RESERVOIR SEDIMENTATION IN BRANTAS RIVER BASIN

1 Brantas River Basin

Brantas River Basin is located in the Island of Java, of the Republic of Indonesia. It runs through the western section of the East Java Province. The basin is situated from Latitude 7^{o} 1' to 8^{o} 15' South and Longitude 110^{o} 30' to 112^{o} 55' East. The river mainstream traverses 9 regencies and 5 municipalities. Starting at the upper regions of the river they are Malang, Blitar, Tulungagung, Kediri, Nganjuk, Jombang, Mojokerto, Sidoarjo, and Surabaya City, including portions of Pasuruan and Gresik. A general view of the Brantas River Basin is shown in **Figure 1**.

Figure 1 Map Brantas River Basin

Volcanoes within the Brantas Basin are Mount Arjuna (3,339 m), Mount Anjasmara (2,282 m), Mount Butak (2,868 m), Mount Kawi (2,651 m), Mount Kelud (1,724 m), Mount Semeru (3,676 m), and others. Mount Semeru is constantly active. In this century, Mount Kelud has erupted on a large scale an average of once every 15 years: 1901, 1919, 1951, 1966, and 1990. The total volume of ejecta is estimated at 100-200 million m^{3}, having a decisive effect on local society as well as the environment.

The Brantas River is characterized by clockwise watercourse centering on Mount Kelud. This is influenced by the process of mountain uplift and the volcanic ranges. The Brantas originates from the southeastern side of Mount Anjasmara located in the center of its basin. The uppermost stream starts its course eastward south around the Semeru volcanic zone, and the runs to the west parallel to the Southern Mountains, which stretch east and west blocking the river's course. It changes its course again to the north to avoid older volcanoes and Mount Wilis, and the runs past the foot of Mount Wilis and Mount Kelud to reach Surabaya City. Thus the Brantas travels past all the major volcanic ranges in the basin.

2 General Features of Objective Reservoirs

The following principal six dam reservoirs were constructed from seventies to eighties of 20th century. The function and original storage capacity of the dam reservoirs are shown in the following table.

Table 1 General Features of Objective Dam Reservoirs

Reservoir	Completion Year	Dam Type	Dam Height (m)	Purpose[1)]	Reservoir Level (m)		**Original Storage Capacity** (million m^3)		
					HWL	LWL	Gross	Effective	Sediment
Sengguruh	1988	Rockfill	33.0	PG	292.5	291.4	21.50	2.50	19.00
Sutami	1973	Rockfill	97.5	PG, FC, IR, DI	272.5	246.0	343.00	253.00	90.00
Lahor	1977	Rockfill	74.0	PG, IR, DI	272.5	253.0	36.11	29.43	6.68
Wlingi	1977	Concrete & Rockfill	28.0	PG, IR	163.5	162.0	24.00	5.20	18.80
Lodoyo	1983	Gated weir	11.3	PG	136.0	125.5	5.20	5.00	0.20
Selorejo	1972	Rockfill	48.0	PG, FC, IR	620.0	598.0	62.30	50.10	12.20

Note: 1) PG = Power generation, FC = Flood Control, IR = Irrigation, DI = Domestic and Industrial Water Supply.

3 Sedimentation Process in Reservoirs

Since completion of the dam construction works, sediment accumulation in the Sengguruh, Sutami, Wlingi, and Lodoyo dam reservoirs has significantly reduced their original storage capacities. As for the Lahor dam reservoir, the sedimentation rate of this reservoir was supposed to be less than that of other reservoirs in the Brantas River basin, however, the study on those reservoirs were also conducted to confirm the current sedimentation condition. Detailed sedimentation characteristics in each dam reservoir are presented below.

3.1 Sengguruh Dam

The Sengguruh dam, which has a catchment area of 1,659 km^2, is located on the upstream reach of the Brantas River and at just downstream reach of the confluence of the Brantas River and the Lesti River. The location is around 25 km south of Malang City, and

approximately 14 km upstream reach of the Sutami dam. Since completion in 1988, sediment accumulation in the Sengguruh reservoir has rapidly reduced its effective storage capacity up to 41.5% of the design storage capacity. Especially, the rate of sedimentation was high immediately after completion and around 15 million m^3 of sediment was deposited in the reservoir in the first nine years, which corresponded to 70 % of the designed gross storage.

Table 2 Storage Capacity Transition of the Sengguruh Dam Reservoir

Surveyed Year	Gross Storage Capacity		Effective Storage capacity		Dead Storage Capacity	
	Volume (million m^3)	Percent (%)	Volume (million m^3)	Percent (%)	Volume (million m^3)	Percent (%)
1988	21.50	100.0	2.50	100.0	19.00	100.0
1993	5.36	24.9	1.21	48.3	4.15	21.8
1996	2.16	10.0	1.24	49.8	2.16	11.4
1997	5.35	24.9	1.20	47.9	4.16	21.9
2001	3.52	16.4	1.09	43.7	2.42	12.8
2002	3.20	14.9	1.13	45.2	2.07	10.9
2003	2.32	10.8	1.04	41.5	1.28	6.7
2008	1.30	6.05	0.89	35.6	0.41	2.2

Figure 2 Sedimentation in Sengguruh Reservoir

3.2 Sutami Dam

The Sutami dam reservoir is located at approximately 14 km downstream reach of the Sengguruh dam and has a catchment area of 2,052 km^2.

The Sutami reservoir has a large scale storage capacity, however, the storage capacity decreasing process of the early years after construction (1973 - 1977) had been very quickly, and decrease of gross storage capacity was about 82 million m^3 for 4 years. After construction of the Sengguruh dam, the rate of the storage capacity decrease slowed down in comparison with that of before construction of the Sengguruh dam. The present gross storage capacity corresponds to 50.9% of that of designed condition, and the effective storage capacity is 57.4% of the designed condition.

Table 3 Storage Capacity Transition of the Sutami Dam Reservoir

Surveyed Year	Gross Storage Capacity		Effective Storage Capacity		Dead Storage Capacity	
	Volume (million m^3)	Percent (%)	Volume (million m^3)	Percent (%)	Volume (million m^3)	Percent (%)
1973	343.00	100.0	253.00	100.0	90.00	100.0
1977	261.68	76.3	194.48	76.9	67.20	74.7
1982	221.29	64.5	167.20	66.1	54.09	60.1
1987	192.41	56.1	152.87	60.4	39.54	43.9
1989	192.39	56.1	152.63	60.3	39.76	44.2
1992	189.97	55.4	154.13	60.9	35.84	39.8
1994	186.27	54.3	151.13	59.7	35.14	39.0
1995	184.59	53.8	149.15	59.0	35.44	39.4
1997	183.42	53.5	147.82	58.4	35.60	39.6
1999	180.45	52.6	147.09	58.1	33.36	37.1
2002	176.00	51.3	145.43	57.5	30.57	34.0
2003	174.57	50.9	145.20	57.4	29.36	32.6
2009	165.45	48.2	141.16	55.8	24.29	27.0

3.2 Lahor Dam

The Lahor dam, which has a catchment area of 170 km^2, was constructed in 1977, and it was connected with the Sutami reservoir by a connection tunnel. The two reservoirs, therefore, are functioning as one reservoir.

In 2002, 25 years after the dam completion, the gross storage capacity of the Lahor dam was 85% of that of designed. The sedimentation rate of the Lahor reservoir is less than other reservoirs in the Brantas river basin.

Table 4 Storage Capacity Transition of the Lahor Dam Reservoir

Surveyed Year	Gross Storage Capacity		Effective Storage Capacity		Dead Storage Capacity	
	Volume (million m^3)	Percent (%)	Volume (million m^3)	Percent (%)	Volume (million m^3)	Percent (%)
1977	36.11	100.0	29.43	100.0	6.68	100.0
1994	33.05	91.5	26.53	91.5	6.52	97.6
1995	32.43	89.8	26.26	89.8	6.17	92.3
1999	31.48	87.2	25.45	87.2	6.08	90.3
2002	30.77	85.2	25.28	85.2	5.49	82.2
2009	28.32	78.4	23.99	81.6	4.33	64.8

3.4 Wlingi Dam

The Wlingi dam, which has a catchment area of 2,890 km^2, is located on the southern skirts of Mt. Kelud in the upstream reach of the Brantas River, and at around 25 km downstream reaches of the Sutami dam. The Wlingi dam was constructed in 1977 for the purpose of hydropower generation for peak demand and irrigation water supply, and it was also expected to take a role of temporary storage of the erupted material from Mt. Kelud.

After construction of the Wlingi dam, the sedimentation rate has been very rapid, and annual average sediment deposit in the reservoir up to 1988 was around 1.3 million m^3. In January

1990, just before the eruption of the Mt. Kelud, the gross storage capacity of the Wlingi reservoir was reduced to 19.2% of the designed gross storage capacity. As stated above, regardless of the eruption of Mt. Kelud, the Wlingi reservoir was suffered by high rate of the sediment inflow.

Mt. Kelud erupted in February 1990. After this eruption, the Wlingi reservoir were filled up completely by the sediment and the removal works of deposited sediment in the Wlingi reservoir by dredging and sediment flushing were implemented to restore the storage capacity. As the result of the continuous removal works, the gross storage capacity in February 2004 was recovered to 4.4 million m^3, which corresponds to 18.4% of the designed gross storage capacity of 24.0 million m^3. The chronological change of the H-V curve and storage capacity change after 1990 have been affected by the sediment removal works.

Table 6 Storage Capacity Transition of the Wlingi Dam Reservoir

Surveyed year	Gross storage		Effective storage		Dead storage	
	Volume (million m^3)	Percent (%)	Volume (million m^3)	Percent (%)	Volume (million m^3)	Percent (%)
1977	24.00	100.0	5.20	100.0	18.80	100.0
1982	18.32	76.3	NA	NA	NA	NA
1985	14.44	60.2	NA	NA	NA	NA
1988	9.50	39.6	NA	NA	NA	NA
Jan. 1990	4.60	19.2	2.20	42.3	2.40	12.8
Eruption of the Mt. Kelud in Feb. 1990						
1991	4.77	19.9	2.34	45.0	2.43	12.9
1995	4.63	19.3	1.33	25.7	3.29	17.5
1996	5.75	24.0	1.83	35.2	3.92	20.9
2001	3.97	16.6	2.11	40.7	1.86	9.9
2004	4.41	18.4	2.01	38.6	2.41	12.8
2006	4.38	18.7	2.12	40.4	2.26	12.2
2007	4.54	18.9	2.48	47.7	2.06	11.0
2008	4.64	19.3	2.11	40.6	2.53	13.4

Figure 3 Sedimentation in Wlingi Reservoir

3.5 Lodoyo Dam

The Lodoyo dam is located at approximately 7.5 km downstream reach of the Wlingi dam, and the dam is on a skirt of Mt. Kelud same as the Wlingi Dam. The Lodoyo dam was

constructed in 1983 for the purpose of afterbay of the Wlingi dam and power generation.

The decreasing rate of storage capacity in the Lodoyo reservoir is high like the Wlingi reservoir. The gross storage capacity of the Lodoyo reservoir in 2003 was reduced to 2.03 million m^3, which corresponds to 39% of the designed gross storage capacity of 5.20 million m^3. There was not significant change in the decreasing rate of the storage capacity after the eruption of Mt. Kelud in 1990, owing to temporary storage effect of the Wlingi reservoir for the erupted material from Mt. Kelud.

Table 7 Storage Capacity Transition of the Lodoyo Dam Reservoir

Surveyed Year	Gross Storage Capacity		Effective Storage Capacity		Dead Storage Capacity	
	Volume (million m^3)	Percent (%)	Volume (million m^3)	Percent (%)	Volume (million m^3)	Percent (%)
1983	5.20	100.0	5.00	100.0	0.20	100.0
1990	3.69	71.0	3.69	73.8	0.00	0.0
1993	2.84	54.6	2.84	56.8	0.00	0.0
1996	2.35	45.1	2.35	46.9	0.00	0.0
2003	2.03	39.0	1.86	37.2	0.17	85.0
2009	2.67	53.4	2.67	51.4	0.00	0.0

3.6 Selorejo Dam

The Selorejo dam, which has a catchment area of 236 km^2, is located at the upstream reach of the Konto River and there are many devastated areas in the mountain hill slope surrounding the reservoir. The Selorejo dam was constructed in 1972 as a multipurpose dam for irrigation water supply, power generation and flood control.

The gross storage capacity of the Selorejo reservoir has been decreased to 44.01 million m^3, which corresponds to 70.6% of the designed gross storage capacity of 62.30 million m^3. The decreasing process of the storage capacity is moderate in comparison with those of the other dams on the Brantas River.

Table 8 Storage Capacity Transition of the Selorejo Dam Reservoir

Surveyed Year	Gross Storage Capacity		Effective Storage Capacity		Dead Storage Capacity	
	Volume (million m^3)	Percent (%)	Volume (million m^3)	Percent (%)	Volume (million m^3)	Percent (%)
1970	62.30	100.0	50.10	100.0	12.20	100.0
1993	48.87	78.4	44.59	89.0	4.28	35.1
1997	47.61	76.4	44.46	88.7	3.15	25.8
1999	42.70	68.5	39.96	79.8	2.74	22.5
2003	44.01	70.6	41.51	82.9	2.50	20.5
2009	39.61	63.6	37.73	75.3	1.88	15.4