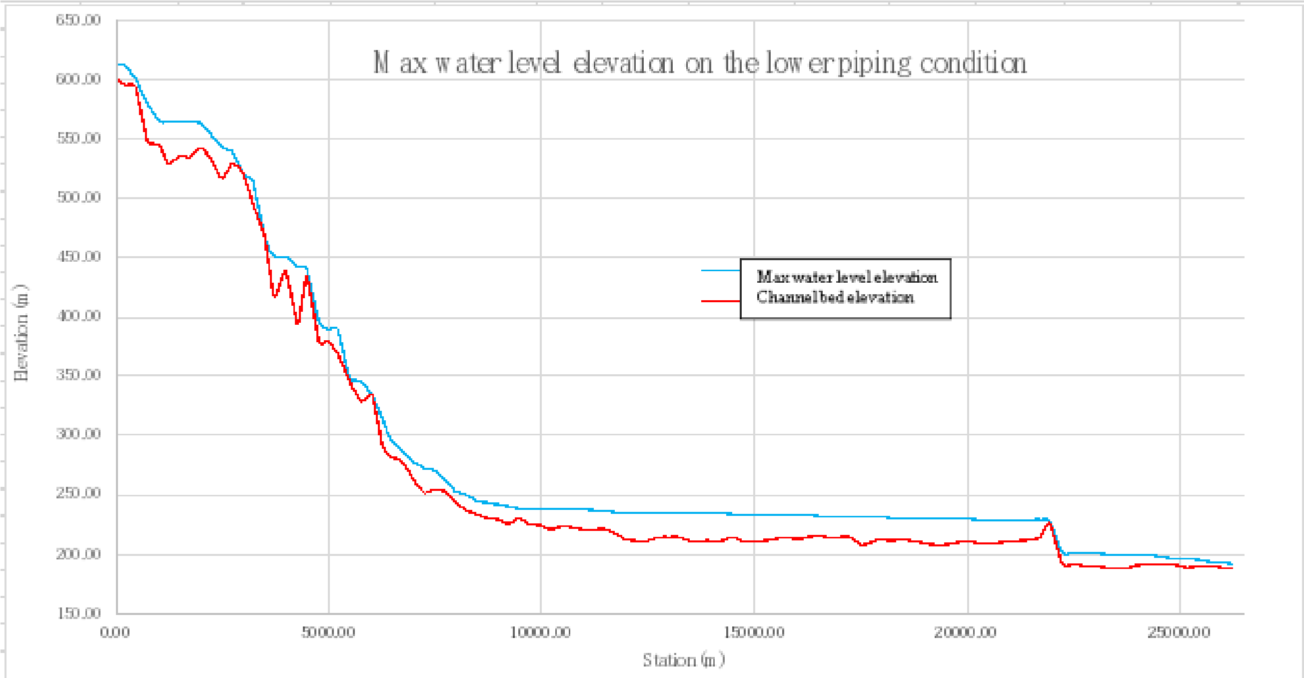

Fig. 10 Maximum water-level elevation due to the Saguling dam break according to the lower piping scenario

4. Conclusion

The Saguling dam is a component of the cascade system in the Citarum river. The general failure or dam break of the Saguling dam can happen due to the internal and external factors.

The factors affecting the Saguling dam break in general can be classified into 2 (two) groups: 1) the internal factor such as the possibility of operation failure (mal-function) in the spillway gate; and 2) external factor such as the maximum design flood with the maximum discharge of 8.099 m^3/s that causes overtopping and or piping.

According to the overtopping scenario, the Saguling dam has the worst impact compared to the piping scenario with the maximum inundation area of 19.39 km^2. The simulation of Saguling dam break suggests that the design flood will reach the Cirata reservoir in 3 hours' time. Moreover, it can cause the Cirata dam break with the additional discharge from the Saguling dam break plus from the Cirata dam itself. Thus, the Saguling dam break adds the risks for the Cirata dam.

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