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Land Use Planning of Way Betung Watershed for Sustainable Water Resources Development of Bandar Lampung City

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ABSTRACT

Way Betung watershed is one of the important water resources in Lampung Province and it provides a clean water for Bandar Lampung City through a regional water supply company (PDAM). By the increase of population and economical activities of Bandar Lampung City, the need of clean water also increase, however by the time, the conditions of Way Betung watershed as water resources are declining. Therefore, to improve or to restore Way Betung watershed, a high cost is needed. The research was aimed: (a) to study the effects of Way Betung watershed land use change on the water resources of Bandar Lampung City, (b) to arrange the sustainable development of Way Betung watershed in order to maintain the availability of water resources. The sustainable developments of water resources of Way Betung watershed were arranged in five alternatives/scenarios and each alternative was related to its erosion (USLE method) and its run off volume (SCS method). The results showed that land use changes of Way Betung watershed (1991-2006) were likely to increase daily maximum discharge (Q_{max}), to decrease daily minimum discharge (Q_{min}), to increase fluctuation of river discharge, and to increase yearly run off coefficient. The best sustainable development of water resources of Way Betung watershed, Lampung Province, was alternative/scenario-4 (forest as 30% of watershed areas + alley cropping in the mix garden). This alternative will decrease erosion to the level lower than tolerable soil loss and also decrease fluctuation of monthly run off.

Keywords: Land use change, run off coefficient, water resources, watershed

INTRODUCTION

Water is one element that is essential for the survival of humans and other living creatures. The existence of water resources that can ensure the needs of human life is necessary. Way Betung watershed is an important water resource, where the Way Betung river is the main supplier of raw water for a regional water supply company (PDAM) to supply the water need of Bandar Lampung.

Way Betung watershed has an area of 5260 ha that are about 2,679.94 ha (51%) in the forest conservation area (*Taman Hutan Raya, Tahura*) and the remaining of 2,580.06 ha (49%) as the cultivation area. Along with the increasing of population and economic activity in Bandar Lampung City, then the greater need for clean water is necessary. On the other hand, the conditions of Way Betung river as water resources are

increasingly concerned. A report from the Unila Research Center (2003) that discharge fluctuations in Way Betung river were relatively large (48:1) and the minimum discharge average decreased from $1.1 \text{ m}^3 \text{ sec}^{-1}$ in year 1997 to $0.92 \text{ m}^3 \text{ sec}^{-1}$ in year 2002, even since year 2002 it has been estimated that there was the deficit of clean water. This is due to the change of land use from forest to other uses (agriculture, mixed garden, shrubs, dry land farming and settlement). Some factors that caused land use changes were the existence of population pressure on land (35 villages around the forest), forest encroachment (23.7%), as well as the forestry community activities (community forest, *Hkm*) in the Way Betung watershed.

Land use change of Way Betung watershed caused a decrease in hydrological conditions, this was due to a decreasing of the land ability to infiltrate rainwater and an increasing the amount of run off. Sinukaban (2007) stated that extensively felling of forests in the upstream watershed could disrupt the distribution of river flow in the downstream. In addition, land use change or

inadequate agrotechnology would affect the quality and the quantity of water that flowed in the downstream. To be able to maintain or even enhance the ability of Way Betung watershed as water resources for Bandar Lampung city, the arrangement of land use is necessary. Various alternatives of land use arrangements that will apply to Way Betung watershed shall be ecologically feasible. Ecological feasibility criteria is one of the requirements of sustainable utilization of natural resources. Ecological feasibility that will be used as a criterion in each land use alternative is that resulting soil erosion has to be smaller than soil erosion that can be left (Tolerable Soil Loss) and the smallest of run off fluctuations (at least) of all the land use alternatives which have been prepared.

This study were aimed to (a) assess the influence of land use change of Way Betung watershed on the hydrology/water resources of Bandar Lampung, (b) formulate alternatives/arrangements of land use of Way Betung watershed for sustainable water resources development.

MATERIALS AND METHODS

Site Location

The research was conducted in the Way Betung watershed, Lampung Province. It was administratively located in the upstream of Pesawaran District and downstream of Bandar Lampung city. The experiment was conducted from November 2008 until June 2009.

Research Methodology

Various types of maps such as soil maps, land use maps, topographic maps and *Image Landsat* were used. The used tools included survey equipments, GPS, map work, soil sampling equipments, and other equipments for laboratory analysis.

This study used survey methods, field observations and laboratory analysis. To assess the influence of land use change on hydrology/water resources, data of land use change of Way Betung watershed in the year of 1991, 1991, and 2006 which were taken from landsat ETM + 7 were used. Discharge data was obtained from the measurement stations of the surface water level of Way Betung river in a series (year 1991-2006), while the rainfall data was obtained from climatological stations of Sumur Putri in the period of year 1987-2006. The station is the observation/measurement location of surface water level for taking raw water of PDAM from a Way Betung river. Land use changes that

were examined included changes in forest cover, mixed garden, shrubs, dry land farming and settlement. In addition to the landsat ETM +7 analysis, a survey field (Ground Check) was also conducted. Hydrological conditions of water resources that were examined included the annual runoff coefficient (CRO), maximum flow rate (Qmax), minimum flow rate (Qmin), as well as discharge fluctuations.

Arrangement of Scenario

Alternatives/arrangements of land use of Way Betung watershed for sustainable water resources development have been prepared on the following scenarios, Scenario-1: current Way Betung watershed condition (existing); Scenario-2: alternative development based on Forestry Law No.41 year 1999 article 18. The upstream watershed with the use of forest land must be maintained at least 30% (thirty percent); Scenario-3: alternative development of Way Betung watershed was prepared under the Law No. 26 year 2007 on Spatial Planning, which was in accordance with article 5 (2), which stated the main functions of spatial planning on the basis of region, ie protected areas and cultivation areas (scenario-3, all protected areas/forests should be rehabilitated/reforested); Scenario 4: The application of scenario-2 plus soil conservation practices (agrotechnology/alley cropping) on the mixed farm land use; and Scenario-5: application of scenario-3 plus soil conservation practices (agrotechnology/alley cropping) on the upland agricultural land use.

In each of the land use alternative/arrangement of Way Betung watershed (scenario), the amount of erosion was computed/infered by a Universal Soil Loss Equation (USLE) method (Weischmeier and Smith 1978) and the amount of monthly run off of each land use with the Soil Conservation Services (SCS) method (Arsyad 2006). The best scenario was the scenario that considered to have the erosion value is lower than Tolerable Soil Erosion and run off is lower than 30 (smallest).

RESULTS AND DISCUSSION

Land Use Change of Way Betung Watershed

Forest area decreased significantly from 16.72% (year 1990/1991) to 9.66% (year 1999/2000) and decreased again to 7.17% (year 2006/2007). The decrease of forest area is partly due to the policy of the government (Department of Forestry), which provides temporary permission civil rights for public (community forest, HKm) to

manage the forest area ± 450 ha for 5 (five) years in year 1999 (Department of Forestry 1999). The impact of community forest management to the agroforestry pattern in year 1999 caused extensive mixed farm increased from 48.63% to 60.33%, and decreased shrub from 24.88% to 12.11%, besides an increase in large settlements from 3.38% to 7.04%, this was due to most of the people built a residential in the community forest management areas.

Once the temporary permit of the community forest (HKm management) expired (2004), it broadly declined in mixed garden from 60.33% to 52.17%, increased in the bush area from 12.11% to 21.98%, and followed by a large decreased in settlement of 7.04% to be 6.82%. This was due to most people of HKm management left the forest areas so that the mixed garden became neglected and it was back into the bushes (Table 1).

Number of residents who relied on forests also affected land use change in the region. So, even though HKm had been discontinued but it was still a decline in forest area from 9.66% to 7.17%. This is in agreement with Awang (2006) which stated that the region of a Way Betung as an upstream of Way Betung watershed was surrounded by a high density residents (Sumber Agung village had 425 households and Hurun village had 1,800 households), where most of their livelihood was a dry land farming in forest areas. Such population pressure conditions were supposed to have contribution to the decreasing of forest area of Way Betung watershed hereinafter to be highly influenced its hydrological conditions.

Impacts of Land Use Change on Hydrological Conditions/Water Resources

Land use change in Way Betung watershed (Table 1) increased the annual run off coefficient (CRO) from an average of 25.31% in the first four

years (1991-1995) to 33.22% in the last four years (2003 - 2006) (Table 2). The amount of run off coefficient described the loss of water that could not be utilized, amounting to 33.69 million m³ year⁻¹ equivalent to Rp111.17 billion year⁻¹ (with PDAM tariff Rp3,300 per m³ of water). This was caused by land use change from forest to other uses, such as mixed garden, shrub, dry land farming or settlement which was apparently reduced the infiltration capacity, so that the amount of rain water that became run off was much greater when compared to the infiltrated rainwater.

Arsyad (2006) suggested several factors that influenced the run off coefficient, namely: (1) the number, intensity, and distribution of rainfall, (2) topography and soil type, (3) watershed area, (4) vegetation cover and soil, as well as (5) land management system. Thus if a watershed that has land use changes causes a decrease in infiltration capacity, it will cause an increase in runoff coefficient. When analyzed further, the magnitude of the run off coefficient value (CRO) in the rainy season only (Table 3) shows that the impact of land use change significantly increased the value of CRO that was 49.98% in year 1991-1995 and 73.86% in year 2003-2006. So, the amount of water that wasted to the sea and was not utilized amounted to 74 million m³ year⁻¹ or equivalent with Rp244,22 billion year⁻¹ (with PDAM tariff Rp3,300 per m³ of water). This shows how great the impact of land use change (Table 1) on the condition of watershed hydrology and the potential loss of water resources. Such a large impact was allegedly because of land use change from forest into another use (mixed garden, dry land, settlements and bushes) which caused changed in land capability to infiltrate the rainfall and increased the runoff. Sinukaban (2008) also stated that land degradation and loss of hydrological functions of watersheds caused by many factors, among others: (a) the land use and

Table 1. Changes in land use of Way Betung watershed in the years 1990/1991-2006/2007.

No	Land use	Year 1990/1991			Year 1999/2000			Year 2006/2007	
		(ha)	%	Δ%	(ha)	%	Δ%	(ha)	%
1	Forest	979.25	16.72	-7.06	508.14	9.66	-2.49	377.10	7.17
2	Mixed garden	2458.12	48.63	11.70	3173.26	60.33	-8.16	2744.28	52.17
3	Bush	1308.51	24.88	-12.77	637.12	12.11	9.87	1156.24	21.98
4	Dry land farming	304.56	5.79	1.24	369.91	7.03	-0.90	322.48	6.13
5	Settlements	178.02	3.38	3.66	370.53	7.04	-0.22	358.66	6.82
6	Others*	31.54	0.60	3.22	201.04	3.82	1.91	301.24	5.73
	Total	5260.00	100.00	0.00	5260.00	100.00	0.00	5260.00	100.00

Source: Data was analyzed from the *Image* interpretation (2009).

*Not identified (cloudy); Δ = land use change between the two periods. (+) increase and (-) decrease.

Table 2. The annual runoff coefficient (CRO) Way Betung Watershed (%).

Year	Precipitation	Watershed area (ha)	Yearly run off ($\text{m}^3 \text{sec}^{-1}$)	Run off volume (mm)	Base flow ($\text{m}^3 \text{sec}^{-1}$)	Base flow volume (mm)	Direct run off (mm)	Run off coefficient (%)
1991	2,052.50	5,260	1.62	974.15	1.01	605.54	368.61	17.96
1992	2,243.00	5,260	1.76	1,056.41	0.96	575.56	480.85	21.44
1993	1,798.00	5,260	1.89	1,130.36	0.96	575.56	554.80	30.86
1995	1,784.00	5,260	1.70	1,020.26	0.78	467.64	552.62	30.98
1996	1,919.30	5,260	1.66	995.52	0.69	413.69	581.84	30.32
1998	1,861.00	5,260	1.69	1,013.72	0.82	491.63	522.10	28.05
1999	2,283.50	5,260	2.22	1,329.30	0.69	413.69	915.61	40.10
2001	1,831.50	5,260	1.79	1,073.04	0.65	389.70	683.33	37.31
2002	1,744.00	5,260	2.02	1,208.53	0.78	467.64	740.89	42.48
2003	1,981.00	5,260	1.93	1,159.73	0.78	467.64	692.09	34.94
2004	1,954.50	5,260	1.85	1,109.58	0.78	467.64	641.94	32.84
2005	2,161.00	5,260	2.14	1,282.86	0.96	575.56	707.30	32.73
2006	1,616.00	5,260	1.74	1,044.68	0.87	521.60	523.08	32.37

Table 3. Run off coefficient (CRO) of Way Betung watershed during the rainy season (January-February-March-October-November-December).

Year	Precipitation (mm)	Watershed area (ha)	Yearly run off ($\text{m}^3 \text{sec}^{-1}$)	Run off volume (mm)	Base flow ($\text{m}^3 \text{sec}^{-1}$)	Base flow volume (mm)	Direct run off (mm)	Run off coefficient (%)
1991	1,544.50	5,260	1.89	1,132.52	1.01	605.54	526.98	34.12
1992	1,533.50	5,260	2.06	1,237.76	0.96	575.56	662.20	43.18
1993	1,082.00	5,260	2.07	1,243.08	0.96	575.56	667.52	61.69
1995	1,235.00	5,260	2.04	1,220.30	0.78	467.64	752.66	60.94
1996	1,063.30	5,260	1.94	1,166.06	0.69	413.69	752.37	70.76
1998	997.00	5,260	2.06	1,233.43	0.82	491.63	741.81	74.40
1999	1,906.00	5,260	3.08	1,845.82	0.69	413.69	1,432.14	75.14
2001	1,042.50	5,260	2.16	1,296.88	0.65	389.70	907.18	87.02
2002	1,059.00	5,260	2.49	1,494.48	0.78	467.64	1,026.84	96.96
2003	1,486.00	5,260	2.56	1,534.23	0.78	467.64	1,066.58	71.78
2004	1,547.50	5,260	2.69	1,611.38	0.78	467.64	1,143.74	73.91
2005	1,338.00	5,260	2.76	1,657.16	0.96	575.56	1,081.59	80.84
2006	1,257.00	5,260	2.31	1,387.82	0.87	521.60	866.22	68.91

the use of land which were deviated from the Spatial Planning/Regional (*e.g.* forest was functioned to agriculture, residential, or industrial land), (b) the use of land that was not rational (not according to land ability), (c) failure to apply soil and water conservation techniques for the cultivation of steep slope, (d) the absence of the governing regulations, and (e) lack of the government commitment in the arrangement of land use.

Changes in land use such as in Table 1. causing an increased daily average of maximum dis-

charge and decreased daily average of minimum discharge of Way Betung river. Decreasing the percentage of forest area was allegedly most responsible for the increasing of Q_{\max} and decreasing in Q_{\min} . this can be seen on the correlation between forest area (%) with Q_{\max} and Q_{\min} (Figure 1). Increased maximum discharge daily average (Q_{\max}) Way Betung river partly because the declining in forest area and increasing of mix garden and settlement areas. As it is known that the forest had greater infiltration capacity than other types of

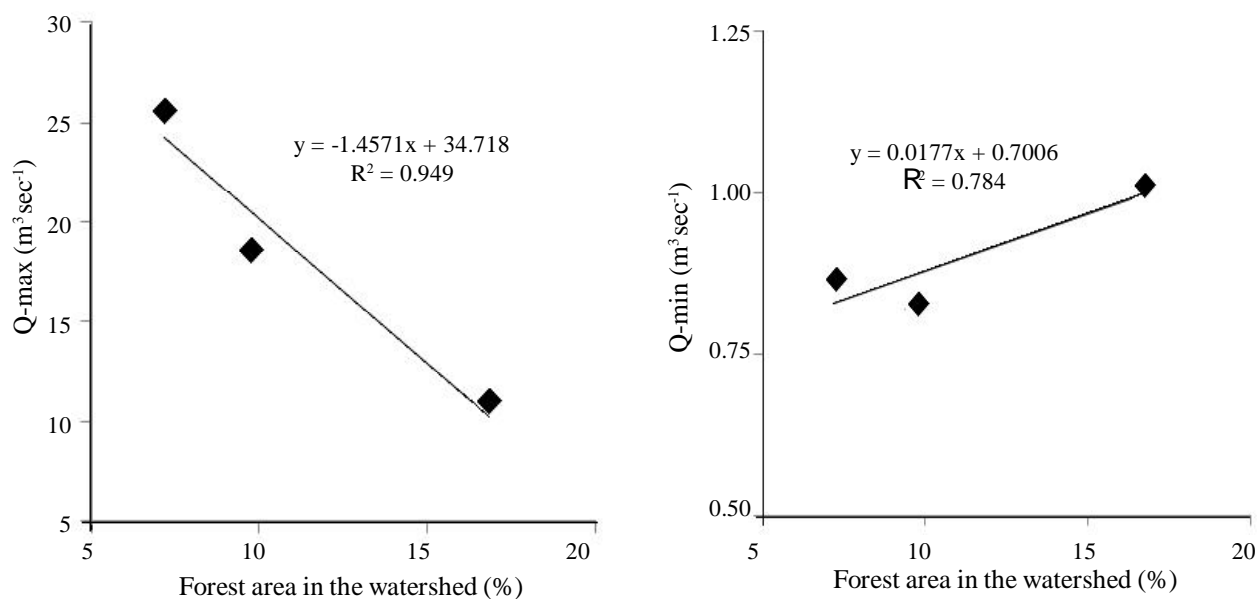


Figure 1. The correlation between the change of forest area (%) (year 1991-2006) and the daily average of maximum and minimum discharges of Way Betung river (m³ sec⁻¹).

land use. so that when the forest area is reduced it will reduce infiltration capacity and increases runoff. This is consistent with Handayani *et al.* (2005) which research done in the upstream of Ciliwung. the decrease in forest cover area of 4,897 ha (18.1% of watershed area) in year 1989 to 4,459 ha (16.2% of watershed area) in year 1998 increased the peak discharge from 489.34 m³ sec⁻¹ to 582.18 m³ sec⁻¹ (up to 18.97%). This fact indicates that the change of land use from forest to other uses contributed substantially to increase the average maximum discharge and runoff volume.

Decrease in a daily average of minimum discharge (Qmin) of Way Betung river could not be separated from the change of land use that occurred. The large amount increasing of mixed farm (year 1991-2006) was considered to cause increasing of surface runoff, because generally a mixture garden land was located at 15-40% slope and the farmers did not apply an adequate soil and water conservations. The combination between the land use to mixed farm and a relatively steep slope without conservation practices led to an increase of run off, on the other hand, this caused the soil water storage decreased so that it directly would reduce the daily average of minimum discharge. This result was consistent with the research of Agus *et al.* (2002) in Sumberjaya, the amount of runoff (including river discharge) was determined by topography, soil physical properties and quality of land cover in a watershed. So if one of these factors changed, it would cause corresponding changes in watershed conditions such as surface flow (stream

flow) discharge both the maximum and minimum discharges. Moreover, Arsyad and Rustiadi (2008) stated, in the context of watershed management that any treatment in a piece of land which performed by humans would affect the water behavior of that land and its downstream. Similarly Sinukaban (2007), that the reduced infiltration capacity on the soil erosion area in the upstream watershed causing replenishment (recharge) of ground water was also reduced so that resulted drought in the dry season and flood in the rainy season.

The impact of land use change (Table 1) caused an increase in annual discharge fluctuations of Way Betung river from years 1991-2006 (Figure 2). A tendency of increased discharge fluctuation was supposed to be caused by an increase in mixed farm and a decline in forest. This caused the decrease in infiltration capacity, the excessive runoff, and reduced the soil water storage. These results were in agreement with Ilyas (2000) that the decrease of forest area in the Karangmumus watershed in East Kalimantan from 18% to 10% could cause the increased of flood peak rate as much as 7.63% from its original condition. While Sinukaban *et al.* (2007) stated that changes in land use from bush into agroforestry (mixed garden) in Manting sub-watershed, East Java, had caused an increase in discharge fluctuation from 9.7 in year 1987 to 10.1 in year 1988 and to 13.1 in year 1999. This is due to agroforestry or mixed farm that was applied causing some land to be opened, so it had the impact on the increasing of the run off. The trend in increasing the fluctuation value of Way Betung river

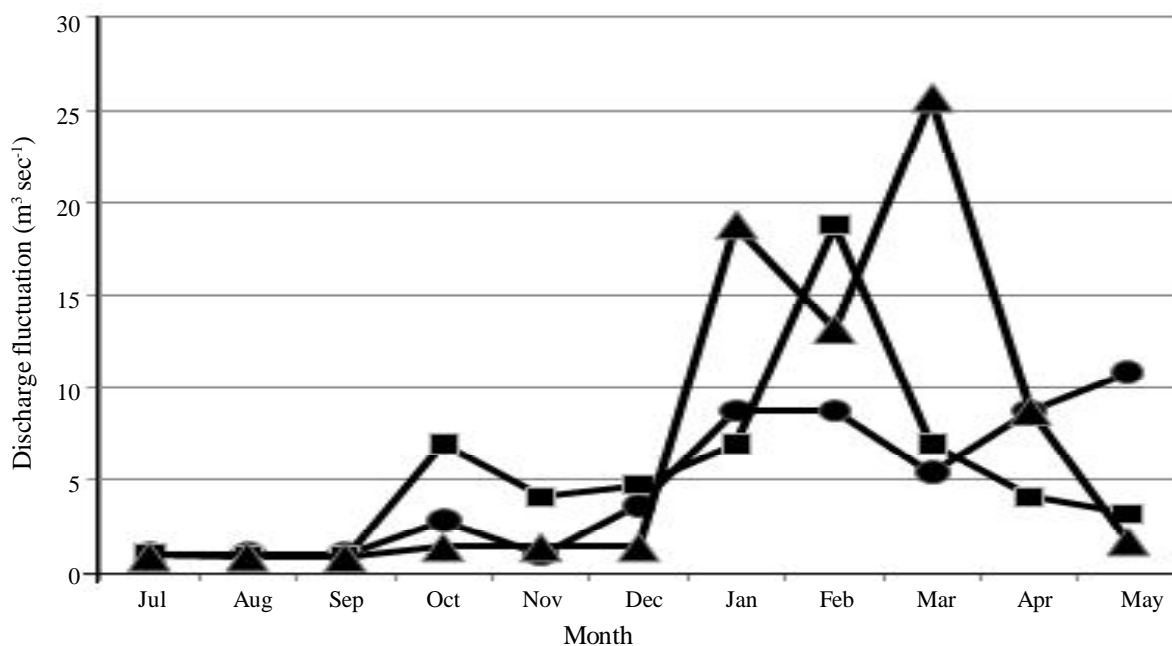


Figure 2. Monthly discharge fluctuations of Way Betung river in the year 1991-2006.

● = 1991, ■ = 1996, and ▲ = 2006.

indicated that the hydrological conditions of Way Betung watershed were worse for that it is needed an alternative land use development that can fix it.

Analysis of Alternatives/Arrangements of Land Use of Way Betung Watershed

Alternatives/arrangements of land use of Way Betung watershed of each scenario (Table 3) is used as the basis for the prediction of erosion and runoff. Alternative land use scenario-3, scenario-4 and scenario-5 could reduce erosion rates to below the erosion that is allowed (Tolerable Soil Loss). This is because in scenario-3 forest area has reached 51.1%, whereas in the scenario-4 and the scenario-5 increasing the forest area as well by adding a soil conservation practices such alley cropping, so that action can reduce erosion to below than TSL (Figure

3). This is in accordance with Sinukaban and Banuwa (2007) and Sunarti *et al.* (2008) that conservation practices could reduce erosion and runoff. Furthermore Hidayat *et al.* (2008), the result of ANSWERS model simulation using daily C factors indicated that rainforest conversion into agricultural land in Nopu Upper Catchment of Central Sulawesi causing soil and water loss of 3,190.5 t yr⁻¹ and 115,441 m³ yr⁻¹, respectively.

Although the scenario-3 and scenario-5 can reduce erosion to less than the TSL, but its implementation will potentially lead to social conflict. This is because in the forest area currently there are HKm activities with an area approximately 450 ha. So if those scenarios are applied (all forest areas are reforested), it will cause conflicts with

Table 3. Changes in land use of each scenario development.

Land use	Scenario-1		Scenario-2		Scenario-3		Scenario-4 *)		Scenario-5**	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Forest	377.1	7.2	1.578.0	29.9	2.691.5	51.1	1.578.0	29.9	2.691.5	51.1
Mixed garden	2.744.3	52.2	1.543.4	29.3	1.434.9	27.2	1.543.4	29.3	1.434.9	27.2
Bush	1.156.2	22.0	1.156.2	21.9	523.7	9.9	1.156.2	21.9	523.7	9.9
Dry land farming	322.5	6.1	322.5	6.1	161.0	3.1	322.5	6.1	161.0	3.1
Settlements	358.7	6.8	358.7	6.8	313.4	5.9	358.7	6.8	313.4	5.9
Others***	301.2	5.7	301.2	5.7	301.2	5.7	301.2	5.7	301.2	5.7
Total	5260.0	100.0	5260.0	100.0	5260.0	100.0	5260.0	100.0	5260.0	100.0

Note: *Scenario-4, mixed garden + alley cropping, **Scenario-5, dry land farming + alley cropping, ***not identified (cloudy).

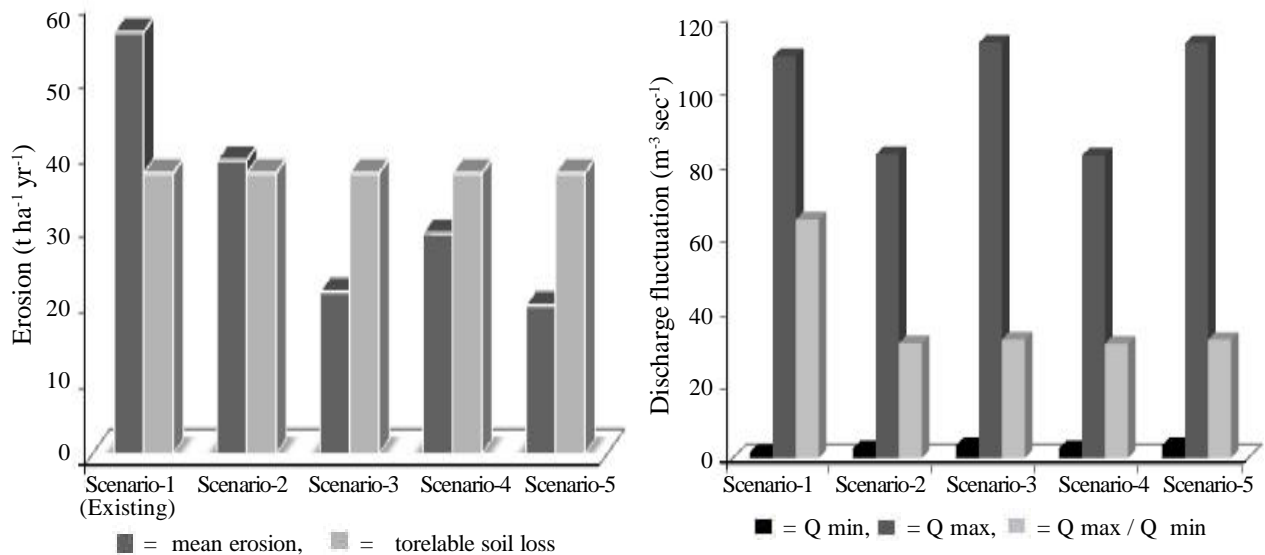


Figure 3. Estimation the amount of erosion and the run off of each scenario.

HKm farmers which have to be moved from the forest area.

If it is based on the run off fluctuations, then the scenario-4 will be able to reduce the monthly run off fluctuations from 64.7 (scenario-1) to 30.9 (scenario-4), and to increase the minimum discharge from 1.68 m³ sec⁻¹ into 2.65 m³ sec⁻¹ or an increasing of 57.73%. It is expected that with the increasing minimum discharge of Way Betung river, it will be able to increase the availability of water that can be used as a source of clean water. Although scenario-5 is able to increase the minimum discharge of 1.68 m³ sec⁻¹ to 3.51 m³ sec⁻¹, but runoff fluctuations that occur (32.05) is still greater than that generated by the scenario-4 (30.94) (Figure 3). Table 4 shows that the scenario-4 (30% forested upstream watershed + alley cropping on mixed farm) is developed as the best alternative, because it can reduce erosion to below the TSL value and it also produces the lowest run off (the smallest discharge fluctuation).

CONCLUSIONS

Land use in the form of forest in Way Betung watershed was likely to decline, viz. in year 1991 covering an area of 979.25 ha (16.72%), in year 1999 covering an area of 508.14 ha (9.66%) and in year 2006 covering an area of 377.10 ha (7.17%). Land use in the form of mixed farm as well as the settlement were likely to increase, while the land use as dry land was likely to remain, and land use in the form of shrub was fluctuated.

Changes in land use of Way Betung watershed in the year 1991-2006 were mainly due to a decrease of forest area and an increase in large mixed farm which causing the trend of increased an annual runoff coefficient (CRO) and a daily average maximum discharge (Qmax), decreased the daily average minimum discharge (Qmin), and increased fluctuations in river discharge.

Alternative/arrangement of land use based on the scenario-4 (30% forested upstream watershed + agrotechnology alley cropping on mixed farm)

Table 4. Decision making of an alternative development of Way Betung watershed.

No.	Development Alternative	Criteria of decision		
		Erosion < TSL (t ha⁻¹ yr⁻¹)	The smallest discharge fluctuation	Decision
1	Scenario-1	56.11	64.68	Unsustainable
2	Scenario-2	39.07	31.13	Unsustainable
3	Scenario-3	21.61	32.12	Sustainable-3
4	Scenario-4	29.39	30.94	Sustainable -1
5	Scenario-5	19.83	32.05	Sustainable-2

Note: TSL = 37.35 t ha⁻¹ yr⁻¹

was the best alternative of a water resource development.

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