3. Brantas Basin Characteristics

(1) Watercourse outline

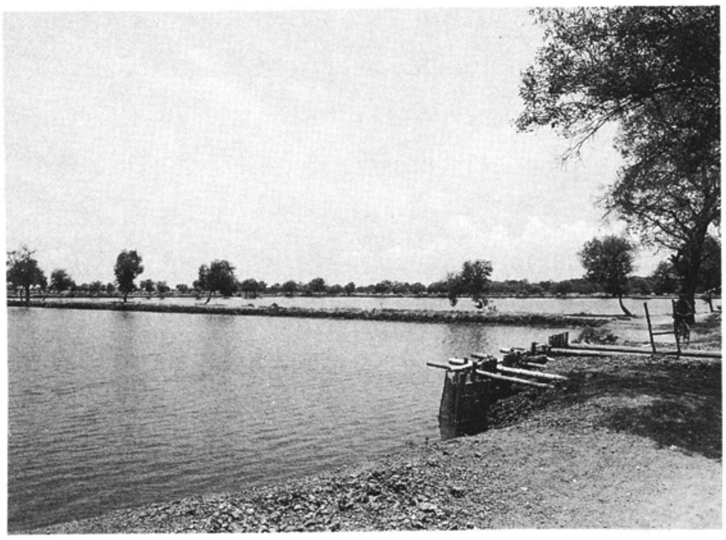
Brantas is the second longest river on Java Island with a length of 320 km and a basin area of 11,800 km^2. Its main stream runs most of the way around the Kelud-Arjuno massif located in the center of the basin.

The Brantas is joined by a left bank tributary, Lesti River, (basin area of 625 km^2), at the point where it flows to the south from its source and its course turns to the west. It changes from a western flow to northern when it enters the alluvial plain, and is joined by a left bank tributary, Ngrowo River (basin area of 1,600 km^2) near Tulungagung City. The Brantas continues to the north until joined by a right bank tributary, Konto (basin area of 687 km^2) and a left bank tributary, Widas (basin area of 1,538 m^2) when it hits the mountainous region of Kendeng after passing Kediri City. Then it turns to the east and branches off in Mojokerto City to Surabaya River and Porong River.

It is generally thought that the Surabaya River was originally the main stream of the Brantas, but in the late 19th century the Porong River was constructed as a floodway channel to protect Surabaya City from floods; and today flood waters from the Brantas main stream all run down the Porong.

Ravine of the Brantas River source

The former main stream, Surabaya River, has a basin area of 650 km^2. Its largest tributary, Marmoyo River, flows to the east running parallel to the Brantas. It meets the Surabaya River downstream of Mlirip Intake Gate in Mojokerto City, at which it turns its course to the northeast and runs through Gunungsari Dam to reach Wonokromo City. At this point it branches off to Mas River and Wonokromo Channel, built as a floodway channel in the Dutch colonial days. The Wonokromo Channel runs straight to the east to flow into the Madura Strait while the Mas River goes up north and passes through Surabaya City to empty into the Madura Strait.



Fish pond at mouth of the Porong River

The Porong River runs through Lengkong Dam to the southeast and is joined by the tributaries Kambing and Sadar in the middle. It then passes through Porong City, an important point along the Surabaya-Malang Highway, before flowing into the Madura Strait. There is a large amount of sedimentation, earth and sand carried from the Brantas, at its mouth forming a large marshland. The river channels criss-cross like the mesh of a net; they look just like the leaves of fatsia japonica. Currently a short-cut channel is located on the right bank for flood water. The river mouth forms a large fish farm, where brackish-water fishery is prospering including shrimp, crab, and milkfish. This area is said to be the birthplace of Indonesian brackish-water fishery.

Madura Island (about 120 km wide) is situated across the Madura Strait just 4 km away from Surabaya City, which is north of the mouth of the Porong River. The Madura Strait forms a triangular water body with the western edge of the island as the vertex and the base, about 60 km long, stretches between the eastern edge and Java Island. The flux of the tides in Madura Strait is thus governed by the wide fronted body of water on the east side, therefore generating coastal currents inshore and offshore, but not in a constant direction. The flow velocity is slow at a maximum of 0.6 m/sec. This prevents the earth and sand from being carried away, therefore causing them to accumulate near the river mouth. Accordingly the river channels are lengthening by an average of approximately 150 m yearly.

The Lesti River, with a basin area of 625 km^2, flows from Mt. Semeru which has an accumulation of newly fallen volcanic ashes on its mountainside. As a result, the river water contains a large amount of sediment.

The Ngrowo River has a basin area of 1,600 km^2. Although there used to be a large marsh in its basin, now it drains into the Indian Ocean through the South Tulungagung-Neyama Tunnel. Flood inundation habitually occur near the junction between the Ngrowo and the Brantas, because the river channel has a small capacity and a high riverbed.

The Widas River has a basin area of 1,538 km^2. The junction between Widas and the Brantas provides a large retarding basin, in which flood waters from the Widas are controlled, thus contributing to a decrease in the flood peaks of the Brantas River. The area between the right bank of the Widas and the main stream of the Brantas is a fertile alluvial plain, complete with irrigation facilities. The area where small and medium rivers run onto the plain from Mt. Wilis is habitually hit by floods. The water seems to flow backwards when a big flood takes place somewhere in the main stream of the Brantas.

Another big tributary is the right bank river, Konto, with a basin area of 687 km^2, which flows from the west side of Mt. Arjuno and then joins the Brantas about 7 km upstream of the Widas junction. Utilizing abundant water volume and steep terrain, run-of-river type of hydroelectric power stations (Mendalan and Siman, with a combined output of 29,000 kW), were constructed in the upper regions of the Konto in the Dutch colonial days.

The incline of the main stream of the Brantas River is steep with 1/3,000-1/8,000 in plains areas, 1/800 in mountainous ones, and 1/200 in the Malang highlands of its upper reaches (see Fig. 1-4).

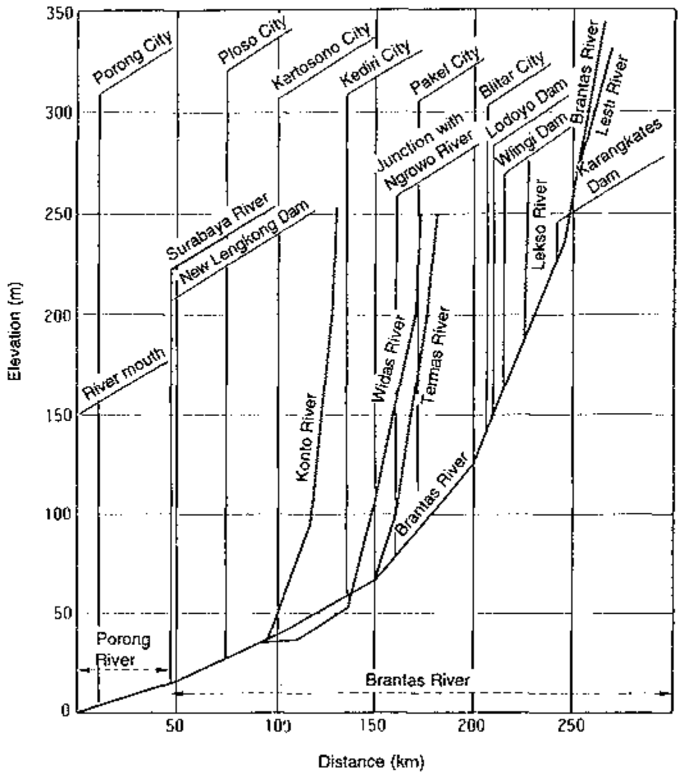


Fig. 1-4 **Longitudinal section of the Brantas, its major tributaries and main stream**

(2) Hydrology

Now let's look at the rainfall trends in the basin from 1960 through 1976. The lowest annual average was 1,288 mm in 1972 and the second lowest, 1,374 mm in 1965 while the highest average was 2,632 mm in 1955. There was a severe drought in 1925, with as little as 996 mm of rainfall in the Widas River Basin. The average monthly rainfall for the years between 1950 and 1983 is listed in Table 1-14.

From the monthly mean runoff records of the main stream and each tributary between 1980 and 1983 (see table 1-15), the Karangkates mean runoff is 67.4 m^3/sec and the specific runoff is 3.4 m^3/sec/100 km^2, about 10 km downstream of its junction with the Lesti River. In contrast, the mean is 135 m^3/sec and the specific runoff, 4.0 m^3/sec/100 km^2, both of which are high, at Pakel about 10 km upstream of its junction with the Ngrowo River, where the Brantas flows onto a plain in the middle reaches. Between Karangkates and Pakel water collects from the South side of the Kelud Massif, where there is abundant annual rainfall of 2,300 mm and large water retention capacity on the mountain.

Table 1-14 Monthly mean rainfall

Unit: mm

Rainfall gauging station/location	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Malang/Kandangan	318	271	261	160	106	61	39	15	31	82	211	294	1,849
Blitar/Lodoyo	311	278	257	140	108	51	34	15	20	91	177	299	1,781
Tulungagung/Campurdarat	216	221	201	103	101	56	61	19	39	108	121	180	1,426
Kediri/Kediri	266	246	277	169	149	43	39	17	25	62	146	270	1,709
Nganjuk/Nganjuk	250	273	266	175	134	43	27	12	8	52	166	289	1,695
Pare/Pare Municipal Office	304	297	271	173	118	51	23	10	37	66	132	195	1,659
Jombang/Jombang	267	316	272	179	91	29	39	19	18	43	135	292	1,700
Mojokerto/Mojokerto Municipal Office	347	325	303	158	100	30	30	9	16	39	119	267	1,743
Mean in the basin	285	277	264	157	113	45	36	14	24	68	151	261	1,695

Source: Brantas River Basin Development Executing Office (1950-83)

At Jabon Run-off Gauging Station, located just upstream from where the Brantas branches off to the Surabaya and the Porong, the annual mean runoff was 259.1 m^3/sec and the water runoff during drought, approximately 35 m^3/sec. With the Karangkates Dam now complete, the water discharge during drought season is 50 m^3/sec thanks to water augmentation of 15 m^3/sec. River water in the dry season at the Lengkong Dam all goes to the Surabaya River and the Brantas Delta irrigation channel, consequently routing almost no supply to the Porong. In addition, water is drawn and consumed before this point at five intakes (as of 1995) along the main stream and other tributaries.

Table 1-15 Monthly runoff by gauging station

Unit: m^3/s

River	Brantas	Brantas	Brantas	Konto	Widas	Solo	Solo
Gauging station	Karangkates	Pakel	Jabon	Kalikonto	Ngudikan	Jipang	Wonogiri
Basin area (km^2)	2,050	3,410	9,675	236	212	10,810	1,252
January	94.3	184.2	426.9	14.1	9.0	422.3	53.9
February	100.5	195.7	510.7	17.5	11.5	586.2	62.0
March	94.3	208.9	520.7	15.8	13.2	536.4	54.8
April	78.3	182.9	387.0	12.3	11.5	411.3	41.3
May	69.5	157.7	285.7	10.1	7.7	267.6	25.2
June	58.0	121.8	174.6	8.3	4.0	96.2	11.8
July	53.8	101.4	141.8	7.4	2.2	93.0	11.1
August	44.0	74.6	82.9	6.0	1.3	43.0	5.0
September	36.7	62.2	50.7	5.4	1.0	23.8	3.7
October	41.8	65.9	73.3	6.1	1.5	39.9	6.3
November	54.8	106.1	160.3	8.6	2.9	176.2	29.0
December	82.3	158.5	294.4	10.9	7.5	327.1	33.9
Mean	67.4	135.0	259.1	10.2	6.1	259.7	27.6
Specific runoff m^3/s/100 km^2	3.4	4.0	2.7	4.3	2.9	2.4	2.2

Source: Brantas River Basin Development Executing Office (1950-83)

At Selorejo along the Konto River, the specific runoff is high at 4.3 $m^3/sec/100\ km^2$. In the lowest month the runoff accounts for 53% of the annual mean, thus showing a minimal annual variation. In comparison to this, at Ngudikan along the Widas River, the specific runoff is low at 2.9 $m^3/sec/100\ km^2$, and the runoff in the lowest month makes up only 16% of the annual mean, showing a large annual variation. This may be because the Selorejo River Basin is composed of the Quaternary volcanic zone forests of the Kelud-Arjuno Massif. Whereas 70% or more of the Ngudikan Basin consists of the Tertiary mountainous zone and paddy fields.

Incidentally, the runoff of the Solo River is much lower in the dry season and the lowest month accounts for only about 10% of the annual mean runoff.

(3) Irrigation

Of the total arable land area in the Brantas Basin, 636,000 ha, paddy fields account for 324,000 ha. For 316,500 ha of this, water is drawn from the main stream or large tributaries. As of 1995 with an increase in Surabaya's urban area, the trend is moving toward decreasing arable land (refer to Appendix 3).

There was an increase in the area of paddy fields during the 23 years between 1970 and 1993, but only 10,000 ha, from 314,000 to 324,000 ha. The arable land area per farm household is 0.29 ha, much smaller than the average 0.30 ha of Java Island. However the yield per unit area is high. The rice yield per farm household is 2.39 t/ha, exceeding the national average of 2.21 t/ha (see Table 1-16).

Irrigation is used in both the dry and the rainy seasons. Since even in the rainy season clear weather sometimes continues for ten days or more, supplemental irrigation is used to compensate for the lack of rainfall. Irrigation in the dry season is limited to the area along the main stream of the Brantas and its tributaries having sufficient river flow. Therefore the irrigated area in the dry season is reduced to about one third the rainy season's area.

Table 1-16 Rice yield per hectare (1993)

	Harvested area (1,000 ha)	Yield per ha (t/ha)	Area of paddy fields per farm household (ha)	Yield per farm household (t)
Entire nation	8,499	5.67	0.39	2.21
Java Island	3,426	7.80	0.30	2.34
Brantas Basin	324	8.23	0.29	2.39

Although most of the existing agricultural facilities were constructed in the Dutch colonial days between the 19th and the early 20th century, there are many newly established facilities built as part of the Brantas River Basin Development Project. Currently a network of water utilization facilities has been carefully established; 5 barrages consisting of newly built concrete and rubber dams in the main Brantas, and diversion dams and small reservoirs in mountainous areas in the tributaries. Although now old, many of them could still be quite functional, if appropriately repaired and maintained.

Back in 1960 there were water intake facilities at 18 locations along the main stream of the Brantas, which covered 300,000 ha for irrigation. However, as of 1995, consolidation and abolishment of such facilities is under way and the irrigated area will soon reach 316,500 ha with only five intake facilities.

(4) Rainfall and runoff characteristics

In tropical regions rainfall continues for a short time, rarely exceeding ten hours. Rainfall is usually very predictable, occurring at almost the same time every day. This is the reason flood peak usually takes place at intervals of approximately 24 hours. In the Brantas Basin it begins to rain at approximately 3 o'clock in the afternoon for about three hours or so. Even storm rainfall involving flood continues for up to 7 or 8 hours, and over 70% of the rainfall occurs during the first two hours (see Attachment (5): Time distribution of storm rainfall at Karangkates). While the largest precipitation in a single storm at a point is usually 200 mm, the average rainfall in the basin is fairly small because of its limited area. The maximum daily rainfall in the Lesti River Basin was 165 mm according to the 1952-75 records.

It is estimated that in the upper regions of Karangkates Dam the runoff coefficient of flood waters (total volume of flood runoff/total volume of rainfall) is some 30% for small and medium scale floods; and some 50% even where the rainfall exceeds 100 mm.

From the characteristics of rainfall and the basin area described above, it follows that the flood peak is comparatively small in mountainous area through which the Brantas runs. For example, at Karangkates Dam, the design flood discharge is 2,580 m^3/sec and the specific yield is 1.4 $m^3/sec/km^2$. For Selorejo Dam, they are 720 m^3/sec and 3.0 $m^3/sec/km^2$ respectively.

After a trial calculation of the annual rainfall in the Brantas River Basin, the water balance in the basin can be expressed as follows:

$$P = R + i + E + \Delta S$$

where, P = rainfall, R = surface runoff, i = percolation , E = evaporation, ΔS = rate of change in storage

Almost all rainfall retained underground experiences evaporation and outflow into river channels. Outflow to the sea is said to be less than 1% because of the exceptionally slow ground flow velocity, therefore it can be disregarded. From the annual water balance, ΔS can be regarded as 0. The water balance in the upper reaches of the Ishikari River in Japan, which was measured for 1957-63, is compared with that in Brantas, the Tone River in Japan, and other areas in Table 1-17.

Table 1-17 Water balance of rivers by area

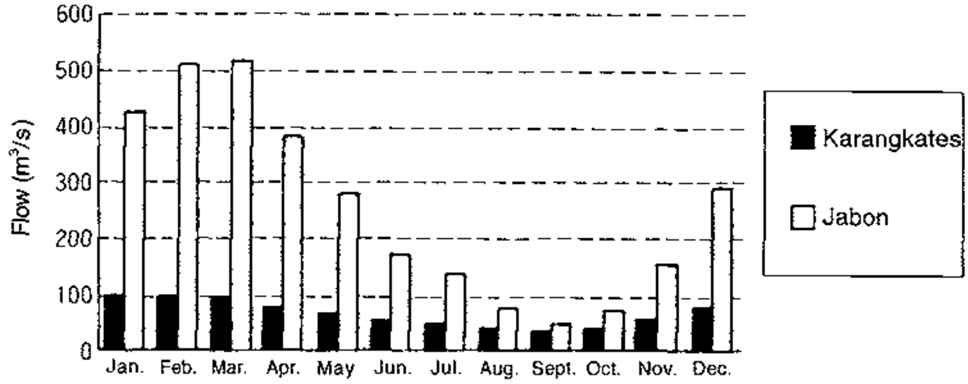
River	Measuring point	P (mm)	R (mm)	E (mm)	E/P (%)
Ishikari, Japan	Upper reaches	1,330	1,003	327	25
Tone, Japan	Middle reaches (Awahashi)	1,326	920	406	31
Brantas	Upper reaches	1,815	1,068	747	41
	Lower reaches	1,683	845	838	50
Asia	River mouth	726	293	433	60
South America	River mouth	1,648	583	1,065	65
Europe	River mouth	734	349	415	57

Remarks: 1) P: mean rainfall in the basin, R: volume of runoff (direct runoff + delayed runoff, groundwater), E: evaporation, E/P: rate of evaporation
2) For Tone River, P is mean rainfall in the whole basin and R is obtained by converting flow to precipitation.
3) Data for the Ishikari River is from "Suimongaku" (Hydrology) by Isamu Kayane.

From the table, it is roughly estimated that the evaporation of the Brantas is between 40% (in upper reach) and 50% (in lower reach) of its rainfall. According to the trial calculation, for the volume of direct runoff from the ground surface, and that of delayed runoff (runoff that becomes groundwater once and then flows out into river channels), it is likely that the latter is the runoff generated in the dry season. Especially assuming that the flow in the three months with the least annual rainfall, August through October, is all from underground, the volume is expressed as in Fig. 1-5.

From the above, though they are roughly estimated values without regard for any outside influences, such as water intake for irrigation in the basin or any other factors, the following can be said: Of the annual rainfall in the Brantas River, approximately 40% is direct runoff from the ground's surface out to river channels (runoff coefficient in the basin); 20% (upper reaches) to 10% (lower reaches) are retained under the ground with delayed runoff to river channels; and the rest of 40% (upper reaches) to 50% (lower reaches) or less undergo evaporation from the ground's surface or trees.

Consequently, making a rough estimate of all rainfall in the Brantas Basin area, 40-50% undergoes evaporation, 10-20% becomes delayed runoff (retained as groundwater later flowing out to river channels), and some 30-40% becomes direct runoff (flowing directly out to river channels).



River	Measuring point	*P* (mm)	*R* (mm)	*Qm* (m^3/s)	*Rc* (mm)	*Ru* (mm)	*Ru/P* (%)
Brantas	Upper reaches (Karang-kates A = 2,050 km^2)	1,815	1,068	25	385	683	38
	Lower reaches (Jabon A = 9,675 km^2)	1,683	845	53	173	672	40

Remarks: 1) *P*: basin rainfall, *R*: runoff from rainfall, *Qm*: dry season flow (Aug., Sept., and Oct.), *Rc*: annual runoff from the ground, *Ru*: direct runoff

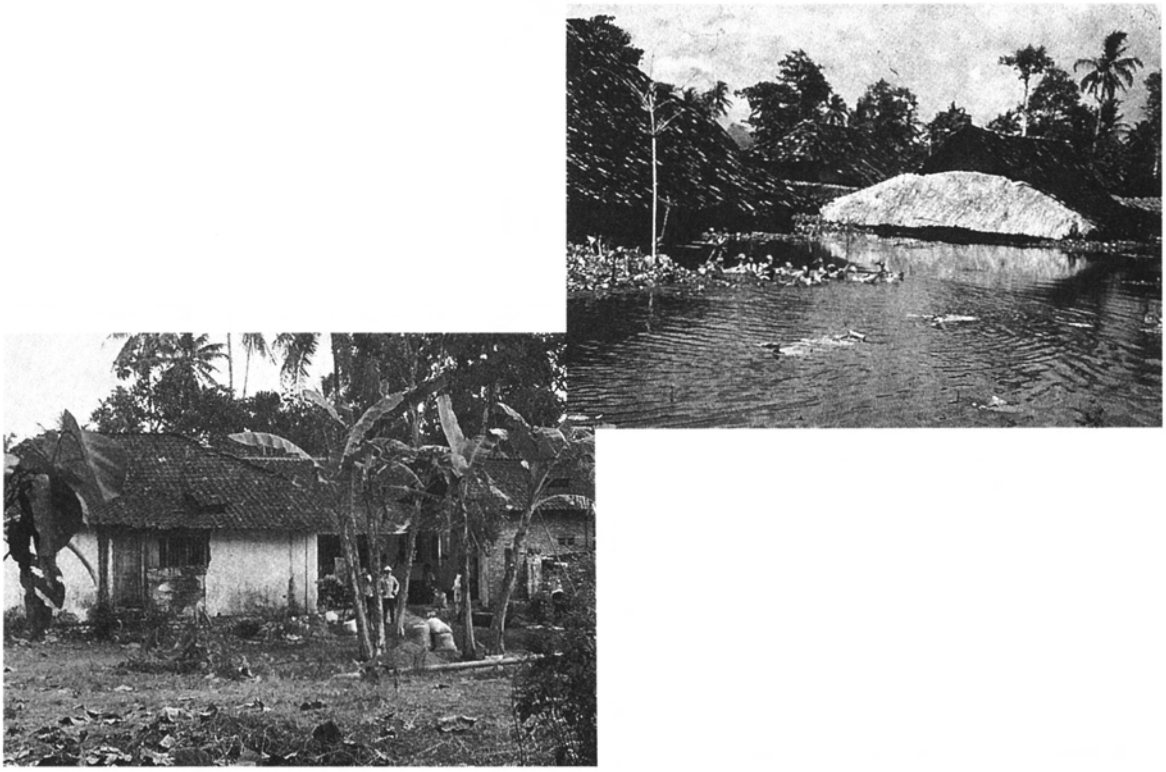
2) *Qm* is calculated after subtracting rainfall occurred in the dry season (little as 2% of annual rainfall) and the 15 m^3/s of discharge from Karangkates Dam.

Fig. 1-5 Monthly runoff by area

(5) Flood waters of Brantas' main stream

From the Malang highlands, the Brantas River forms comparatively deep gorges until flowing onto plains in the middle reaches of the basin, collecting water from its tributary streams along the way and generating almost no flooding. The river channel capacity near Pakel is 1,500 m^3/sec, where the Brantas flows onto plains, and it has enough river channel capacity until the junction with the tributary, Ngrowo River.

At the junction with the Ngrowo, the main stream of the Brantas meanders in the shape of S, with a sharp decrease in river width and channel capacity (to about 500 m^3/sec) to Kediri City. As a result, flooding occurs near this junction, part of it flowing backwards into the Ngrowo. The largest flood took place in November 1955, at a rate of 1,700 m^3/sec at Pakel, when a great flood occurred near the junction causing part of the overflow to run down into the paddy fields on the Brantas right bank and flow backwards into the Ngrowo marsh as well. The area near this junction used to remain filled with flood waters for a considerable time; however after the Karangkates Dam was completed in 1972, the frequency of such flooding has decreased drastically.



Area near Tulungagung: before river improvement (1959) and after (1993)

For the Brantas, continuous banks are provided in the lower reaches of Kediri City. The flood waters that run down to the city hardly ever overflow until the junction with the Widas River. Near which, the right bank of the Brantas is 3 m higher than the opposite paddy fields, making a deep channel of the Widas. This might be natural embankment or else the result of a modification to transfer the junction to the side of a mountain, because the junction is higher than the banks of the Widas behind it. This was probably designed to direct the flood waters, if over a given level, to the lower land behind the Brantas/Widas junction, keeping them there and preventing backflow into the main stream of the Brantas.

Since the renovation work on the middle reaches of the river was completed, the occurrence of flood damage near Brantas main stream has been considerably reduced. Ngrowo and Widas river improvement plans are complete and their implementation is underway.

Lengkong Dam, where the Brantas branches off to the Surabaya and Porong Rivers and Mlirip Intake Gate at the inlet of the Surabaya River branch, was constructed in 1957; closing the Lengkong Gates in the rainy season make the flood waters to run down the Porong.

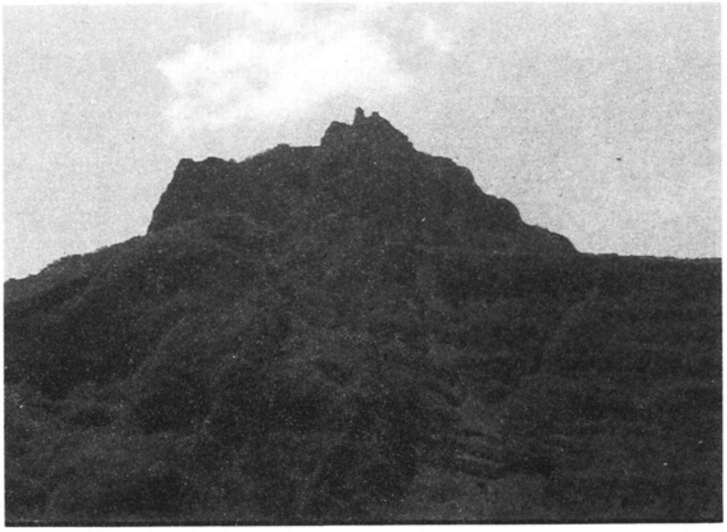
Palm fields eroded by Porong River flooding

The flood waters of the Brantas are controlled at its junctions with Ngrowo and with Widas, and thus it is allowed to flow through the Lengkong Dam with a very flat peak.

As can be seen from the above description, the present flood control of the Brantas River main stream is performed by closing off the Surabaya River first, to protect Surabaya City located in its lower reaches. Further the flow is also controlled by utilizing junctions with large tributaries of Ngrowo and Widas as retarding basins to protect paddy fields along the main stream. Recently a large flood took place in 1984, between March 2 and 5, generating a maximum peak runoff of 1,180 m^3/sec at Karangkates and 1,470 m^3/sec in the Porong River. A flood of nearly the same scale occurred in February 1992, causing no damage.

(6) Eruption of Mount Kelud

In the basin at the source of the Brantas River there are both active and dormant volcanoes. The latter includes Mt. Arjuno (3,339 m), Mt. Anjasmoro (2,282 m), and Mt. Kawi (2,651 m). Active are Mt. Kelud (1,731 m), and Mt. Semeru (3,676 m) located in the basin at the source of the Lesti River, a tributary of the Brantas. Mount Semeru was very active in the 19th century, with yearly lava flows, mainly outside of the Brantas River Basin.

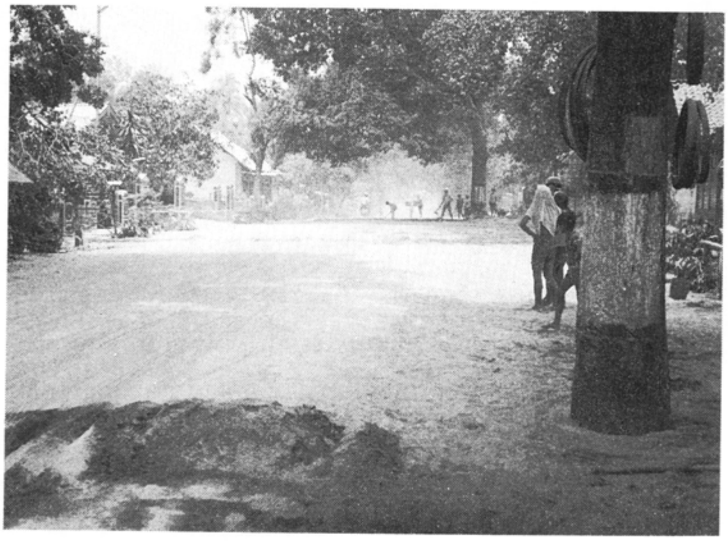


Near summit of Mt. Kelud

As Mt. Kelud, 1,731 m above sea level, is situated in the middle of the Brantas Basin, a large amount of ejecta has formed a specific topography in the basin. It is difficult to accurately determine how much ejecta a single eruption produces. However according to recent records, it was estimated at 200,000,000 m^3 in the August 1951 eruption, 90,000,000 m^3 in 1996, and 125,000,000 m^3 in 1990. The south and west sides of Mt. Kelud are composed of lahar that mixed with the water of the crater lake and flowed down the slopes making them unstable. The lower west side of the mountain forms a gentle slope covered by nutrient volcanic ejecta, over which stretch various plantations including coffee, cocoa, and rubber. The area at the foot of Mt. Kelud near Kediri and Blitar Cities has been made into paddy fields.

The crater lake is estimated to have been created after the May 1848 eruption. In areas around the lake there are sheer andesites, which resemble castle walls. In the eruption of January 1875 there was a partial collapse of the lake's natural retaining wall, resulting in the lake overflowing, and the lahar running down into Blitar City.

For hundreds of years the residents around Mt. Kelud have been suffering destructive damage to their lives and assets. There are tragic Javanese folk tales concerning the eruptions of Mt. Kelud and people have a very real fear of it. The Mojopahit Dynasty, which ruled all of Indonesia around the 14th century, collapsed after the 1451 eruption.



Town with volcanic ash fall

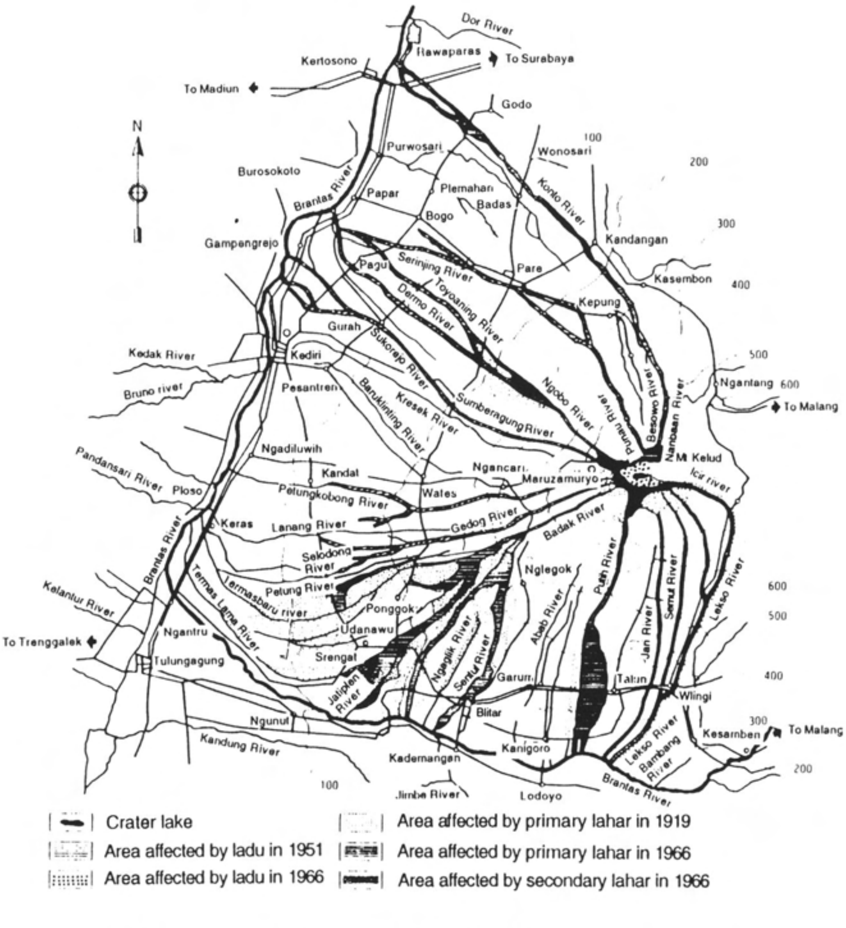


Fig. 1-6 Distribution of ejecta from Mt. Kelud

There are no detailed records of eruptions before 1800. The first record of Mt. Kelud's erupting was made by the Dutch in June 1811, followed by October 1826, January 1851, 1864, and 1875. The 20th century experienced five eruptions in 1901, 1919, 1951, 1966, and 1990. The May 1919 eruption caused 38,000,000 m^3 of water, which had collected in the crater, to gush out and flow down the Badak River in the form of lahar. This caused an unprecedented disaster with a loss of 104 villages, 9,000 houses, and 5,110 lives. After this eruption, the Dutch planned to drain the lake through a drainage tunnel to prevent further disasters resulting from lahar; its construction commenced in September 1919 and was finished in April 1923. Since then, the tunnel has been reconstructed after damages caused by subsequent eruptions, consequently contributing to a remarkable reduction in damage caused by lahar. The eruption in 1990 generated no lahar, causing a few deaths (12 are reported in the National Volcanic Disaster Prevention Team survey). However the drainage tunnel was again destroyed and its remedial work is under way by Mount Kelud Volcanic Disaster Prevention Project, which is directly under the Ministry of Public Works in charge of forestry conservation (see Fig. 1-6).

People removing ash from rooftops