Analysis Of Watershed Function Sediment Transfer Across Various Type Of Filter Strips

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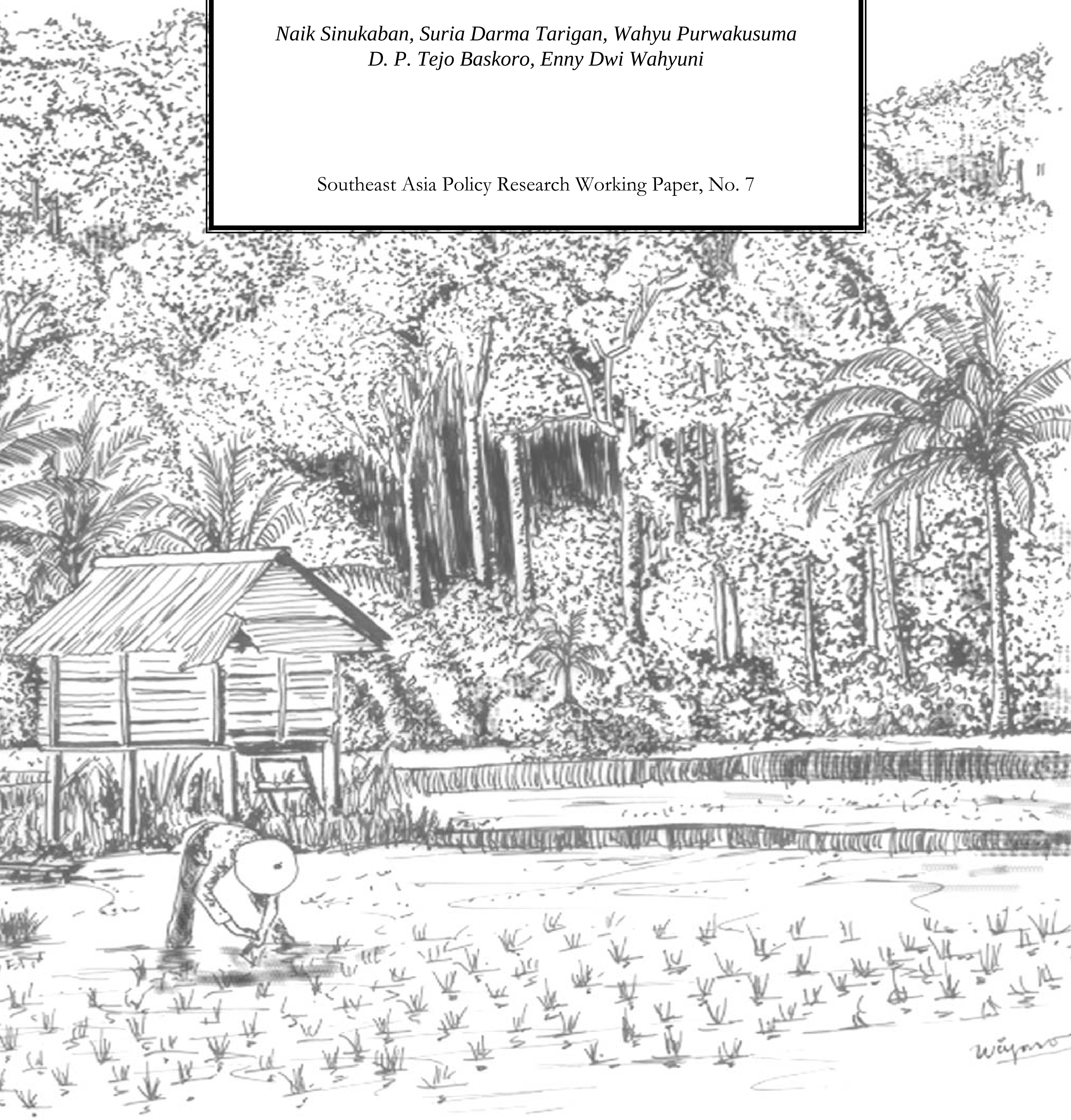

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ANALYSIS OF WATERSHED FUNCTION
SEDIMENT TRANSFER ACROSS VARIOUS TYPE OF FILTER STRIPS

LABORATORY OF
SOIL PHYSICS AND SOIL CONSERVATION
DEPARTMENT OF SOIL SCIENCE
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University of Lampung
(UNILA)

BOGOR
January, 2000

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FINAL REPORT

Naik Sinukaban
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PREFACE

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The report describes various types of filter strips generally found at the research area and their effect on sediment transfer from adjacent land use, application of ANSWER Model in Unila Erosion Plot-Kampong Karang Bodong, and hydrological and climatological analysis of the Way Besai Upper Catchment.

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Bogor, January 2000
Bogor Agriculture University (IPB) Team

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I. INTRODUCTION

1.1. Background and Objective

The relationship between erosion measured in a standardised 'erosion plot' or predicted by a model calibrated from such experiments and the magnitude of sediment yield in rivers can be overstated due to the intercepting effect of filter strips/border strips and hedgerows that capture sediment from erosion higher up slope.

There appears to be a major gap between results of plot level erosion studies and studies based on stream flow. The whole matrix of field borders in which the plots are set appears to have been ignored in most previous researches. To properly link between the on-site erosion and sediment yield in rivers, factors, such as field border strip and the 'hot spots' that directly contribute sediment to streams e.g. from footpaths should be taken in to consideration.

The first part of this research emphasises the measurement of sediment transfer across various types of filter strips. The working hypothesis is that transfer beyond filter strips is small, regardless of land use, despite significant soil loss within fields for some types of land use.

Nevertheless, those measurements are considered as point measurements. At landscape scale, the spatial configuration of mentioned filter strips will greatly influence the linkage between on-site and off-site effect. The configuration of the filter strips in a catchment scale has not been taken into consideration in the first part of this research. Therefore, those point measurements need to be transferred into broader scale. To transfer into a broader scale a spatial model is needed.

An existing spatial model, the so called ANSWERS model is considered as an appropriate tool to simulate the sediment transfer. The application of the ANSWERS to simulate the sediment transfer across filter strips is the second emphasis of this research.

The third part of this research deals with analysis of the flow pattern of the Way Besai river in Sumber Jaya (Lampung, Sumatra). We analysed these flow patterns and their association to rainfall and land use change over the past 25 years.

1.2. Location

This research was located at the Way Besai catchment in the northern part of Lampung Province, between 4^o 15' to 5^o 15' S and 104^o 15' to 104^o 30' E (see Figure 1.1).

Location of Sediment Transfer Measurement

The measurement of sediment transfer was carried out in 5 different filter strips/land use. These filter strips were situated at the upper parts of the Way Besai catchment. Surrounding the area some small erosion plots having size 3x1 m^2 had been established to measure erosion.

Location of ANSWERS Model Application

The values of parameters used for model prediction and calibration were collected from a micro-catchment. This micro-catchment is situated 2 km to the East of Fajar Bulan Village. The micro-catchment has an areas of approximately 2 ha.

Location for Hydrological Analysis of Way Besai

Historical stream flow data of Way Besai catchment is taken from Way Besai - Petai hydrological station. This catchment encompasses an area of 369 km^2. The time series of land use data is taken from, 1980 until 1995.

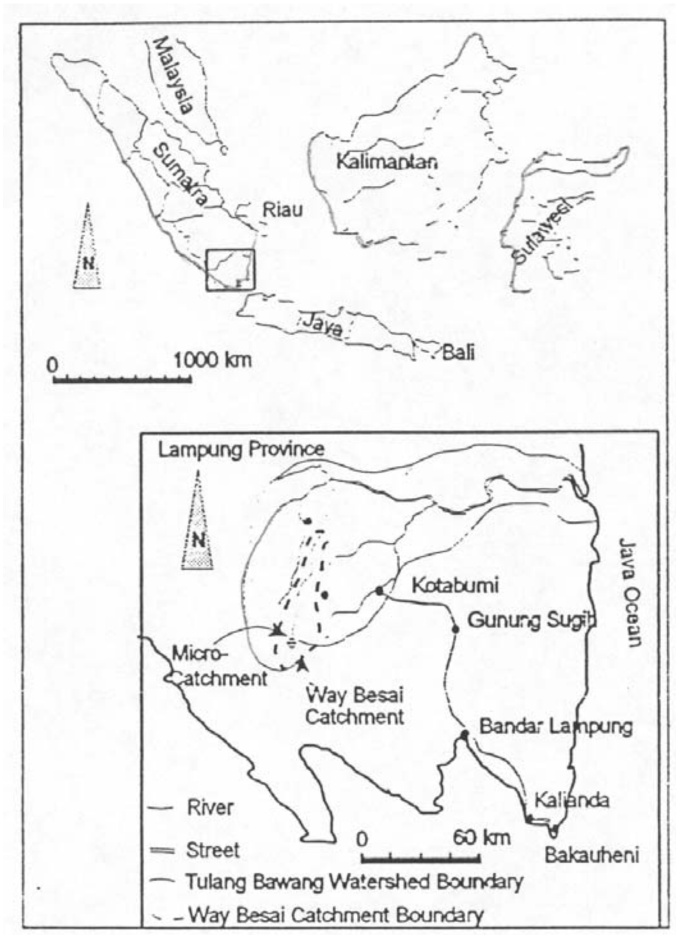


Figure 1.1. Research Location in Lampung Province

II. METHODOLOGY

2.1. Sediment Transfer across Filter strips

2.1.1. Identification of Land Use Type and Its Corresponding Filter strips

To identify and characterise the physical condition of various land use type and their corresponding filter strips, a field survey was carried out in the surroundings of Kampong Karang Bodong as a representative area of the Way Besai Catchment (sub-watershed of the Tulang Bawang river). The survey was conducted in 26 - 30 December 1998. The following land use types were selected: :

a. Natural forest
b. Cleared land with recently felled trees (next to natural forest)
c. Reforestation zone with Calliandra (in former coffee gardens)
d. Coffee gardens
e. Mixed gardens or multi strata systems
f. Tegalan with upland horticultural crops

Land use characteristics identified were coverage (canopy and basal cover), slope characteristics (slope steepness, length, and configuration), and major filter strips in the respective land use type. In addition, some other physical condition related to sediment transfer process were also identified.

In every selected land use type and its corresponding filter strips, representative sites for sediment yield and transfer measurement were then located. The selection was based on the prevailing characteristics found on the field. The number of selected sites for measurement on each land use type were variable depending on the characteristics of the land use type.

2.1.2 Measurement of Sediment Transfer

Sediment transfer across filter strips was evaluated by measuring trapped sediment on upper and lower site of filter strips/ field boundaries. To measure trapped sediment, simple sediment traps were installed in each representative filter strips. Sediment traps were made of PVC pipe of 2.5 inch in diameter and of about 100 cm long (the length of the PVC pipe are not necessarily the same, but can be different to suit the soil condition, especially the presence of bed rock). On the lower half of the pipes, the pipes wall were perforated to enable water penetrating the soil through the pipe wall and sediment were left deposited in the pipe (Figure 2.2).

Sediment traps were installed in pairs both in the upper and lower site in every filter strips (in pairs before and after filter strips as a filter element). The number of sediment traps for each filter strips depended on the width or length of the filter strips. The minimum number of sediment trap installed were 5 pairs for each filter strips.

The total trapped sediment in every sediment trap was observed by measuring the depth of sediment in the sediment trap. The measurements were carried out at least once a month or whenever cumulative rainfall exceeded 150 mm (time interval and cumulative rainfall between measurement are not necessarily the same). Every measurement of sediment in all sediment traps was completed in a single day and that was carried out when there was no rainfall during observation. Data from measurements of different times were considered as replication in statistical analysis.

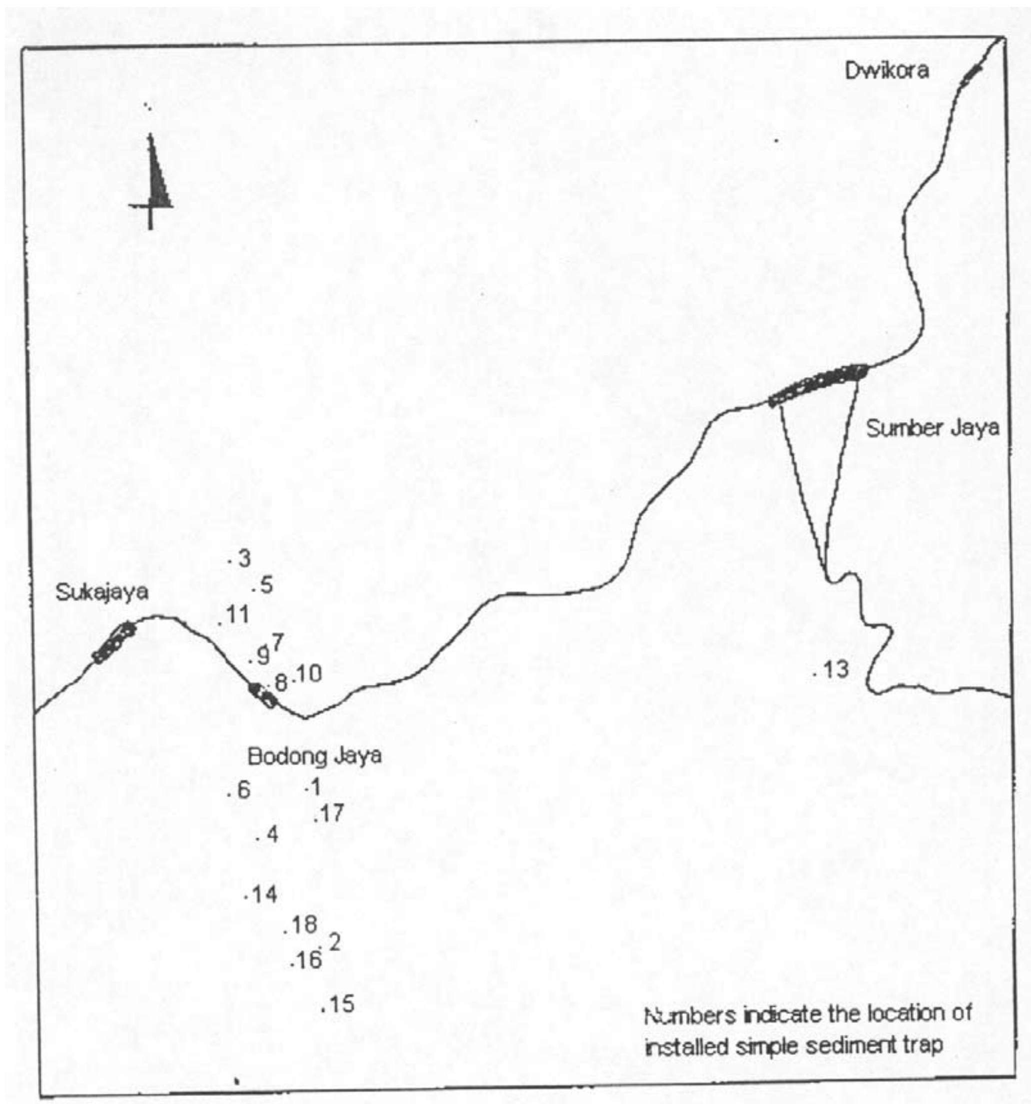


Figure 2.1 Location of simple sediment trap

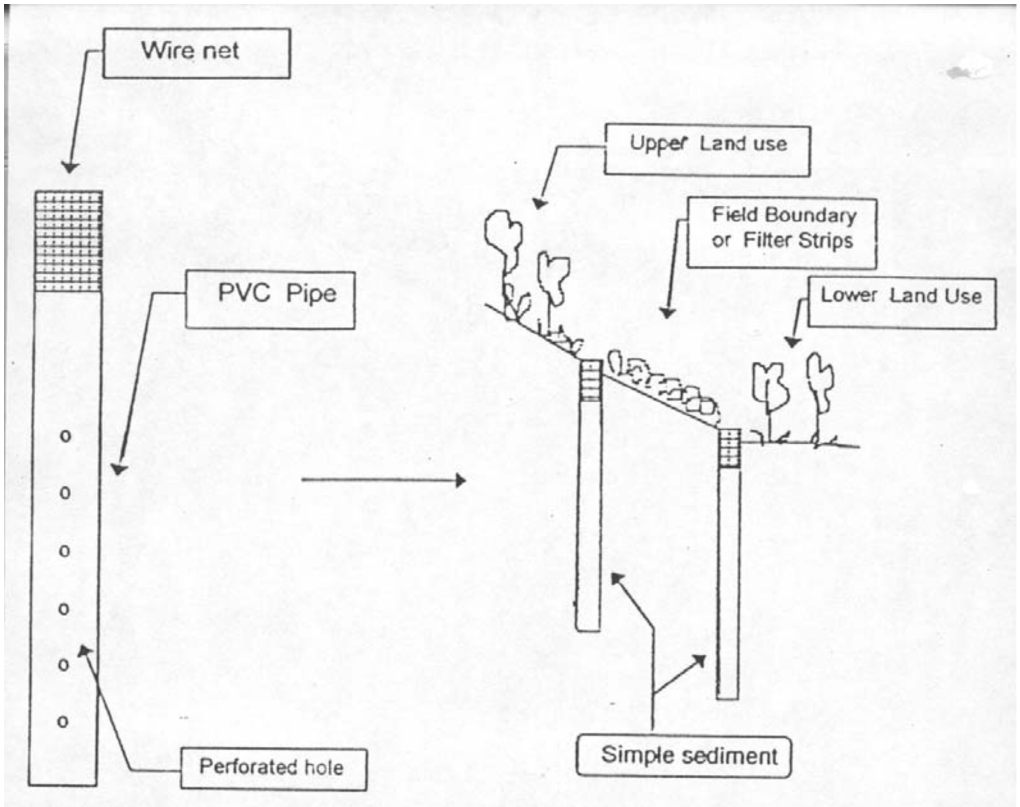


Figure 2.2. Design of simple sediment trap used in the experiment

2.1.3. Measurement of Soil Erosion

Additionally, a more conventional plot method was used for quantifying soil erosion per unit area under representative land uses. To measure soil erosion, two small plot were installed for each selected representative land use type (design of the erosion plot are illustrated in Figure 2.3).

Selected representative land use type on which soil erosion are measured are as follow :

1. Natural forest
2. Calliandra (in former coffee gardens)
3. Multistata system (Coffee gardens with Erythrina overstory)
4. Clean weeded coffee gardens
5. Unweeded coffee gardens

Measurements were done for every rainfall event on 9 December 1999 until 24 January 2000. Cumulative rainfall in this periods was, however, only 97 mm.

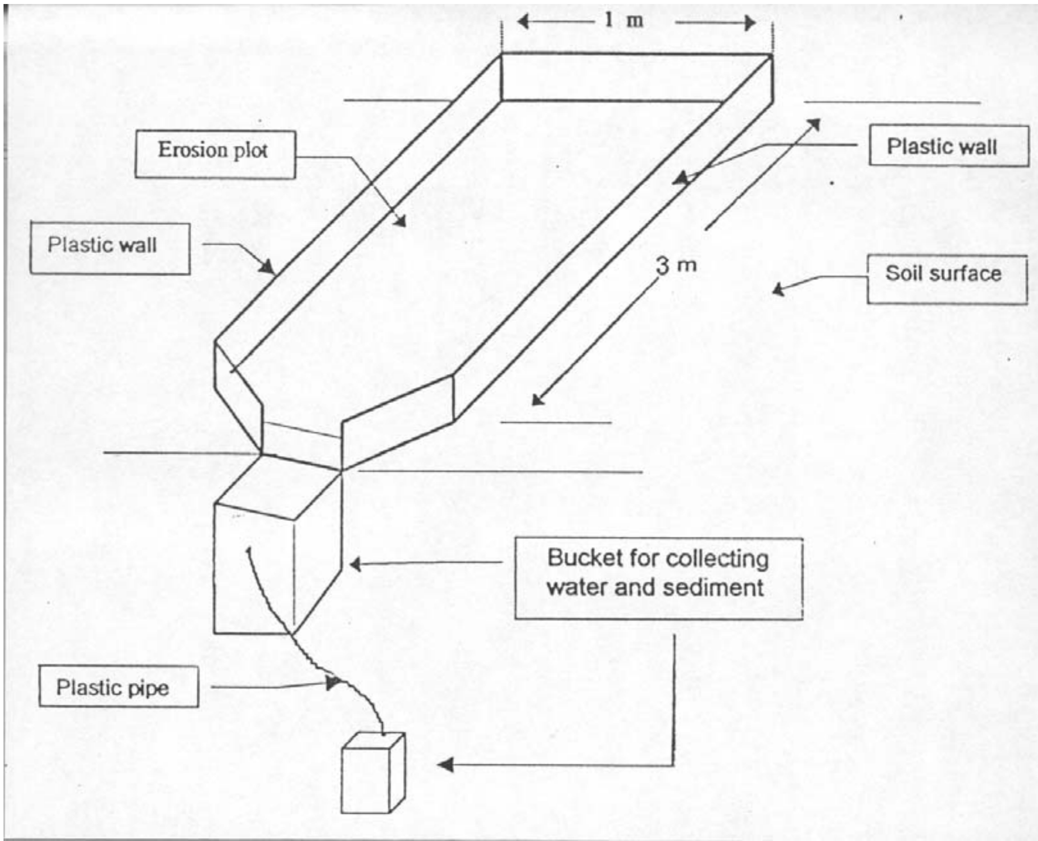


Figure 2.3 Design of small erosion plot used in the experiment

2.2. ANSWERS Model

As mentioned in the previous section, the ANSWERS model was used to simulate the role of filter strips/filters strips in sediment transfer. The function of filter strips in trapping sediment had to be incorporated into ANSWER model through the use of options available at the BMP (Best Management Practices) descriptors.

The robustness of the model in predicting erosion/sedimentation and validation of it's measured parameters should be first proven, before it can be used for the simulations. For this purpose the ANSWERS Model was run using data from the micro-catchment. The result of the discharge and sedimentation prediction was compared to the measured data.

2.2.1. Structure of ANSWER Model

ANSWERS is a deterministic model based upon the fundamental hypothesis that: "At every point within a watershed, functional relationship exist between water flow rates and those hydrologic parameters which govern them, e.g., rainfall intensity, infiltration, topography, soil type, etc. Furthermore, these flow rates can be utilized in conjunction with appropriate component relationship as the basis for modelling other transport related phenomenon such soil erosion and chemical movement within that watershed". An important feature of the above hypothesis is applicability on a "point" basis.

In order to apply this approach on a practical scale, the point concept is relaxed to refer instead to a watershed "element". An element is defined to be an area within which all hydrologically significant parameter are uniform. Of course, the process of going from a point to an elemental area could be extended indefinitely until one assumed the entire watershed was composed of a single element with “averaged” parameter value, i.e., a lumped model. The actual geometric size of an element is not critical because there is no finite-sized area within which some degree of variation in one or more parameters does not exist. The crucial concept is that an element must be sufficiently small that arbitrary changes of parameter values for a single element have a negligible influence upon the response of the entire watershed.

2.2.2. Data Collection of Soil Parameter

The soil parameters include the following characteristics: Total porosity (TP), field capacity (FP), antecedent soil moisture (ASM), infiltration rate descriptors (FC and A) and infiltration exponent (P). The soil parameters are classified according to it’s soil group. To determine the soil group in the research location, a soil survey had been carried out.

2.2.2.1 Total Porosity (TP) and Field Capacity (FP)

Total Porosity (TP)

Total porosity of a soil is defined as:

TP = 100 - (BD/D) *100, where;
TP = Total porosity, percent
BD = Bulk density
PD = Particle density (assumed to be 2.65)

Field Capacity (FP)

Field capacity is determined using *Bouyoucus* method. Where a saturated soil sample is put under 1/3 atm air pressure. The respective soil moisture is determined using dry weigh method. Field capacity is expresed in percent of saturation.

2.2.2.2.Antecedent Soil Moisture (ASM)

The form of the moisture balance equation is:

ASM = ASML + RAIN - ET - RO - PERC, where:
ASM = antecedent soil moisture
ASML = last known (initial) soil moisture
RAIN = rainfall
ET = evapotranspiration
RO = runoff
PERC = percolation

Antecedent soil moisture is expressed in percent of saturation.

2.2.2.3.Infiltration Rate Description (FC and A) and Infiltration Exponent (P)

Infiltration rate description is very important parameter in ANSWERS Model. The steady state infiltration rate (FC) indicates the rate at which the soil will absorb water when the soil is saturated. The difference between the maximum and steady state infiltration rates (A) combined with the infiltration exponent (P) helps to describe the typical exponential “drawdown” of the infiltration rate.

In this research the steady state of infiltration rate is measured using permeameter equipment.

The detail assembly is show in Figure 2.4. The water is infiltrated/transmitted from a simple constant head parameter, consisting of two concentric tubes provided with a set of vertically adjustable legs, into a slightly wider auger-hole.

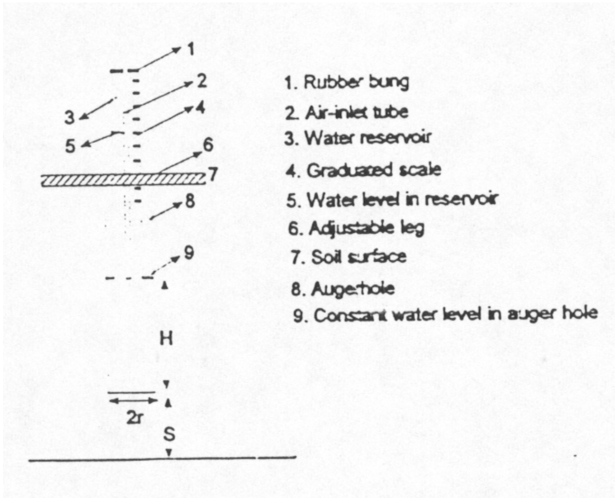


Figure 2.4. Sketch of Simplified Well Permeameter Assembly (not to scale)

The results of the permeability data are used to determine the steady state infiltration by the following manner

- The midpoint of the upper 2/3 of the range is assumed to be the maximum rate.
- The value of A is equal to the maximum rate minus FC.

2.2.3 Data Collection of Land Use and Surface Parameter

The land use and surface parameters consists of the following components: Interception parameters (PIT and PER), surface storage descriptors (HU and RC)

2.2.3.1 Interception Parameters (PIT and PER)

Potential interception volume (PIT) describes the volume of moisture that could be removed if the area were completely covered by that crop. The actual percantage of cover (PER) assumes the non-covered area has no interception. The actual percentage of cover (PER) is defined as:

PER = (Pa/Pp) *100%, where;
PER = actual percentage of cover
Pa = actual coverage area of sampled location
Pp = potential coverage area.

2.2.3.2 Surface Storage Descriptors (HU and RC)

The roughness coefficient (RC) is a shape factor which describes the frequency and the severity of the roughness. The maximum roughness height (HU) is used to establish the upper limits of the surface roughness and is physically measurable. The typical value of HU and HC are presented in Table 2.1.

Table 2.1.Typical Value of Roughness Coefficient (HU) and Maximum Roughness Height (HC)

Surface Condition	RC	HU (Inches)
Plowed Ground:		
Turn Plowed		
Smooth	0.25 - 0.35	1.0 - 3.0
Rough	0.65 - 0.80	2.0 - 12.0
Chisel Plowed		
Smooth	0.35 - 0.45	1.5 - 4.0
Rough	0.60 - 0.70	2.0 - 8.0
Disked		
Smooth	0.30 - 0.40	1.0 - 3.0
Rough	0.50 - 0.60	2.0 - 5.0

Remarks: RC = Roughness coefficient; HU = Maximum roughness height

2.3. Hydrological Analysis

2.3.1. Rainfall

Historical rainfall data 1975-1997 were collected from 3 rainfall stations: Sumberjaya (R 234), Fajarbulan (A 12), and Air Hitam (R 248). Regional rainfall data were analyzed to find mean rainfall of the study area using Thiessen Polygon method. Variability of the rainfall is indicated by its coefficient of variation

CV = standart deviation/mean

2.3.2. Stream flow

Stream flow data were collected at Sumberjaya stream gauge station which is located at 05 00 S and 104.29.00 W. Historical data (1975-1997) from this station were analyzed. In this report the analysis include average annual stream flow using arithmatic mean, minimum discharge (Q minimum), maximum discharge (Q maximum), ratio of Qmax/Qmin, and hydrograph sparation using straight line method.

III. RESULT AND DISCUSSION

3.1. Sediment Transfer across Filter Strips

3.1.1. Description of Filter Strips and Land Use Type

General characteristics of the measured filter strips and adjacent land use are presented in Table 3.1. Filter strips and its corresponding land use type vary greatly in their characteristics. All filter strips tend to have more gentle slope and higher canopy coverage as compared to its upper land use. The same land use type does not necessarily have similar filter strips. Natural forest generally covers the upper part of the slope and tend to have no representative filter strip or field boundary. This suggests that filter strips are usually established by human activities, especially when they cultivate the land.

Natural forest generally has the densest vegetative coverage both in canopy and basal cover, followed by calliandras, multistrata systems, unweeded coffee gardens, clean weeded coffee gardens, and tegalan with horticultural crops. Coffee gardens vary in coverage especially due to differences in their age and arrangement. Some coffee gardens have small ridges that follow the crop rows. In tegalan with horticultural crops, most crops are planted on small ridges (guludan)t along the slope. The newly cleared land (the former natural forest) has no canopy cover, but since the falling trees are left and still remain on the field, its basal cover (especially litter) are very high.

Table 3.1 Characteristics of Various filter strips and its corresponding Land Use Type

No		Filter Strips/Land Use Type	Slope			Coverage	
			Steepness (%)	Length (m)	Shape	Canopy	Basal
1	A	Small ridge	-	0.75-1	-	-	-
	b.	Multistrata System (Dense coffee with Erythrina)	8 - 12	20 - 40	Straight	High	High
2	a.	Small ridge covered by litter		0.75 - 1			
	b.	Tegalan with horticultural crops (clean weeded)	12 - 15	15 - 20	Straight	Low	V. Low
3	b.	Hedgerow of Banana with small ridge covered by grass	2 - 3	2 - 2.5	-	Low	V High
	B	Horticultural crops	35 - 40	15 - 20	Straight	Low	Low
	c.	Multi strata System (Mixed garden with coffee under growth)	5 - 8	12 - 15	Convex	High	Medium
4	a.	Hedgerow of Banana with small ridge covered by grass	2 - 3	1.5 - 2	-	Low	High
	b.	Mixed gardens (Banana with young coffee and Talas under growth)	50 - 60	25 - 40	Straight-concave	Medium	Low
5	A	Hedgerow of Banana with small ridge covered by grass	2 - 3	1.5 - 2	-	Low	High
	B	Unweeded coffee gardens with sparse Gliricidia and banana	40 - 50	50 - 60	Straight-concave	Medium	Medium
6	a.	Dense woody shrubs	50 - 55	2 - 3		High	Medium
	b.	Coffee gardens with small soil bund along crop rows	15 - 20	30 - 50	Straight	Medium	Low
7	a.	Dense woody shrubs	50 - 55	2 - 2.5	-	V high	Medium
	b.	Unweeded coffee gardens with sparse Gliricidia and banana	34 - 37	6 - 10	Convex	Medium	Medium
8	A	Dense grass	1 - 2	4 - 5	-	-	V high
	b.	Woody young shrubs	55 - 60	6 - 8	Straight	V. High	Medium
	C	Clean weeded coffee gardens	50 - 60	20 - 30	Convex	Medium	V. Low
9	a.	Terraced land with woody young shrubs	55 - 60	8 - 10	-	Medium	Medium

	B	Clean weeded coffee gardens	50 - 60	15 - 20	Convex	Medium	V. Low
10	a.	Woody shrubs with imperata grass undergrowth	30 - 35	20	straight	High	High
	b.	Unweeded coffee gardens with sparse Gliricidia and banana	25 - 30	40 - 60	Straight	Medium	Medium
11	a.	Hedgerow of Pisangan	3 - 5	1.5 - 2	-	V High	High
	B	Clean weeded coffee gardens	15 - 20	30 -35	Concave	Medium	V.Low
12	A	Calliandra with coffee undergrowth (Dwikora)	38 - 42	22 - 25	Straight	High	V. high
	B	Calliandra with Pinus (Dwikora)	40 - 45	15 - 20	Straight-convex	High	V. high
13	a.	Calliandra with coffee undergrowth (Tebo)	30 - 40	15 - 20	Straight-convex	High	V. high
14	a.	Clean weeded coffee gardens	25 - 35	15 - 20	Straight	Medium	V. Low
15	a.	Natural Forest	75 - 80	> 75	Straight-convex	V. high	V. high
16	a.	Cleared Land with falling trees (Former Natural Forest)	50 - 55	20 - 25	Straight-convex	-	Dense litter
17	a.	Multistrata System (Dense coffee with Erythrina)	25 - 30	15 - 20	Straight	High	High
18	a.	Tegalan with horticultural crops (clean weeded)	35 - 40	15 - 18	Straight	Low	Low

Note : a : Filter strips or Lower Land Use
b : Upper Land Use

Natural forest which generally covers the upper part of the hill, has a very steep slope (75 % to over 80 %). Calliandra covers the area with slope steepness vary from 30 % to 45 %. Coffee gardens and tegalan with horticultural crops areas has a very high variation on slope steepness. In this experiment, selected Coffee gardens occupy the area with slope steepness, range from 8 % to over 60 %, whereas horticultural crops occupy the area that relatively gentle slope (about 12 %) to relatively steep slope (up to 40 %). Coffee and horticultural crops on steep slope seems to have a high soil erosion and may become a major problem in the area. Field observations indicated that some newly cleared land with young coffee are progressively increasing the area.

3.1.2 Effect of Filter Strips on Sediment Transfer

The effect of filter strips on sediment transfer is assumed as the differences between sediment yield on the upper site and that on the lower site of filter strips (percent of decrease). This differences represent the amount of of sediment that are trapped due to the presence of a filter strip. Therefore, the differences can actually represent the effectiveness of filter strips in reducing sediment transfer across filter strips.

Result of the experiment shows that effectiveness of filter strips in trapping sediment vary significantly. As shown in Table 3.4, hedgerow of banana that planted in a small ridge with grasses undergrowth tends to show the highest value of trap efficiency, followed by terraced land covered by shrubs, hedgerow of *pisangan*, shrubs, and small ridge. This results indicate that characteristics of filter strips and its corresponding upper land use have a considerable effect on sediment transfer.

Table 3.2 also shows that effectiveness of hedgerow of banana that planted in a small ridge with grass underground vary considerably, with the average value of decreament range from 58.7 % to about 94.9 %. This variation is apparently due to the differences in coverage of basal cover (litter and grass) and the width of the filter strips since other characteristics are being equal. As shown in Table 3.4, coverage of basal cover and the width of filter strip no 3 are higher and wider than that of filter strip No 4 and No 5. Besides, the high effectiveness of filter strip No 3 in trapping sediments is also caused by the present of small channel (40 to 60 cm wide and 15 to 20 cm depth) on the upper site of the field boundary (see Figure in Appendix 3).

Table 3.2. Trap efficiency of various filter strip as compared to that on upper land use

No	Filter Strip (Filter Strips)	Trapped Sediment (cm)		Trap Efficiency (%)
		After Filter Strip	Before Filter Strips*	
1	Small Ridge	10.3	16.7	38.2
2	Small ridge covered by litter	5.7	15.4	63.0
3	Hedgerow of Banana with small ridge covered by grass	8.74	170.0	93.9
4	Hedgerow of Banana with small ridge covered by grass	28.6	114..0	73.8
5	Hedgerow of Banana with small ridge covered by grass	3.2	7.75	58.7
6	Dense woody shrubs	10.2	28.0	62.5
7	Dense woody shrubs	10.9	37.4	64.2
8	Woody young shrubs	24.8	65.3	54.9
8	Dense grass	7.0	11.1	54.2
9	Terraced land with woody young shrubs	6.0	47.8	82.2
10	Woody shrubs with imperata grass undergrowth	6.6	34.9	80.0
11	Hedgerow of Pisangan	3.5	19.9	82.4
12	Caliandra with coffee undergrowth(Dwikora)	2.8	4.9	42.5

*) at upper land use

Woody shrubs with dense canopy and basal cover can also effectively trap sediment, with the average value of trap efficiency ranging from 62.5 % to 64.4 %. Woody shrubs with imperata grass have a relatively high value of trap efficiency (81.2 %). The presence of imperata grass under the woody shrubs increases the effective coverage of the filter strip which in turn decreases the energy of surface run-off and absorb the raindrop impact energy. Woody young shrubs, on the other hand, shows lower value of trap efficiency (54.9 %). This results suggest that the growth stage of shrubs and its corresponding coverage have a significant effect on sediment yield. Older shrubs tend to have a stable canopy and litter cover; therefore the effectivenes of this filter strip in trapping sediment is relatively constant. Younger shrubs, on the other hand, tend to grow progressively with its canopy coverages and basal cover; therefore, its trap efficiency will also increase progressively. Data of sediment yield collected in some period of time supports this statement. As shown in Figure 3.1, the value of trap efficiency is increasing from measurement 1 (167 days after installation of sediment trap) to the end of the experiment (312 days after installation of sediment trap).

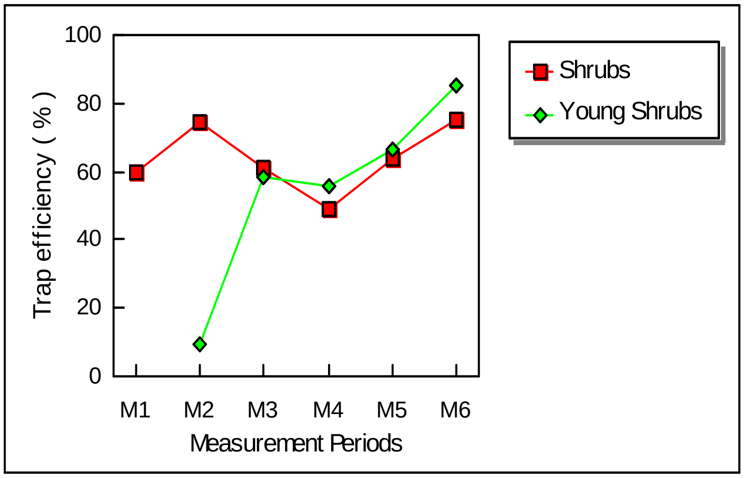


Figure 3.1. Trap efficiency of Shrubs and Young Shrubs Over 312 days of observation

The results of the experiment also shows that small ridge constructed across the slope (about 20 cm high and 75 m wide) can also significanly reduce sediment yield about 38.2 % (Table 3.2). The small ridge reduce surface run-off transport capacity which in turn reduce erosion and increase deposition. Though sediment yield decreases, the value of trap efficiency is not high enough. Since the soil on the ridge are not protected adequately against raindrop impact, soil erosion on the ridge still occurs. The presence of litter or basal cover that protect the ridge against raindrop impact will significantly improve the function of the ridge in reducing soil erosion as shown by the field boundary No 2.

Tabel 3.3 Trap efficiency of various Filter Strips (filter strips)

No	Filter Strip (Filter Strips)	Trap Efficiency (%)						
		M1	M2	M3	M4	M5	M6	Avg
1	Small Ridge	40.30	21.88	-	40.55	33.90	54.13	38.15
2	Small ridge covered by litter						63.0	63.0
3	Hedgerow of Banana with small Rill & ridge and dense grass			93.49	88.86	96.61	96.56	93.88
4	Hedgerow of Banana with small ridge covered by grass	50.99	67.48	84.28	75.93	82.57	81.69	73.82
5	Hedgerow of Banana with small ridge covered by grass						58.7	58.7
6	Dense woody shrubs	59.86	74.49	50.00	33.33	78.61	78.73	62.50
7	Dense woody shrubs			71.64	65.00	48.49	71.75	64.22
8 b	Woody young shrubs		9.32	58.16	55.55	66.17	85.17	54.87
8 c	Dense grass				4.25	75.64	42.26	54.15
9	Terraced land with young shrubs		63.64	97.95	89.35	84.25	75.83	82.20
10	Shrubs with imperata grass underground		46.63	85.71	91.96	86.84	90.08	80.04
11	Hedgerow of "*pisangan*"						82.4	82.4
12	Caliandra (Dwikora)				43.93	75.00	17.5	42.5

Note : M1 : 75 Days after installation of simple sediment traps with cumulative rainfall 641 mm
M2 : 50 Days after M1, with cumulative rainfall 163 mm

M3 : 15 Days after M2, with cumulative rainfall 156 mm
M4 : 32 Days after M3, with cumulative rainfall 132 mm
M5 : 53 Days after M4, with cumulative rainfall 202 mm
M6 : 75 Days after M5, with cumulative rainfall 259 mm

The result of the experiment also shows that the effectiveness of calliandra with coffee undergrowth in trapping sediment is not as high as it is expected. The average value of trap efficiency is only 42.5 %, slightly higher than that of small ridge with no litter and significantly lower than that of the others. Low value of trap efficiency on calliandra is apparently due to similarities of the characteristics of the filtersStrips to that of upper land use (calliandra with pinus). Besides, low sediment yield from upper land use might also be the reason for this low trap efficiency.

3.1.3. Sediment Yield (Trapped sediment) on Various Land Use Types

Sediment yield in this experiment were obtained by measuring the depth of trapped sediment (in cm) in the simple sediment trap in a given time. Sediment yield on various representative Land use types as measured at some periods of are shown in Table 3.4.

Table 3.4. shows that land use type with different vegetative coverage has a significant effect on sediment yield. Sediment yield in tegalan with horticultural crops is considerably higher than that on other land use types. Second largest of sediment yield is resulted from clean weeded coffee gardens, then followed by unweeded coffee gardens, multistrata systems, newly cleared land with the falling trees, calliandra, and natural forest.

Tegalan with horticultural crops, though has relatively gentle slope and short slope length has the highest sediment yield. Cultivating the soil with ridges and furrows along the slope for better drainage and aeration which is commonly practiced in this horticultural crop fields increases soil erosion and hence, sediment yield. The presence of ridges contructed along the slope allow run off to flow concentratedly, and this will increase its destructive force and transport capacity. Furthermore, tegalan with horticultural crops has high exposure to raindrop impact due to its low coverage.

Table 3.4 also shows that sediment yield in Coffee gardens vary significantly. Clean weeded coffee gardens shows significantly higher sediment yield than other type of coffee gardens. Mixed coffee gardens with different canopy strata that have dense litter/ basal cover generally have low sediment yield even in steep slope. Mixed gardens with low density and low coverage of basal cover/ litter cover, on the other hand, have higher sediment yield (Table 3.4). Sediment yield in mixed garden with low basal cover and medium canopy cover (No 4b) is 19.9 cm; it is much higher than sediment yield in other multistrata systems.

Table 3.4 Sediment Yield (Trapped Sediment) of Various Land Use Types

No		Land Use Type/Filter Strips	Sediment Yield (cm)						
			M1	M2	M3	M4	M5	M6	Cum*
1	a	Small ridge	4.00	2.50	0.50	1.07	1.17	1.10	10.3
	b.	Multistrata System (Dense coffee with Erythrina)	6.70	3.20	0	1.80	1.77	3.27	16.74
2	a	Small ridge covered by litter						5.66	5.7
	b.	Tegalan with horticultural crops (clean weeded)						15.40	15.4
3	a.	Hedgerow of Banana with small ridge covered by grass			4.50	1.17	1.67	1.10	8.8
	b.	Horticultural crops			69.10	10.50	49.30	40.70	170.0
	c.	Multistrata System (Mixed garden with coffee undergrowth)				1.10	1.06	2.74	4.9

4	a. Hedgerow of Banana with small ridge covered by grass	15.00	4.00	2.83	2.37	1.18	.24	28.6
	b. Mixed gardens (Banana with young coffee and Talas under growth)	50.60	12.30	18.00	8.64	6.77	17.70	114.0
5	a. Hedgerow of Banana with small ridge covered by grass						3.20	3.2
	b. Unweeded Coffee gardens with sparse Gliricidia and banana						7.75	7.8
6	a. Hedgerow of banana with dense woody shrubs	6.50	0.50	0.67	1.00	0.83	0.67	10.2
	b. Coffee gardens with small soil bund along crop rows	16.20	1.94	1.33	1.50	3.88	3.15	28.1
7	a. Dense woody shrubs			4.40	1.50	1.70	3.33	11.0
	b. Unweeded Coffee gardens with sparse Gliricidia and banana			18.10	4.23	3.27	11.8	37.4
8	a. Dense grass				3.83	0.67	2.50	7.0
	b. Woody young shrubs		10.70	3.00	4.00	2.75	4.33	24.8
	c. Clean weeded Coffee gardens		11.80	7.17	9.00	8.13	29.20	65.3
9	a Terraced land with woody young shrubs		2.88	0.33	1.15	0.20	1.45	6.0
	b Clean weeded coffee gardens		5.50	24.20	10.80	1.27	6.00	47.8
10	a Woody young shrubs		3.40	0.50	1.16	0.25	1.24	6.6
	b. Unweeded Coffee gardens with sparse Gliricidia and banana		6.30	3.50	10.70	1.90	12.50	34.9
11	a Hedgerow of Pisangan						3.50	3.5
	b Clean weeded coffee gardens						19.90	19.9
12	a. Calliiandra with coffee undergrowth (Dwikora)				1.20	0.30	1.32	2.8
	b Calliandra with Pinus (Dwikora)				2.14	1.20	1.60	4.9
13	a. Calliandra with coffee underground (Tebo)	4.60	1.58	0	0.64	0.74	1.90	9.5
14	a. Clean weeded Coffee gardens	46.70	5.33	6.33	4.83	3.83	20.70	87.7
15	a. Natural Forest	1.00	1.40	0	0.75	0	0.93	4.1
16	b. Cleared Land with falling trees (in former Natural Forest)		1.60	0.80	0.40	0.70	0.94	4.4
17	a. Multistrata System (Dense coffee with Erythrina over growth)	7.50	1.17	1.33	1.72	0.80	6.20	18.7
18	a. Tegalan with horticultural crops (clean weeded)	90.5	12.2	-	-			102.7

Note : M1 : 75 Days after installation of simple sediment traps with cumulative rainfall 641 mm
M2 : 50 Days after M1, with cumulative rainfall 163 mm
M3 : 15 Days after M2, with cumulative rainfall 156 mm
M4 : 32 Days after M3, with cumulative rainfall 132 mm
M5 : 53 Days after M4, with cumulative rainfall 202 mm
M6 : 75 Days after M5, with cumulative rainfall 259 mm
Cum : Cumulative sediment yield at 312 days after installation of simple sediment traps with cumulative rainfall 1553 mm

This tendency suggests that basal cover or litter cover plays more important role in reducing soil erosion than high canopy cover.

Calliandra (in former coffee gardens) has a relatively low sediment yield. As compared to coffee gardens, sediment yield and/ or soil erosion on calliandra is much lower even though slope steepness on calliandra is higher than that on coffee gardens. This is because vegetative coverage (especially basal cover) of calliandra is higher than that of coffee gardens (Table 3.1).

Cleared land with falling trees (in former natural forest) has a relatively low sediment yield (Table 3.4). Sediment yield in cleared land with falling trees is quite similar to that from natural forest. Very high litter and basal cover after clearing (because the fallen trees are left on the field) is apparently the main reason for this low sediment yield. This result suggests that cleared land without removing tree remnant can still effectively maintain soil condition.

Natural forest, despite its very steep slope, has the lowest sediment yield. Dense canopy cover with very good stratification of its canopy coverage as well as high basal cover (especially of litter) seems to be the reason for such a low sediment yield in natural forest. Furthermore, soil in natural forest without human intervention tend to have high organic matter content and good soil physical properties (crumb to granular structure and good porosity that lead to high infiltration capacity).

3.1.4. Soil Erosion from Some Representative Land Use Type

In relation to the amount of sediment yield in a given unit area, sediment yield resulted from simple sediment traps are of little value. Therefore, as a comparison, soil erosion from some representative land use type were also measured in small erosion plot. Soil erosion measured using small erosion plot are presented in table 3.5.

Table 3.5 shows that clean weeded coffee gardens have the highest soil erosion, followed by unweeded coffee gardens, multistrata system, calliandra, and natural forest . This tendency is quite similar to that from sediment yield measurement as previously discussed.

From various coffee gardens, clean weeded coffee garden has the highest soil erosion (Table 3.5). Soil erosion from clean weeded coffee gardens is about 307.7 gram per plot (equivalent to 1.1 ton per hectare), whereas soil erosion from unweeded coffee gardens is about 74.9 gram per plot or equivalent to 0.25 ton per hectare. Though soil erosion from those two land uses are the highest among others, they are still considerably low. This soil erosion is only for about one month with cumulative rainfall about 97 mm. As compared to yearly rainfall at the area, rainfall occurs during the measurement is quite low. Therefore, with regard to total soil erosion in a year, the figures are of little value. Nevertheless soil erosion data obtained in the experiment are still useful to make comparison about soil erosion from various land use types.

Table 3.5. Soil erosion and run-off on some representative land use type

No	Land Use Type	Slope of erosion plot (%)	Soil Erosion (gram/plot)	Run-off (Litre/ plot)
1	Natural Forest	55 - 65	24.2	22.3
2	Calliandra	40 - 45	25.3	17.8
3	Multistrata System	30 - 35	70.9	23.3
4	Clean weeded coffee gardens	35 - 40	307.7	89.1
5	Unweeded coffee gardens	30 - 35	74.9	36.0
6	Unweeded coffee gardens	25 - 30	32.2	23.7

Note : Area of the plot : 3 x 1 m
Sediment were collected 5 times from 9 December 1999 to 24 January 2000
with total rainfall 97 mm

Soil erosion on natural forest and calliandra is significantly lower than that of other land use types, even though the slope on these two land use types are steeper. These two land use type are characterized by dense and very good distribution of canopy strata so that its effectiveness to intercept raindrop impact is very high. This characteristic is apparently the main reason for such a low soil erosion. Furthermore, relatively low human intervention in these two land use types maintain high soil organic matter content and high infiltration capacity; therefore run-off is low. Result of run-off measurements support this argument (Table 3.5). Run-off from natural forest and calliandra are lower than that from other land use type.

Table 3.5 also shows that soil erosion from unweeded coffee gardens can also be low and similar to that of multistrata systems or even to that of natural forest. This is because grass and litter under coffee gardens are very dense; the litter and grasses can effectively protect the soil from raindrop impact. This result suggests that-apart from possibility of nutrient competition-weed and litter in coffee gardens play a positive role in reducing soil erosion.

3.2. ANSWERS Model

To run the ANSWERS model an extensive field data collection has been carried out. This include among others are topographic survey, soil survey, sampling for soil physical characteristics, measurement of infiltration descriptors and land use survey. Those data were distributed to the corresponding elements in the model. Data collection and data entry are the most tedious work in running ANSWERS Model.

Application of ANSWERS Model

Input formation for the ANSWER Model contains the following types of data :

- Rainfall characteristics
- Soil Parameters
- Land use characteristics
- Individual element information (location, topography, drainage, soils, land use and BMP’s)

The individual element information is the largest body of data and the most time consuming to collect.

3.2.1 Rainfall Characteristics

To run the ANSWERS model an extensive field data collection has been carried out. This include among others are topographic survey, soil survey, sampling for soil physical characteristics, measurement of infiltration descriptors and land use survey. Those data were distributed to the corresponding elements in the model. Data collection and data entry are the most tedious work in running ANSWERS Model.

3.2.2 Soil Parameters

Four soil types were identified at the research location. Infiltration descriptors (FC, A and P) is a very important component of soil parameter. Steady state infiltration (permeability) using permeameter equipment has been measured in 55 location. The description of soil parameters for each soil types presented in Table 3.6.

Table 3.6. Description of Soil Parameters for Each Soil Types

		Soil Parameters						
Nr	Soil Type	TP (% vol)	FP (% sat)	FC (mm/h)	A (mm/h)	P	DF (mm)	K
1	Typic Dystropepts	62.8	71	41.0	80.00	0.65	200	0.21
2	Typic Dystropepts	61.9	72	19.0	73.00	0.75	200	0.21
3	Typic Dystropepts	61.7	76	49.0	90.00	0.75	200	0.21
4	Typic Hapludults	59.1	79	6.0	26.00	0.75	200	0.30

Remarks:
TP = Total porosity
P = Infiltration component
ASM = Antecedent soil moisture
A = Diference between maximum steady state infiltration rate
FP = Field capacity
DF = Infiltration control depth zone
FC = steady state infiltration rate

3.2.3 Land Use Characteristics

Existing land use at the research location is grouped into 8 types. The characteristics of each land use type is shown in Table 3.7.

Table 3.7. The Characteristics of Each Land Use Type

		Land Use Parameters					
Nr	Land Use Type	PIT (mm)	PER (%)	RC	HU	N	C
1	Coffee, banana, and Gliricidae (high density)	1.1	0.15	0.45	4.0	0.14	0.15
2	Scrubs	1.2	0.15	0.40	4.0	0.15	0.10
3	Coffee, banana, and Gliricidae (medium density)	1.1	0.10	0.45	3.0	0.14	0.10
4	Coffee (low density)	1.1	0.10	0.45	3.0	0.14	0.15
5	Coffee (aged 4-5 years)	1.1	0. 5	0.40	4.0	0.14	0.15
6	Coffee (aged 1-3 years)	1.1	0. 5	0.45	4.0	0.14	0.15
7	Coffee with significant contact cover	1.1	0. 5	0.45	4.0	0.14	0.15
8	Coffee (in erosion plot)	1.1	0.15	0.45	3.0	0.15	0.15

Remarks:
PIT = Potential interception volume
PER = Percentage of surface covered by specific land use
RC = Roughness coefficient
HC = Maximum roughness heigh
N = Manning's n
C = Relative erosiveness of a particular land

3.2.4. Individual Element Information

The catchment is divided into 630 element having 5 x 5 m in size. The element is established from topographic map and field check with scale of 1:250. Only one rainfall station is available at the research location.

3.2.5. Predicted Run-off and Erosion in the Unila Catchment with Existing Filter strip

The pattern of sediment and run-off prediction of ANSWERS Model for selected rainfall events are presented in Appendices 18, 19 and 20. Alongside the model results, the observation data of run-off are also presented for comparison. For rainfall event of February 21st, 1999 the measured peak discharge at the outlet is 1.0 mm/h. Meanwhile, the peak discharge predicted by ANSWERS model is 0,95 mm/h. For the rest of the rainfall event there seems to be a large gap between observed and predicted run-off. This large gap could result from the size of the catchment which has an area of only 1.6 ha. As it was mentioned before, the simulation of catchment erosion using ANSWERS model involves many parameters. Some parameters such as infiltration descriptors (FC, A, and P) and surface roughness (HU) are very responsive to the change of the rainfall characteristic. Actually it is impossible to determine the real values of those parameters in a catchment level. The deviation seems always to exist. But in a large catchment the positive and the negative deviation might balance each other. In a small catchment this balancing effect seems to be minor. As a result the predicted and the measured parameters might deviate considerably in a particular characteristic rainfall event.

Nevertheless, the simulation of ANSWERS model to the role of filter strip in sediment trapping seems consistent from one rainfall event to other rainfall event as it is discussed below.

The influence of filter strip in sediment transfer can be judged by observing the result of model simulation at outlet level (Table 3.8) and at selected element level of filter strip under consideration (Table 3.9). Influence of filter strip on predicted runoff volume and average soil loss at catchment outlet is shown in Table 3.8. In general the filter strip reduce the rate of both parameter.

The ANSWERS MODEL has a built-in procedure to simulate trapping effect of filter strip. These procedures are called Best Management Practices (BMP's). There are four options of special structural BMP's included in the ANSWERS model, these are: Ponds, parallel tile-outlet terraces, grass waterways and field boundary . All of those BMP's have different trap efficiency.

In this research the option of BMP's used to simulate the effect of filter strip in sediment transfer is field boundary option. The spatial configurations of the existing filter strips are presented in Appendix 21. The filter strip commonly consists of hedgerow of banana with small ridge covered by grass having 35 m in length and 1 m in width. There are two types of filter strips existing in the catchment. The first type of filter strip is perpendicular to the flow direction. The second type is situated to the left and right side of existing channel (see Appendix 21).

The effect of those BMP's on sediment transfer are handled in the ANSWERS MODEL using sub-routine STRUCT. An excerpt for those sub-routine is attached in Appendix 11. This sub-routine is based on the trap efficiency concept. The trap efficiency can be adjusted according to the need by re-programming and re-compiling this sub-routine.

Table 3.8. Effectiveness of Existing Filter Strip to Reduce Run-off and Trap Sediment as Predicted by ANSWERS MODEL at Catchment Outlet

Parameter	Without Filter strip	With Filter strip
1 Runoff volume (mm/h)	0.249	0.222
2. Average soil loss (kg/ha)	14	12

The general trend of role of filter strip in trapping sediment at element level is obvious from Table 3.9.

Table 3.9. Net Erosion or Deposition at Selected Element of Filter strip as Predicted by ANSWERS MODEL

Net Erosion (-) or deposition (+)																	
before filter strip						on the filter strip						after filter strip					
Nr.	Rainfall event					Nr.	Rainfall event					Nr.	Rainfall event				
	17-02-1999	21-02-1999	24-02-1999	26-02-1999	13-05-1999		17-02-1999	21-02-1999	24-02-1999	26-02-1999	13-05-1999		17-02-1999	21-02-1999	24-02-1999	26-02-1999	13-05-1999
237	-59	-63	-188	-191	-72	**263**	+62	+53	+61	+36	+48	**289**	+10	-1	-96	-92	-3
238	-80	-84	-250	-254	-96	**264**	-2	-3	-53	-53	-3	**290**	-63	-68	-212	-221	-7
239	-93	-100	-302	-311	-155	**265**	-93	+9	-36	-43	+9	**291**	-63	+14	-37	-39	+12
259	+11	0	+26	0	0	**285**	+11	0	+26	0	0	**312**	+1	0	+44	0	0
265	+14	+9	-36	-43	9	**291**	+14	+14	-37	-39	+12	**318**	-73	-79	-255	-272	-85
285	4	0	32	0	0	**312**	4	0	32	0	0	**339**	-5	0	0	0	0

Remark: Nr. = Number of element

On the first three selected element before filter strip the net erosion occurs for every rainfall event (Element Nr. 237, 238, and 239). Meanwhile, on the elements of filter strip it's self net deposition occurs (Element Nr. 263) or net erosion become lesser (Element Nr. 264, and 265) due to the trapping effect of filter strip. Some elements of the filter strip (for example element Nr. 285) do not show any trapping effect. This might have been caused by the fact , that the deposition is not merely stimulated by filter strip. Other factors like degree of slope changes in steepness, the presence of rough terrain which are expressed by parameters of roughness coefficient (RC) and roughness height (HU) could induce deposition as well.

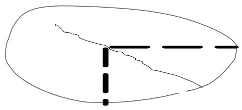
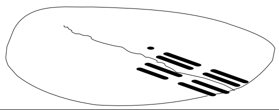
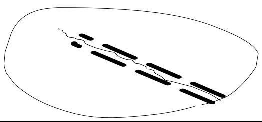
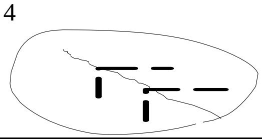
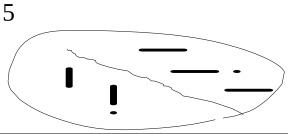
Trap Efficiency of Filter strip

The efficiency of filter strip in trapping sediment in element scale vary considerably from one element to another element. For example, the incoming erosion to the element Nr. 263 amounts to 63 kg/ha. This amount of material will be deposited as many as 53 kg/ha, the trap efficiency is therefore 84% (assuming that the element Nr. 263 receives material exclusively from its upper neighbouring element). This trap efficiency is in order of magnitude with result obtained from field experiment of first research. On the other case, the incoming erosion to the element Nr. 265 amounts to 100 kg/ha, the amount of material deposited in the element Nr. 265 is only 9 kg/ha. This case reflects a lower trap efficiency. This variety is attributed to the difference in rainfall characteristics and other factor like degree of slope changes in steepness, the presence of rough terrain which are expressed by parameters of roughness coefficient (RC) and roughness height (HU).

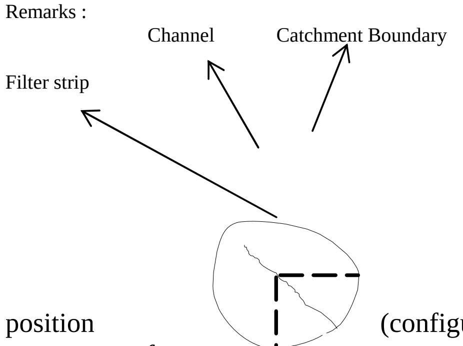
3.2.6. Simulation of Filter strip Role in Sediment Transfer

Filter strip might consist of combination of different types of vegetated strips ranging from hedgerow of banana to tree crops. In an effort to reduce sediment yield by applying agroforestry practices, the following question often arises: how should the configuration of tree crop strips in the field be laid to increase its effectivity to trap sediment.

Table 3.10 Simulation Results of Different Configuration of Synthetic Filter strip

Schematic Configuration of Filter strip	Average Soil Loss (kg/ha)	Run-off (mm/H)
1 	12	0.219
2 	11	0.217
3 	13	0.230
4 	12	0.222
5 	12	0.218

Remarks :



According to some literatures (Van Noordwijk,1998), the position (configuration) of the tree crop strips is more important than the percentage of coverage. In this research the ANSWERS model is used to simulate the effect of different position (configuration) of filter strip on average soil loss and run-off. Five different types of synthetic field boundaries are used in the simulation process. The relative position of each filter strip to the direction of flow are presented in Appendices 22, 23, 24, 25, and 26. The results of the simulation are presented in Table 3.10.

For each simulation the number of elements representing filter strips are kept constant. As it is obvious from Table 3.9, the most effective trapping effect is shown by a double layer riparian-like strip situated at the half-lower-end of the channel. A single but longer riparian-like strip show less effective trapping effect. The reason why the double strips are more effective in trapping sediment is likely to be related to the capacity of the strip to trap incoming sediment. Double layer riparian-like strip seems to have better capacity to trap sediment.

3.3. Hydrological Analysis and Effect of Land Use Change on Streamflow Characteristics of Upper Way Besay Catchment

3.3.1. Hydrological Analysis

3.3.1.1.Rainfall

The rainfall over the Way Besay Upper Catchment is primarily characterized by high intensity convection storms of short duration and limited aerial extend. These storms usually occur as the result of warm air raising off the land mass in the late afternoon.

The rainfall in the Way Besay Upper Catchment has been studied and the result are presented in the following section.

Annual Rainfall

The average long term annual rainfall on the Upper Way Besay Catchment is about 2589 mm. This long term average was obtained from Thiessen polygonal generation of annual rainfall from Air Hitam, Fajar Bulan and Sumber Jaya rainfall station during observation period of 1975-1998. Coefficient of variation for the 24 years observation is 0.16. This indicates that the annual rainfall variation of the study area during period of observation is relatively small and it might be considered that there has been no significant climatic change during that period.

Monthly Rainfall

The monthly variation in rainfall is large with a definite wet season extending from November to May (Figure 3.2.). The wettest months are spread evenly between December to March and the driest month are July and August.

The monthly rainfall distribution of 1975, 1980, 1985, 1990, 1995 was used for monitoring the hydrological condition of the study area and studying the effect of land use change. The data are presented in Figure 3.3, 3.4, 3.5, 3.6 and 3.7. Total annual rainfall for the year of 1975, 1980, 1985, 1990 and 1995 are 2531 mm, 2797 mm, 2959 mm, 2459 mm, and 2664 mm, respectively. Based on Schmidt and Ferguson Classification, there were no dry month (a month with less than 60 mm rainfall) during 1975, 1980, and 1985. In 1990 and 1995, the October and August were dry months, respectively. The number of wet months (a month with more than 100 mm rainfall) varied from 4 to 12 months. The shortest period of consecutive wet months occured in 1995 and the longest one occured in 1975, 1980, and 1985.

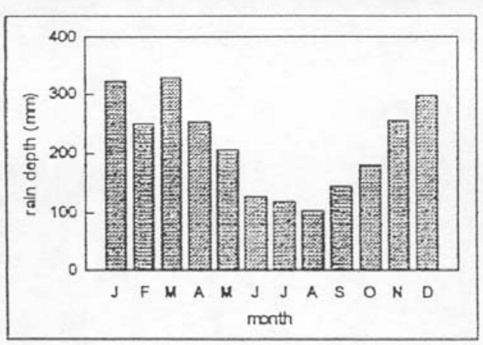


Figure 3.2. Monthly Rainfall Distribution of the study area

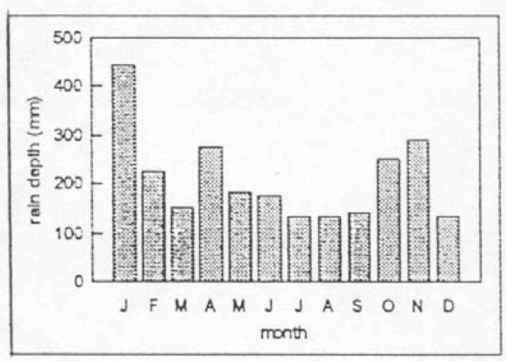


Figure 3.3. 1975 Monthly Rainfall Distribution

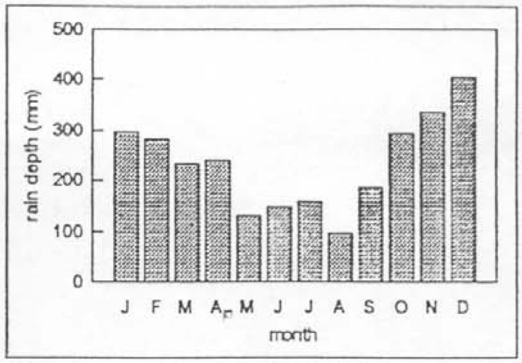


Figure 3.4. 1980 Monthly Rainfall Distribution of the study area

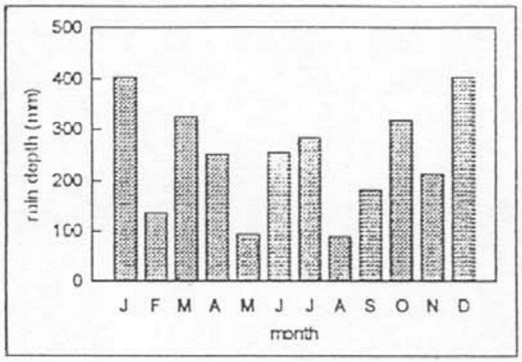


Figure 3.5. 1985 Monthly Rainfall Distribution of the study area

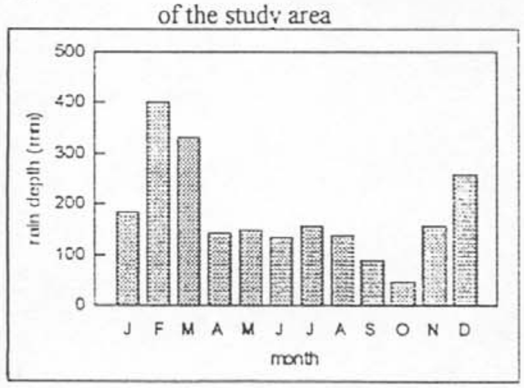


Figure 3.6. 1990 Monthly Rainfall Distribution of the study area

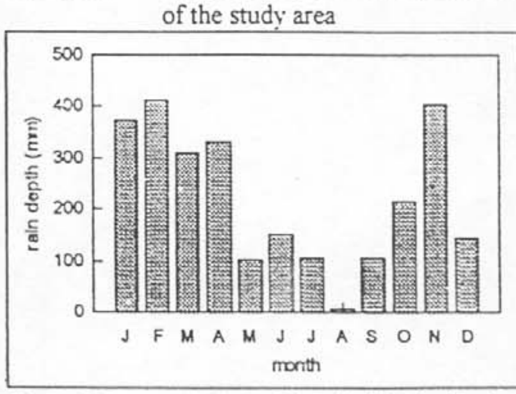


Figure 3.7. 1995 Monthly Rainfall Distribution of the study area

Daily Rainfall

Heavy rainfall over the Upper Way Besay Catchment is usually caused by high intensity convective storms of short duration and limited areal extend. The maximum daily rainfall recorded at the representative rain gages vary between 35 mm to 83 mm. During 24 years observation (1975-1978), the lowest maximum rainfall occurs in 1990 and the highest one occurs in 1985.

3.3.1.2.Streamflow

The quantity and distribution of streamflows are essentially dependent on rainfall, evapotranspiration, and physical characteristics of a catchment. Vegetation cover and land use type will strongly influence streamflow; therefore any changing in land use will affect the streamflow. The Upper Way Besay Catchment has a drainage area of 38900 ha.

Mean Flows

The average annual streamflow or total water yield at the study area (1975-1997) is 20.2 m^3/second or 650 million m^3/year from drainage area of 389 km^2. It is about 63.7% of the average annual rainfall of the study area, where the average rainfall is 1007 million m3. Variability of the total water yield ranged from 513 million m^3/year to 781 million m^3/year with a coefficient of variation of 0.15.

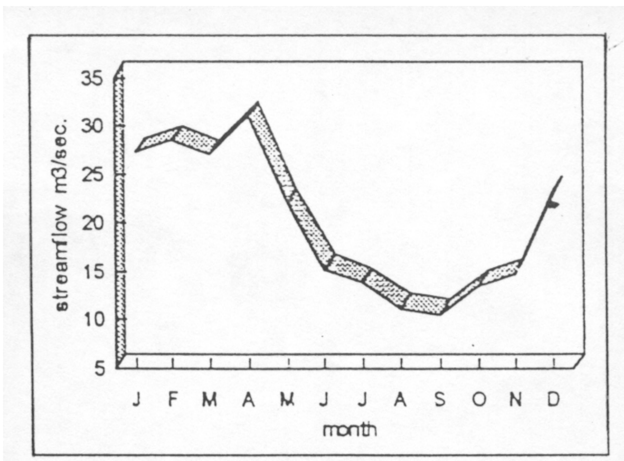
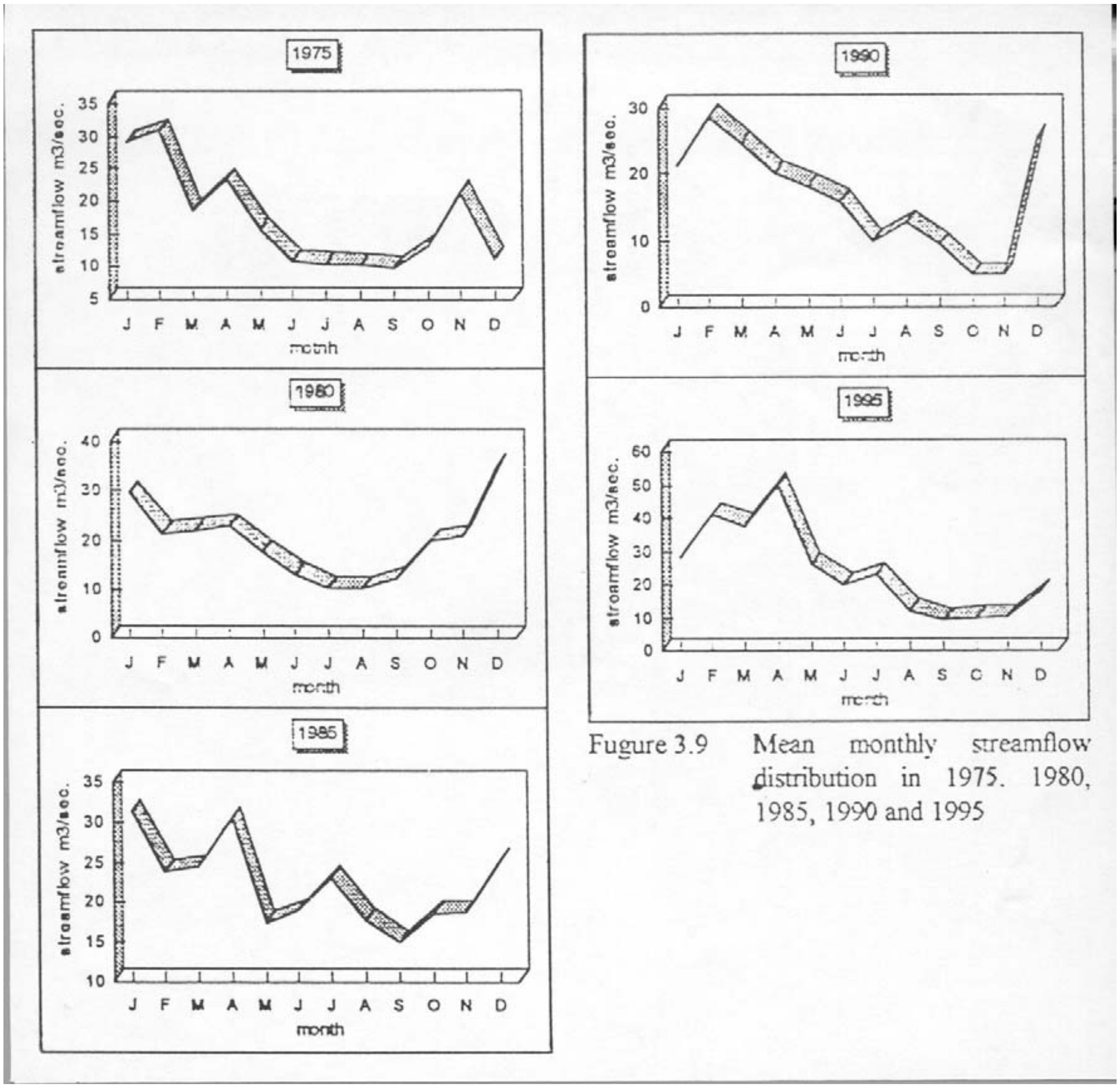


Figure 3.8. Monthly streamflow distribution

The average mean monthly stremflow in 1975-1997 is presented in Figure 3.8 and the mean monthly streamflow of period 1975, 1980, 1985, 1990, and 1995 are depicted in figure 3.9. Stream flow represented 54%, 60%, 61%, 61% and 75% of rainfall for the respective years.

As shown in Figure 3.8, the maximum monthly streamflow occurred in April and the minimum occurred in September. The seasonal distribution of streamflow seems to largely correspond with the distribution of rainfall. Average monthly streamflow from December through May is high, while from June through November it is low.



Fugure 3.9 Mean monthly streamflow distribution in 1975. 1980, 1985, 1990 and 1995

Minimum and Maximum Flows

Figure 3.8 shows that low stream flows occured between June and November. The average annual streamflow was 20.4 m^3/second; however during the dry season (June through November) the flow can drop to nearly zero. During the wet season the flow could reach as high as 100 m^3/second in April. The minimum and maximum flow based on a two weeks average for the selected years and the ratio between them is presented in Table 3.11. Table 3.11 shows that ratio between Qmax and Qmin is increasing from 1975 to 1995. It indicates that there is a progressive changes of the hydrological condition which resulted in increasing peak runoff.

Table 3.11. The minimum and maximum flow of 1975, 1980, 1985, 1990, 1995

Year	Qmin	Month of occurrence	Qmax	Month of occurrence	Ratio
1975	8.1	July	44.3	February	5.4
1980	9.5	August/September	38.8	December	4.1
1985	10.9	August/September	36.3	April	3.3
1990	3.9	November	30.3	February	7.7
1995	7.2	September	56	March/April	7.8

3.3.1.3. Rainfall-Run Off Relationship

The relationship between rainfall and run off on average monthly basis is presented in Figure 3.10. As it is mentioned in section 3.3.1.2, the seasonal distribution of run off is largely dependent on the distribution of rainfall, as it is shown in Figure 3.10. The same pattern is also indicated in daily based distribution (Figure 3.11).

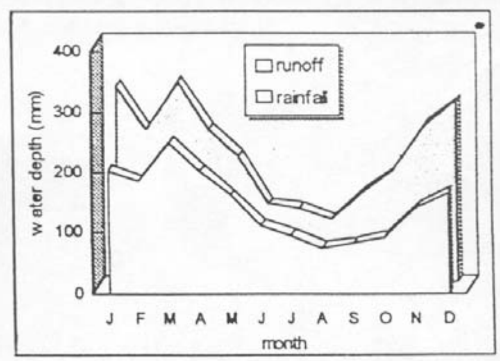


Figure 3.10. Monthly basis rainfall-runoff relationship

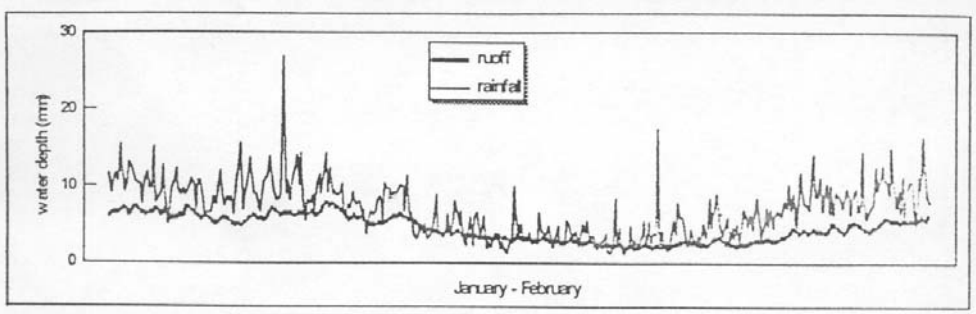


Figure 3.11. Daily basis rainfall-runoff relationship.

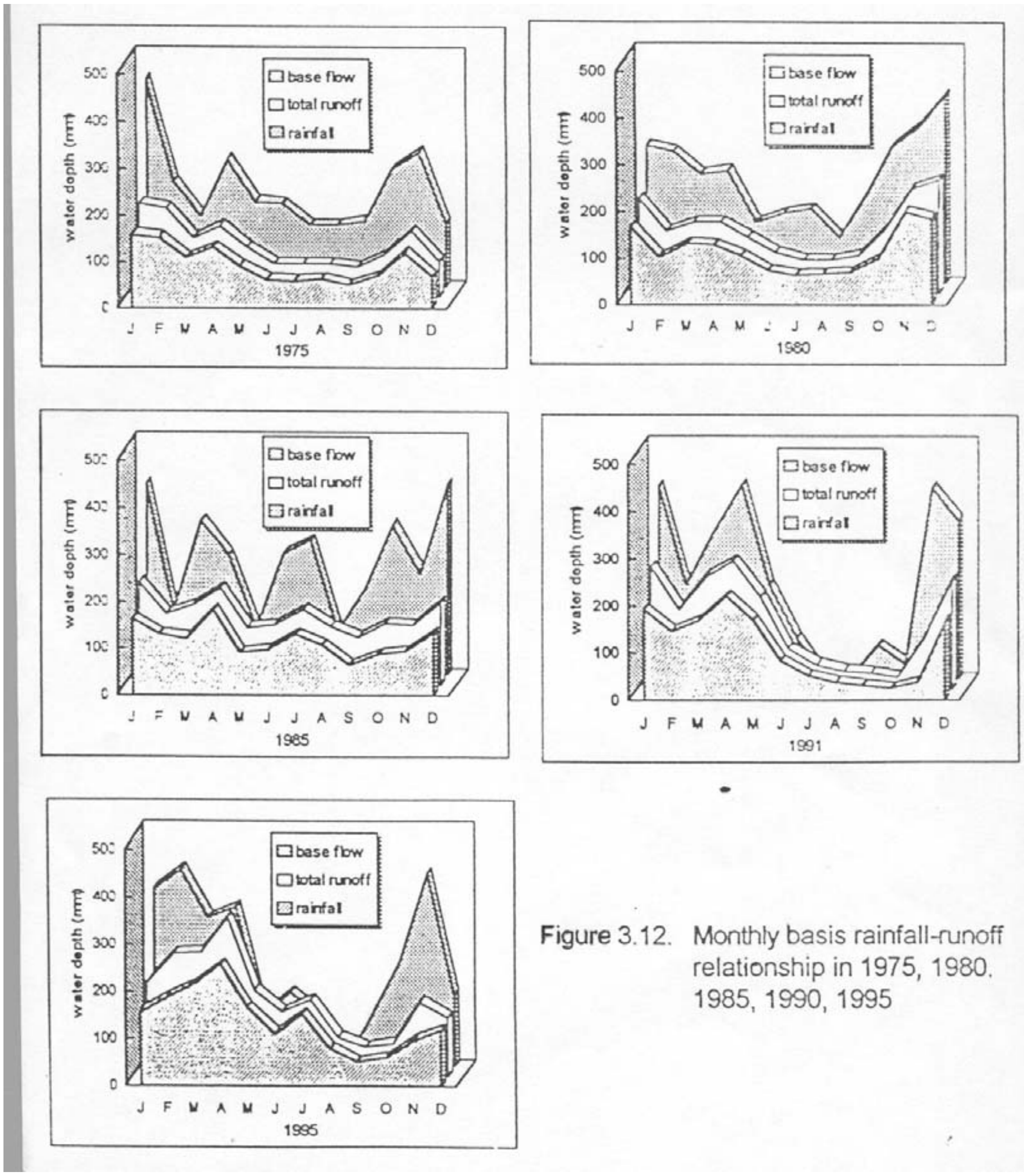


Figure 3.12. Monthly basis rainfall-runoff relationship in 1975, 1980, 1985, 1990, 1995

The rainfall-runoff relationship in 1975, 1980, 1985, 1991, and 1995 are presented in Figure 3.12. The base flow in these figures were separated from the total stream flow using the straight line method.

3.3.2. Effect of Land Use Change on Streamflow Characteristics

Land Use Change

Study carried out by Syam et al (1997) indicated that a progressive land use changes have occurred in the study area during 1970 to 1990 period table (3.12).

Table 3.12. Changes in percentage of land use system from 1970 to 1990*)

No	Land use type	Year			
		1970	**1978**	**1984**	**1990**
1	Residential areas	0.83	1.03	1.70	2.20
2	Paddy fields	0.36	2.92	5.02	5.35
3	Upland field	5.29	2.20	1.07	0.12
4	Shifting cultivation	9.38	4.81	0.33	0.00
5	Monoculture plantation	0.00	20.83	41.77	41.11
6	Mixed plantation	0.00	0.93	0.95	19.26
7	Dense forest	57.38	32.60	21.39	12.72
8	Underbrush forest	11.88	16.20	10.79	18.05
9	Ponds	0.00	0.03	0.01	0.07
10	Grassland	8.96	18.44	16.98	1.12

*) Syam et al (1997)

Syam et al (1997) said that in period 1970 most of the study area was occupied by dense forest (57%) followed by underbrush forest (12%), upland area under shifting cultivation (9.4%) and grassland (9%). Crops and vegetables is 5% and paddy fields accounted for less than 1%. No plantation area was found in 1970.

In 1978, the area under dense forest decreased substantially from 57% to 33%. The underbrush forest increase from 12% to 16% and grassland increase from 9% to 18%. Plantation areas were found and had occupied 21% of the total area. Based on stream flow characteristics data of 1980, these land use changes were followed by the increase of ratio of total runoff to rainfall from 54% in 1975 to 60%. The surface runoff increase from 9 to 10% and the base flow increase from 45 to 50%. Lack of stream flow data of 1970, and land use data between 1970-1978 caused the loss of the very important information of the early stage of land use changes especially from dense forest and under brush forest to plantation and grass land. Transmigration was believed to be the major driving force for the land use changes in Lampung which started in 1970s. 15% of total transmigrant were located in Lampung during this period. At the same time two remarkable land use changes were found.

Streamflow characteristic and land use change

The monthly distribution of surface runoff for the selected years are presented in Figure 3.13 and the water balance is presented in Table 3.13. Figure 3.13 shows that surface runoff tend to slight increase after 1980. The increasing of surface runoff seems to be related to the land use changes in the area (Table 3.12). A drastic increase of mono culture plantation and decrease of dense forest have been occurring in the area after 1980 (Table 3.12). This change have progressively increased surface run-off (quick flow). However, because some soil and water conservation practices (crop residue mulch, slit pits, unweeded coffee gardens) have been practiced in the mono culture plantations, base flow (low flow) has also been increased during the period.

Table 3.13. Water balance of the study area for the year 1975, 1980, 1985, 1991 and 1995.

Component	Unit	Year				
		1975	**1980**	**1985**	**1991**	**1995**
Rainfall	(mm)	2531	2797	2959	2459	2663
Total Runoff	(mm)	1369	1678	1793	1718	2001
Surface Runoff	(mm)	237	293	382	374	342
(Quick flow)	% to rainfall	9	10	13	15	13
Base flow	(mm)	1132	1385	1411	1344	1659
(Low flow)	% to rainfall	45	50	48	55	62

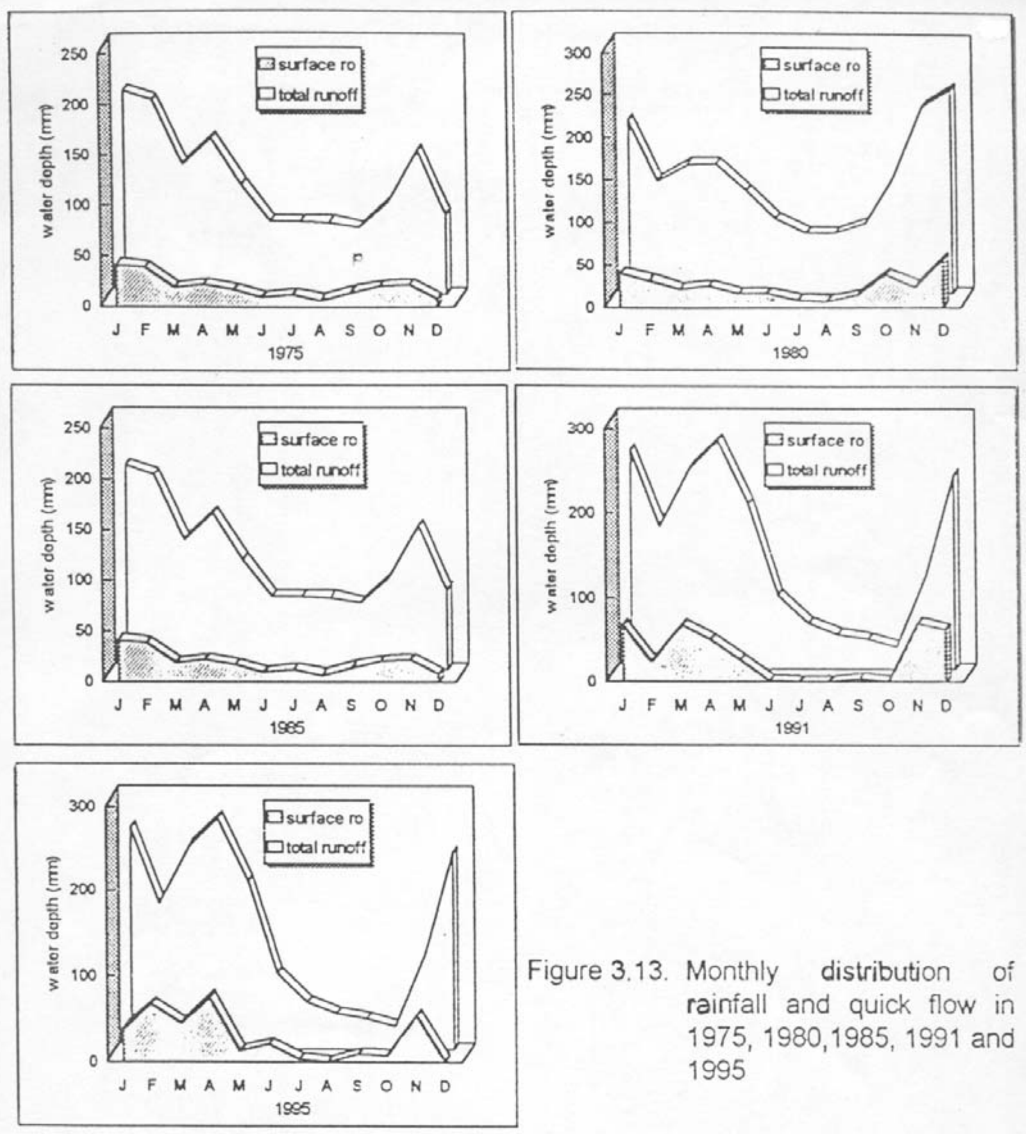


Figure 3.13. Monthly distribution of rainfall and quick flow in 1975, 1980,1985, 1991 and 1995

A “positive” correlation between land use change in period 1970-1978 with base flow may be explained that at the end of this period, as being recorded in 1980, the plantation area had been stable (almost 10 years old) so that a good coverage and rooting system as well as other supporting factors which conducive for infiltration had been well established. This “positive” correlation however, was not reached in the 1985. Table 3.13 shows that since 1985 to 1995 the ratio between total runoff to rainfall tend to increase from 60% in 1980 to 61% in 1985, the surface runoff increase from 10% in 1980 to 13% in 1985, while the base flow decrease from 50 to 48%. This condition correlates with some land use changes occurred during that period. Based on table 3.12 since 1984 total plantation area are doubled and become the largest cover of the study area while area under forest and underbrush forest decreased to 21% and 11% respectively and became 11% and 18% respectively in 1990. In 1990 mix plantation increase to 19% from only 1% in 1980, the grass land decreased from 17% in 1984 to 1% in 1990. Most of the grass land were converted to mixed plantation during this period.

Change of composition of the land uses from 1980 to 1990 were correlated with changes in stream flow characteristics recorded in 1985, 1991, and 1995. The large conversion of dense forest to monoculture plantation during 1978 to 1984 correlates with the increase of surface runoff from 9% to 13% although the total runoff is relatively constant. It seems that this conversion had decreased the capability of the watershed to absorb rainfall water so that more rainfall water run over the surface of the watershed, base flow decreased from 50% to 48%. During 1984-1990 some of the watershed characteristics seem to recover. The ratio of total runoff to rainfall tend to increase, the surface runoff was slightly increase, and base flow was increase from 48% to 55%. This condition correlate with the conversion of nearly half of the areas under monoculture plantation in 1984 to mixed plantations and under brush forest. And 30% of dense forest, 34% of grass land and 47% under brush forest were converted to monoculture plantation. The area under dense forest in period 1984-1990 decreased mainly due to the conversion to plantation area. This condition seem to correlate with the recovery of some watershed characteristics so that more water was being available as base flow increase and the surface runoff seem to stand for the next period as it is indicated by the hydrological condition recorded in 1995 that the surface runoff decrease and the base flow tend to increase.

IV. CONCLUSION

1. Sediment yield was significantly influenced by land use type. Natural forest had the lowest sediment yield, followed by Calliandra (in former coffee gardens), Cleared land with falling threes (in former natural forest). Multi strata systems, unweeded coffee gardens, clean-weeded coffee gardens and tegalan with horticultural crops. The presence of litter or basal cover on a land use significantly reduced sediment yield.

2. The presence of vegetative filter strips in the field decreased sediment yield. The effectiveness of a filter strip in trapping sediment yield (filter efficiency) varied depending on the characteristics of the field boundary and upper land use from 38 – 95%, thus letting only 62 - 5 % of the suspended sediment pass through, or reducing the sediment outflow by a factor 1.5 to 20. A hedgerow of banana with a small ridge covered by grass showed the highest sediment trap efficiency, followed by a hedgerow of "*Pisangan*", terraced land with woody young shrubs, woody shrubs with imperata grass undergrowth, dense woody shrubs, small ridge covered by litter, calliandra with coffee undergrowth, and a small ridge with no litter and basal cover.

3. The presence of litter and basal cover that result in good vertical distribution of vegetative coverage can significantly increase the sediment trap efficiency of a filter strip.

4. The ANSWER Model can be used to simulate the effect of filter strips on sediment transfer. The different effectivity of filter strip in trapping sediment can be accommodated by reprogramming and re-compiling the existing sub-routines in the ANSWER Model.

5. The rainfall at study area is relatively homogenous and the variability of annual rainfall relatively small.

6. The pattern of seasonal distribution of stream flow is greatly influenced by and tend to correspond to rainfall pattern. Substantial reduction of dense forest area has increased total water yield and quick flow progressively, but has had a similar effect on increasing baseflow and has not modified the proportion of quickflow in total water yield.

V. REFERENCES

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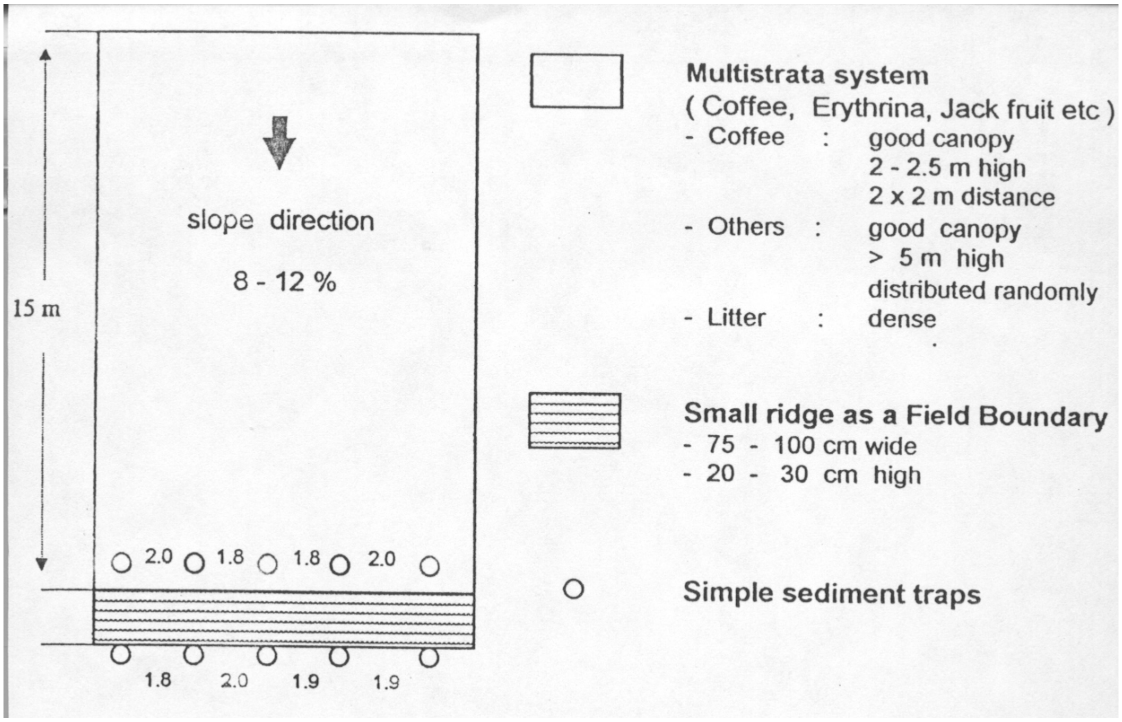
APPENDICES



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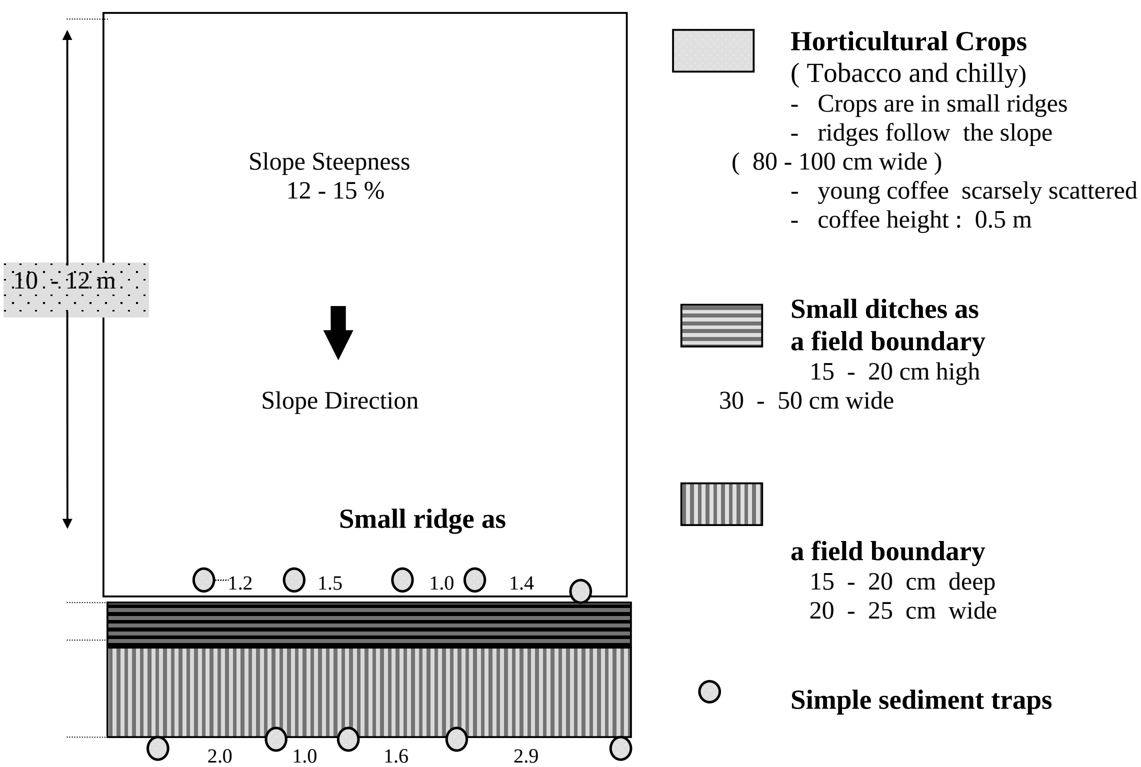
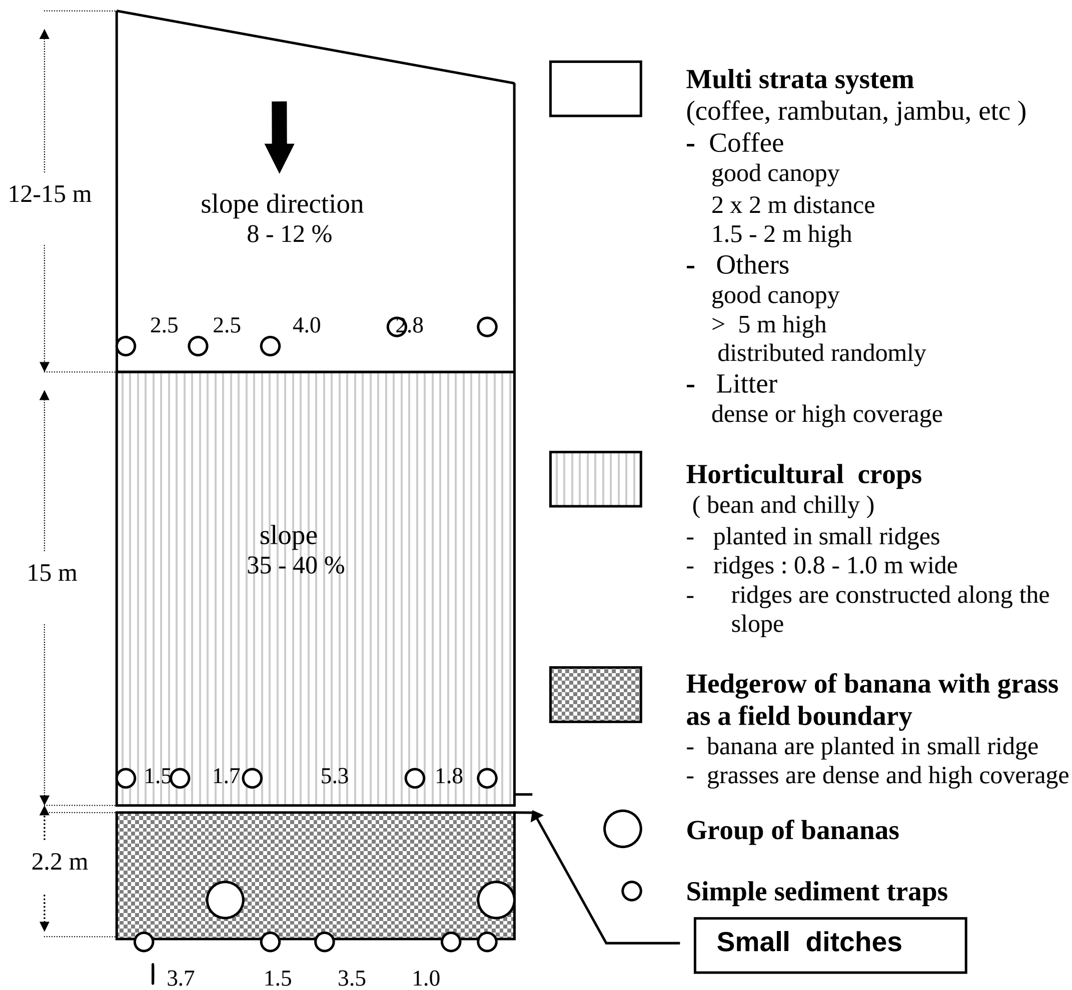
Appendix 1. Small ridge as a field boundary in multi strata system (dense coffee with Erythrina overground)



Appendix 2. Small ridge as a field boundary in tegalan with horticultural crops



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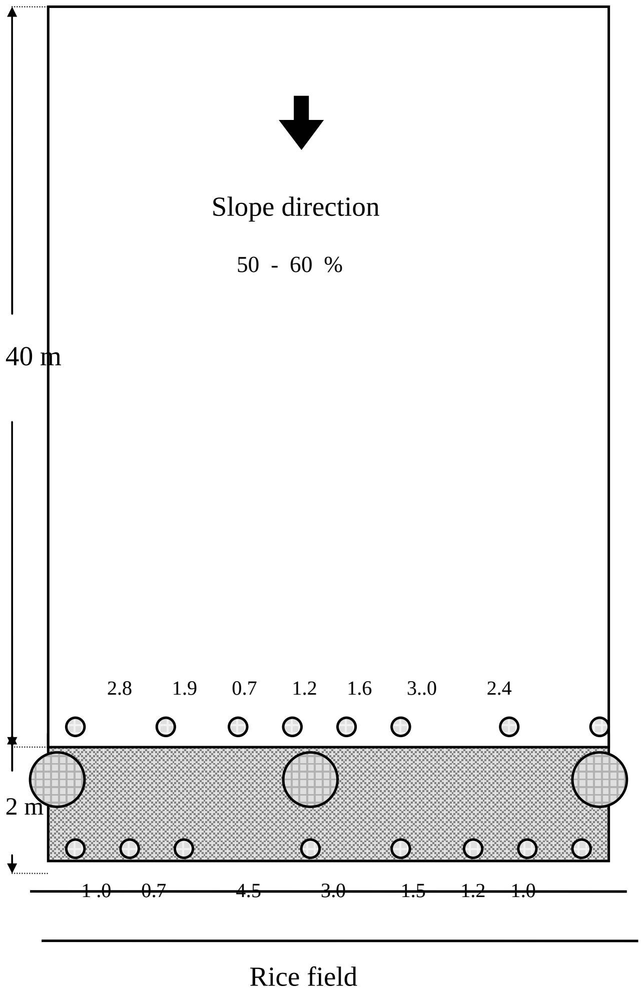
Appendix 3. Hedgerow of banana with small ridge covered by grass as a field boundary, tegalan with horticultural crops, and multi strata system (mixed gardens)



Mixed Gardens
(Banana with young coffee and talas underground)
- medium canopy cover
- coffee distance : 2 x 2 m
- coffee height : 0.5 - 1 m
- talas are scarcely scattered
- banana : 8 x 8 m

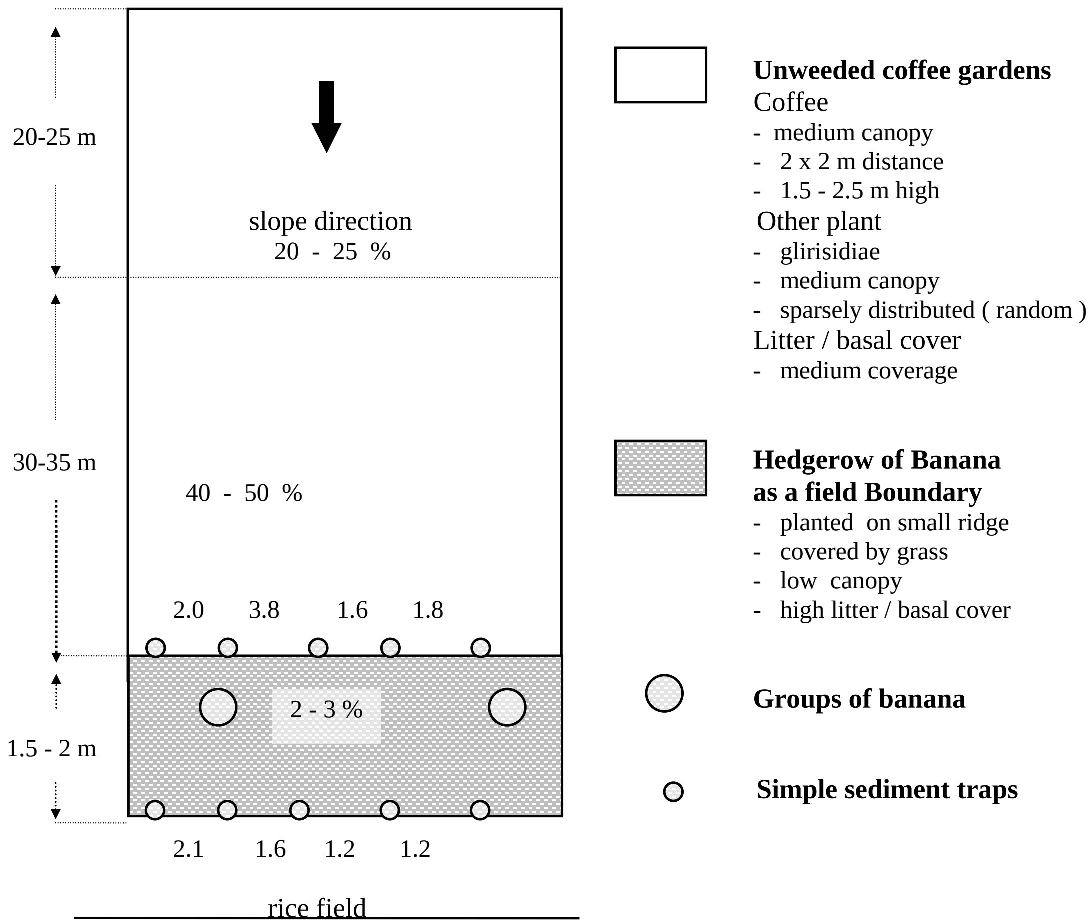
Hedgerow of banana with grass underground as a field boundary
- banana and grass are growth in small ridge
- Plant residue of banana are incorporated to the ridge
- slope steepness 2 - 3 %

Simple sediment traps

Group of Bananas

Note : figures are not to scale

Appendix 4. Hedgerow of banana with small ridge covered by grass as a field boundary



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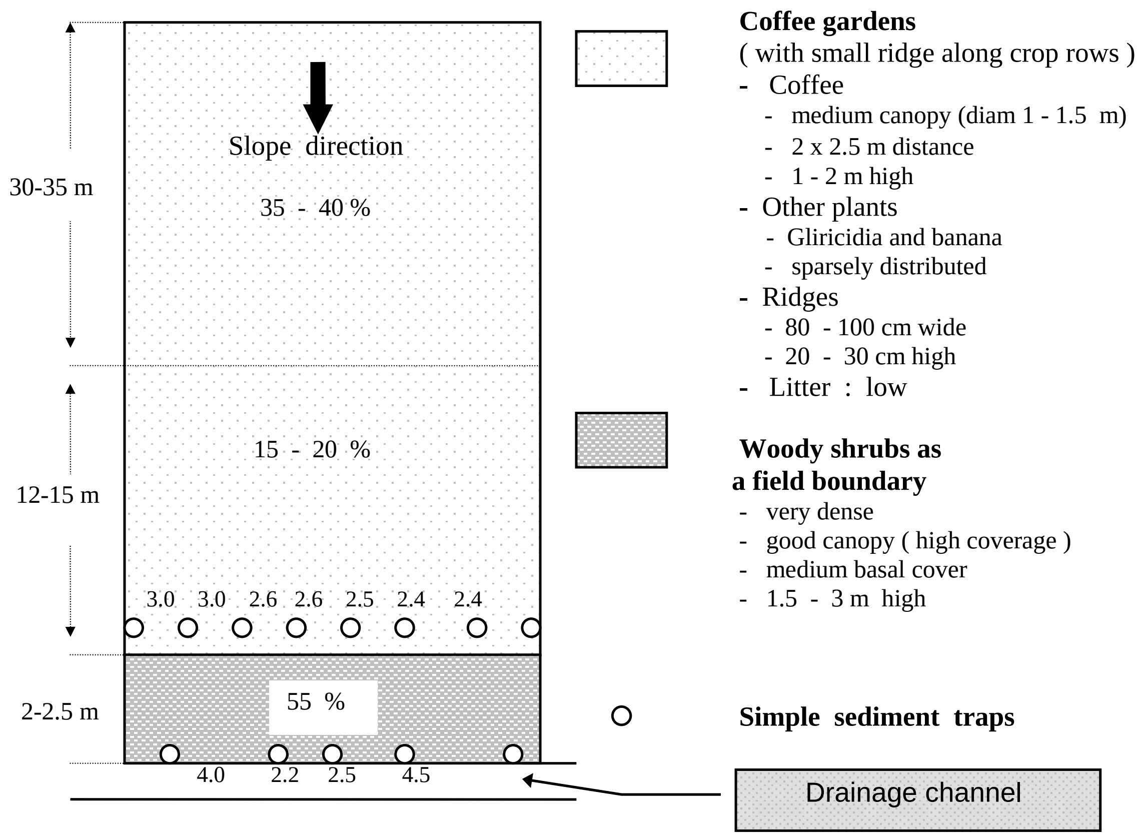
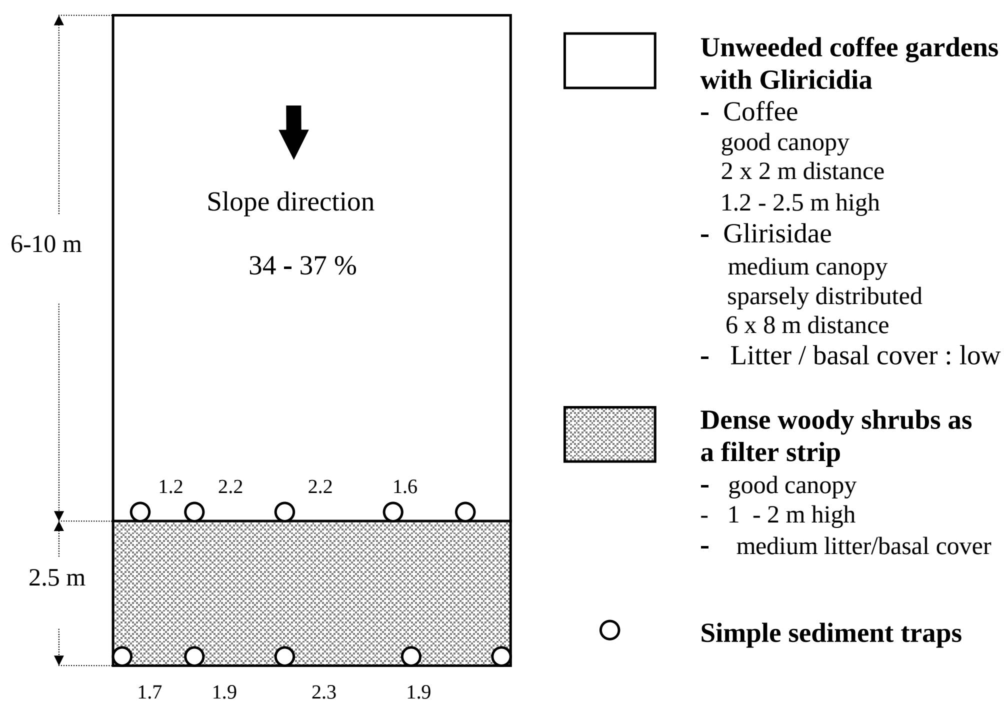
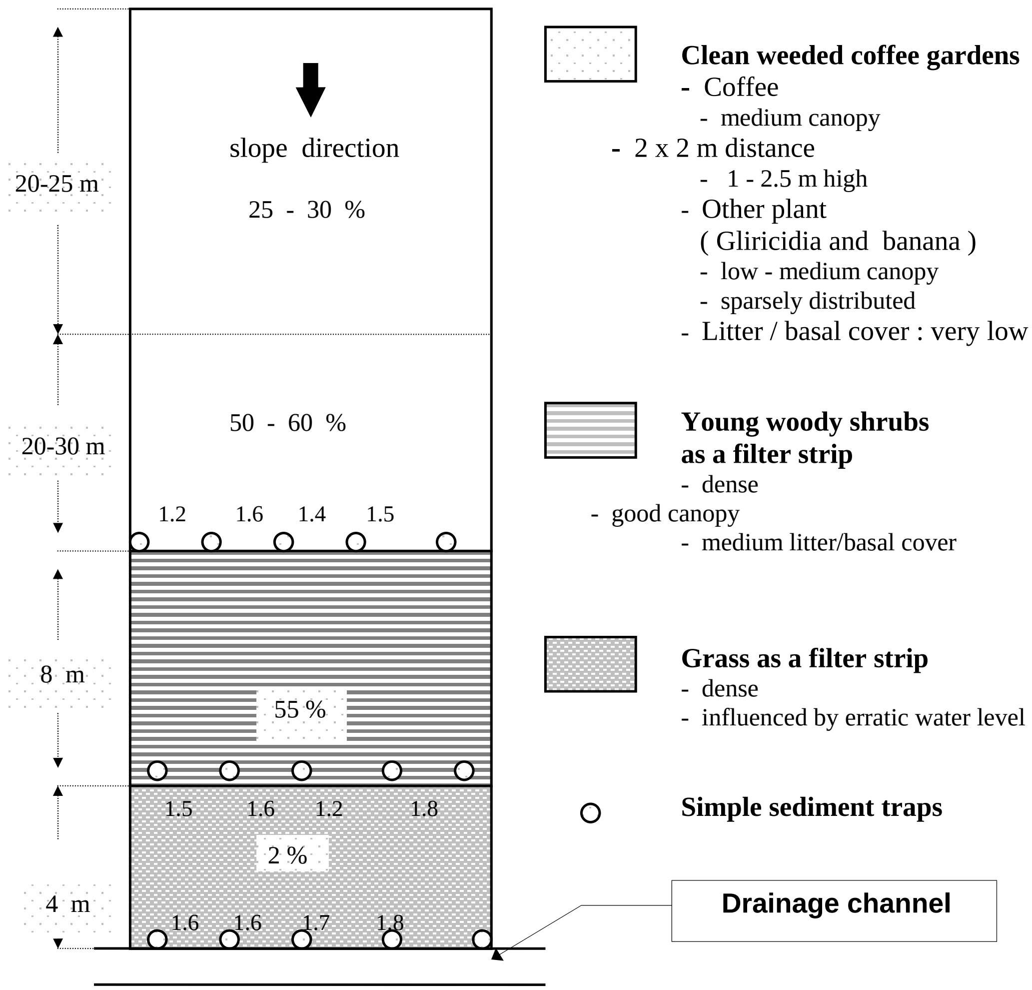
Appendix 5.Hedgerow of banana with small ridge covered by grass as a field boundary and unweeded coffee gardens



Appendix 6. Dense woody shrubs as a field boundary and coffee gardens



Appendix 7. Dense woody shrubs as a filter strip and unweeded coffee gardens



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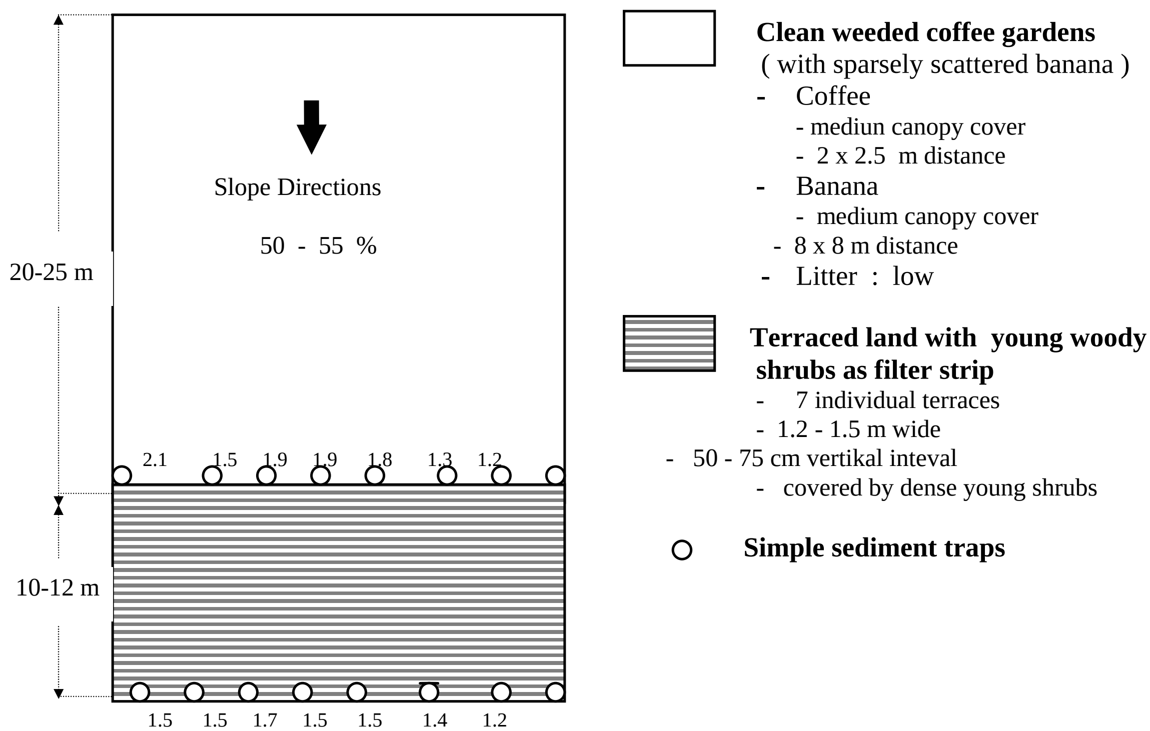
Appendix 8. Dense grass and young woody shrubs as filter strips and clean weeded coffee gardens



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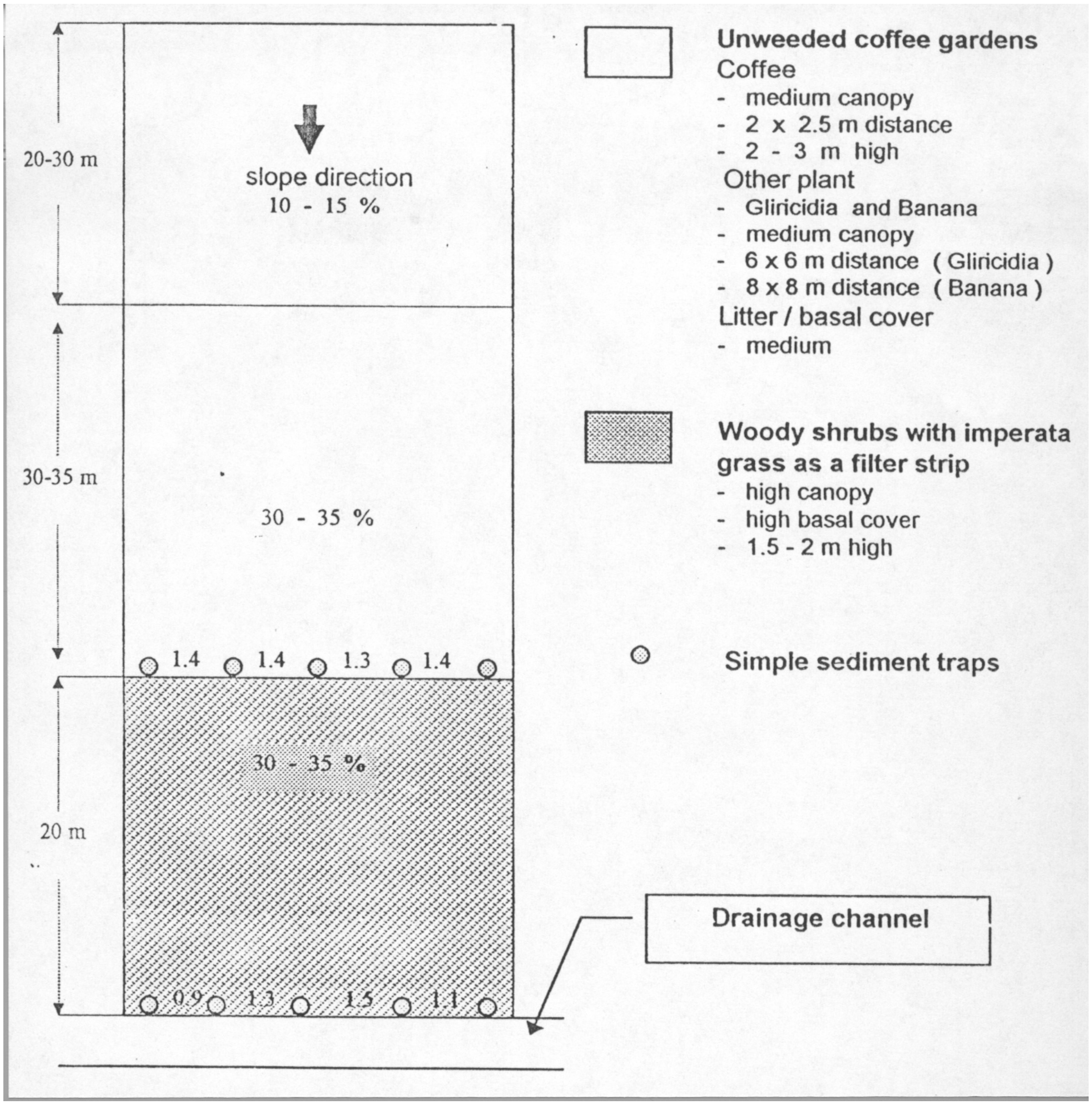
Appendix 9. Terraced land with woody young shrubs as a filter strip and clean weeded coffee gardens



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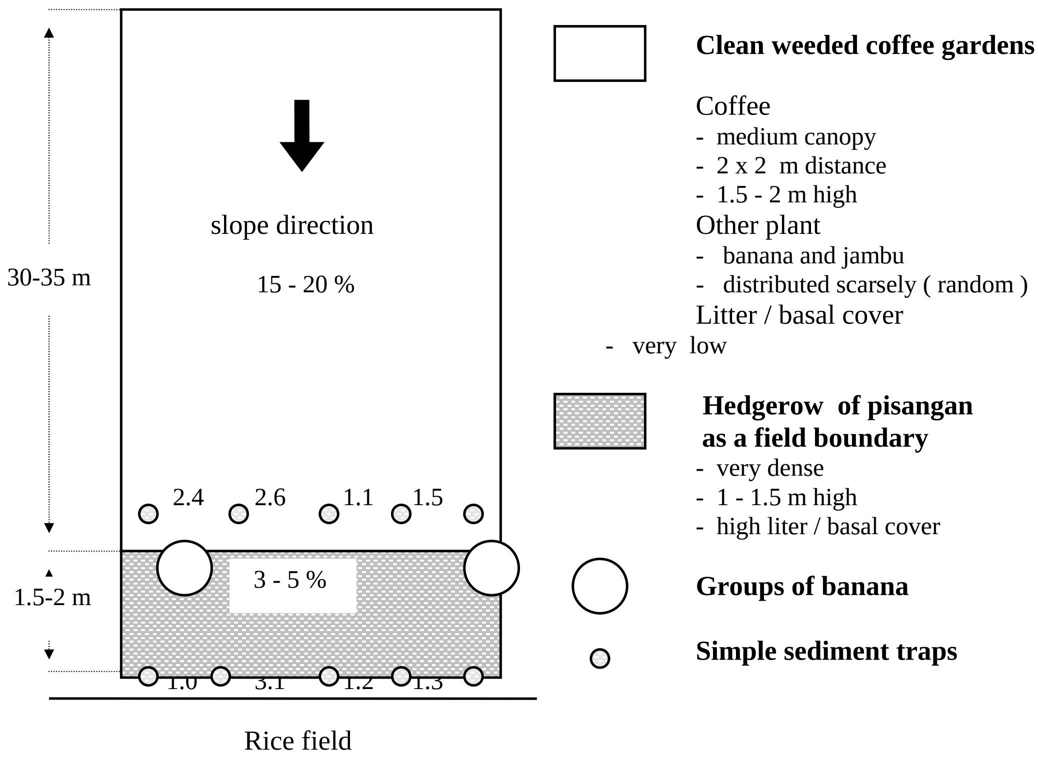
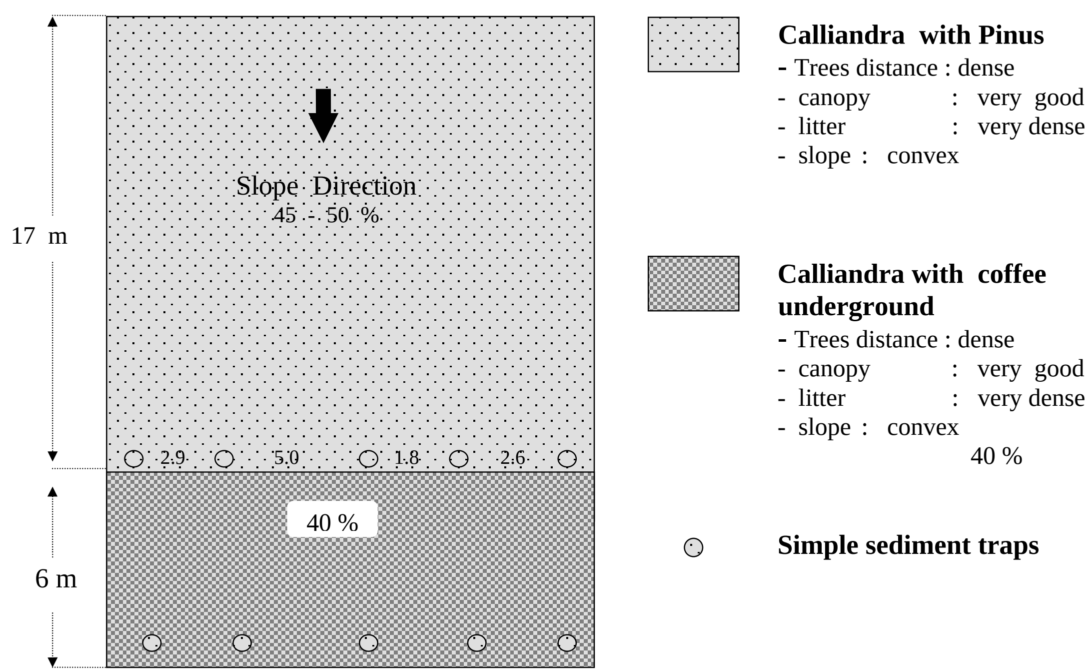
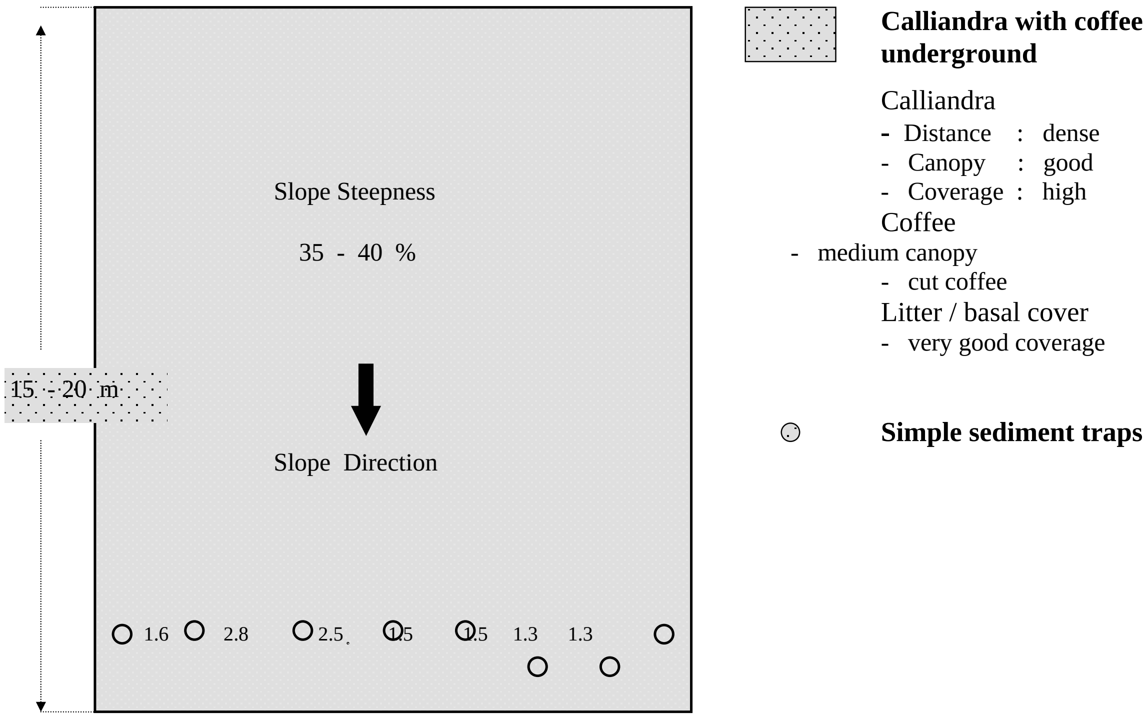
Appendix 10. Young woody shrubs with imperata grass as a filter strip and unweeded coffee gardens



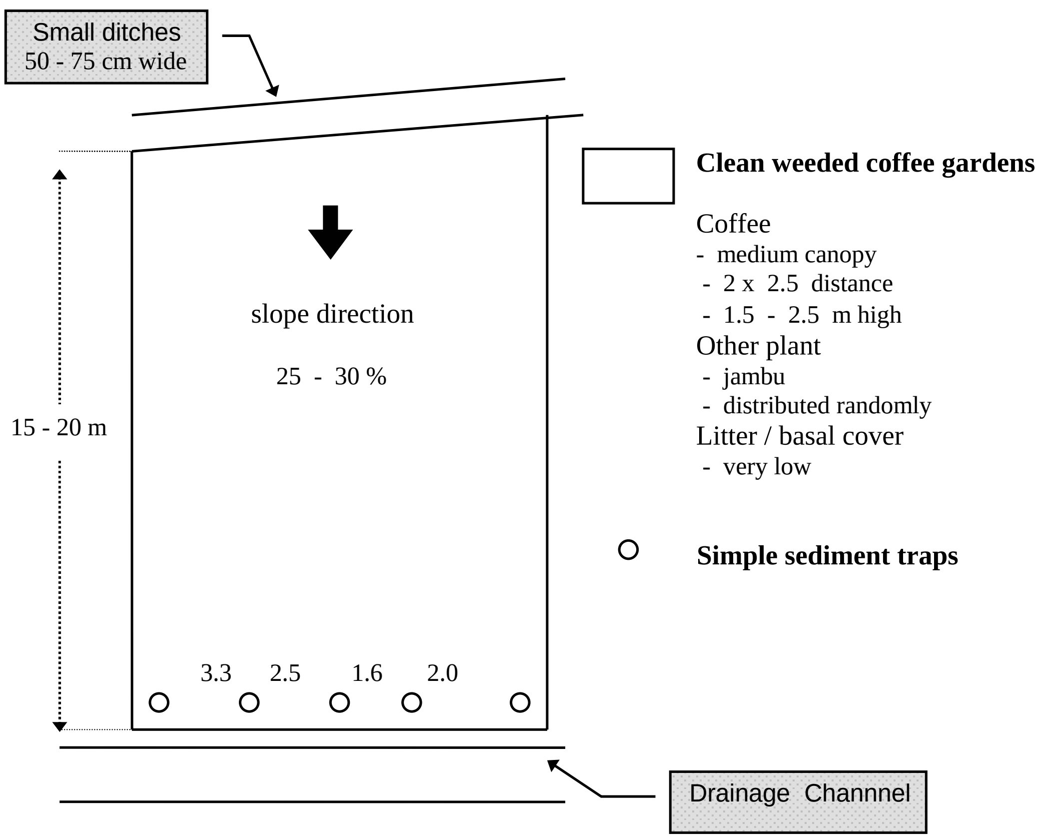
Appendix 11. Hedgerow of "pisangan" as a field boundary and clean weeded coffee gardens



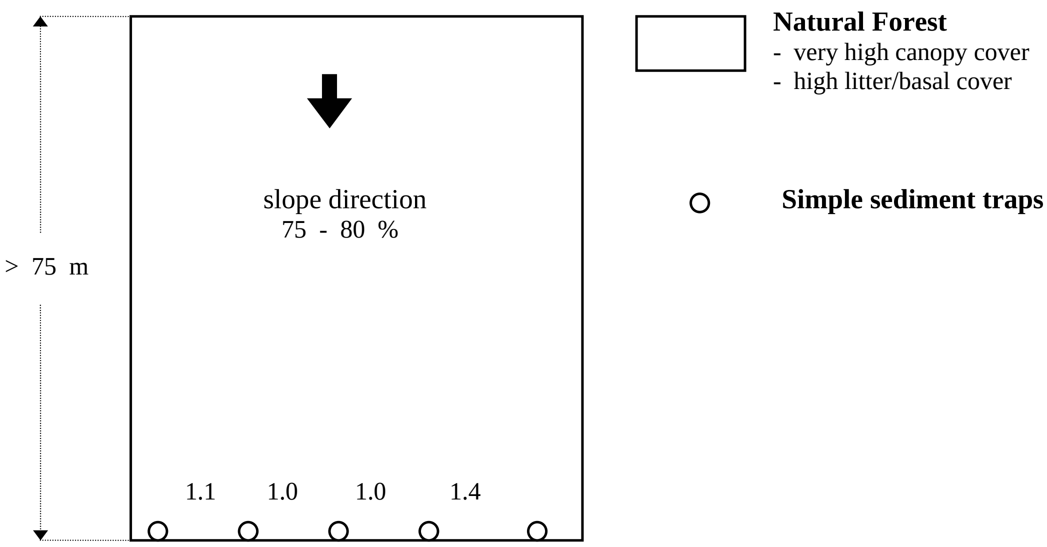
Appendix 12. Calliandra with coffee underground at Kampong Dwikora



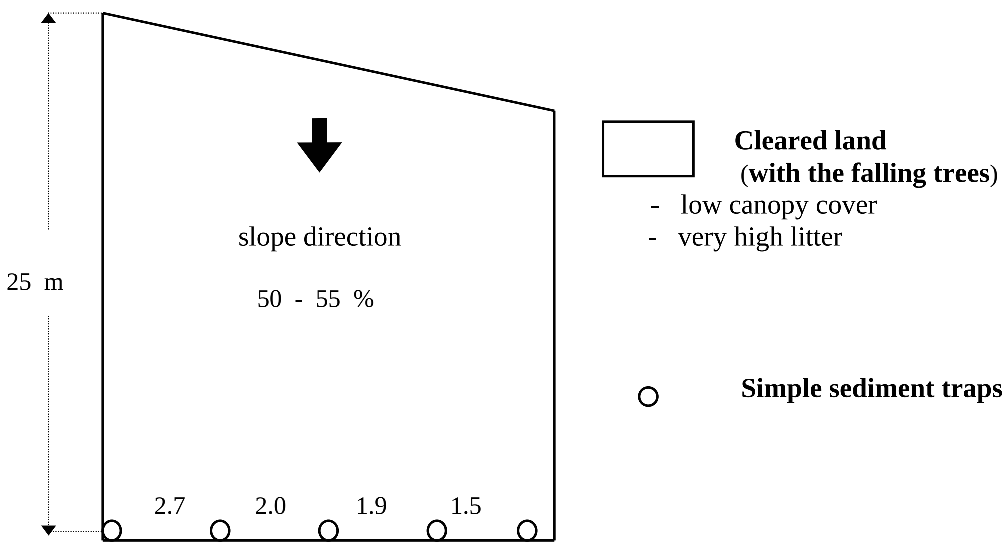
Appendix 13. Calliandra with coffee underground at Kampong Tebo



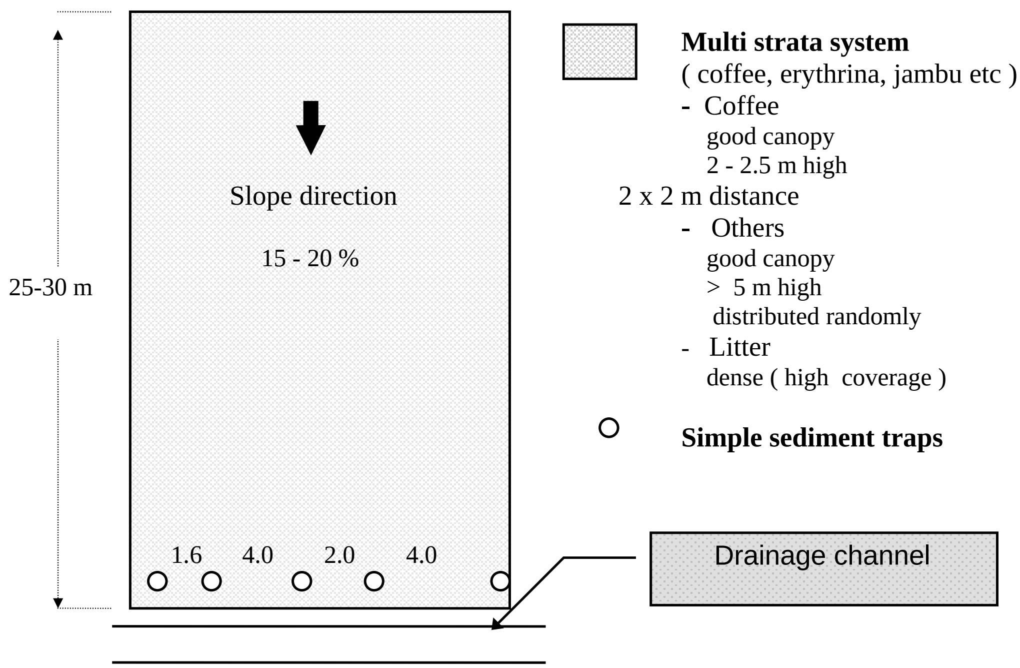
Appendix 14. Clean weeded coffee gardens



Appendix 5. Natural Forest



Appendix 16. Cleared land with the remnant falling trees (the former natural forest)



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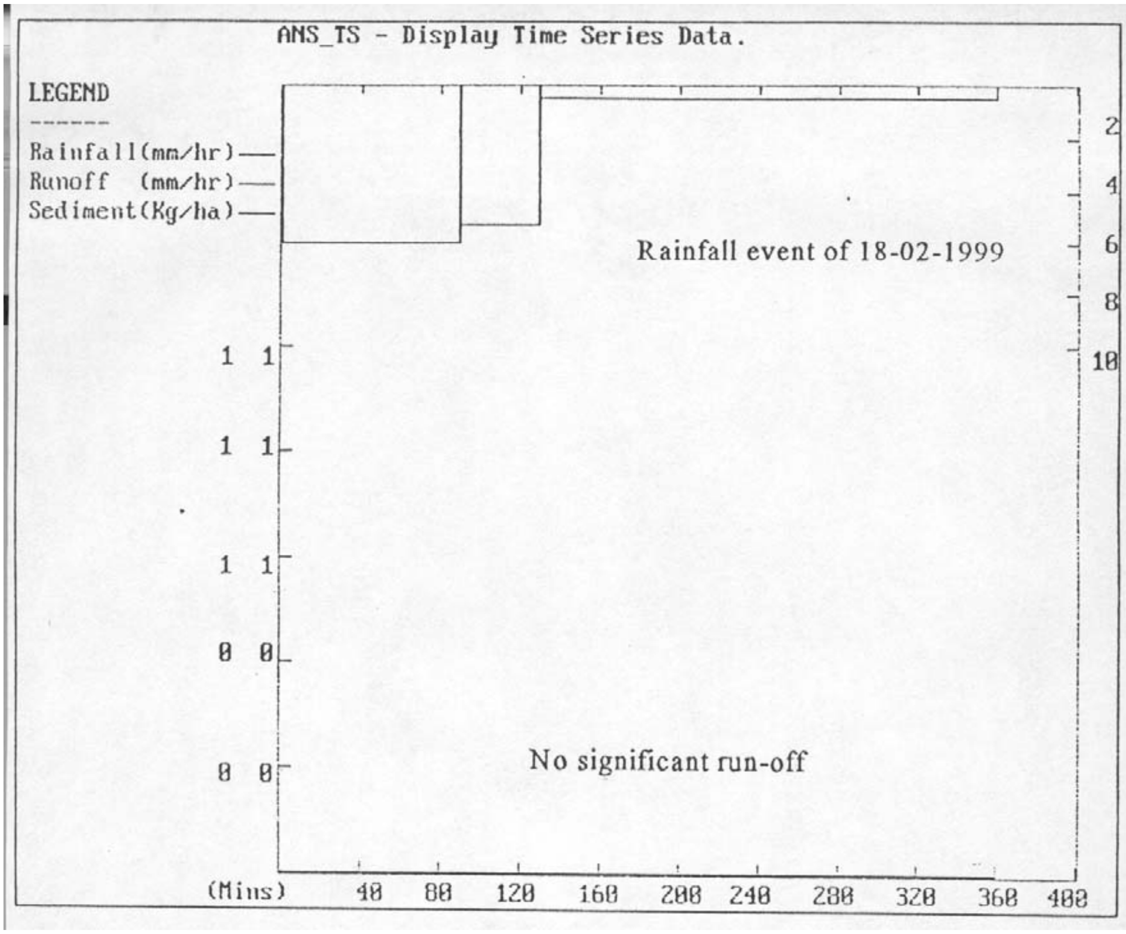
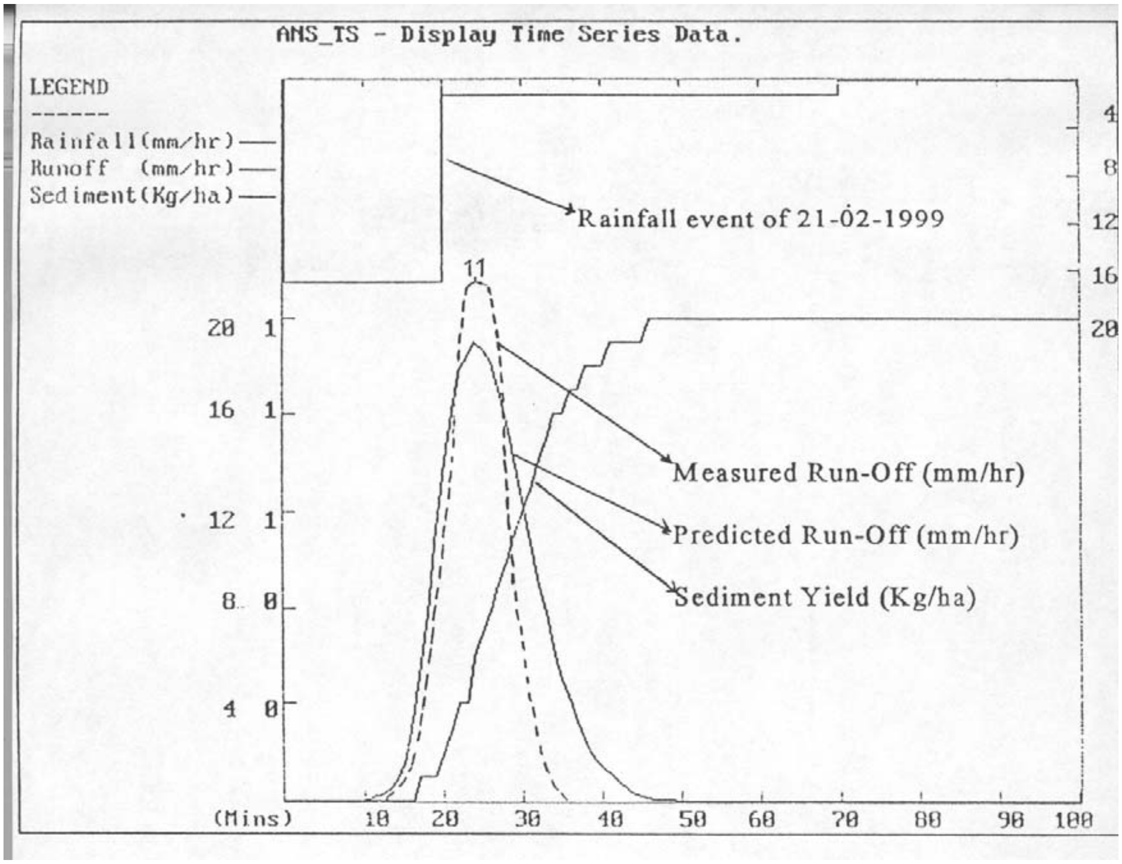
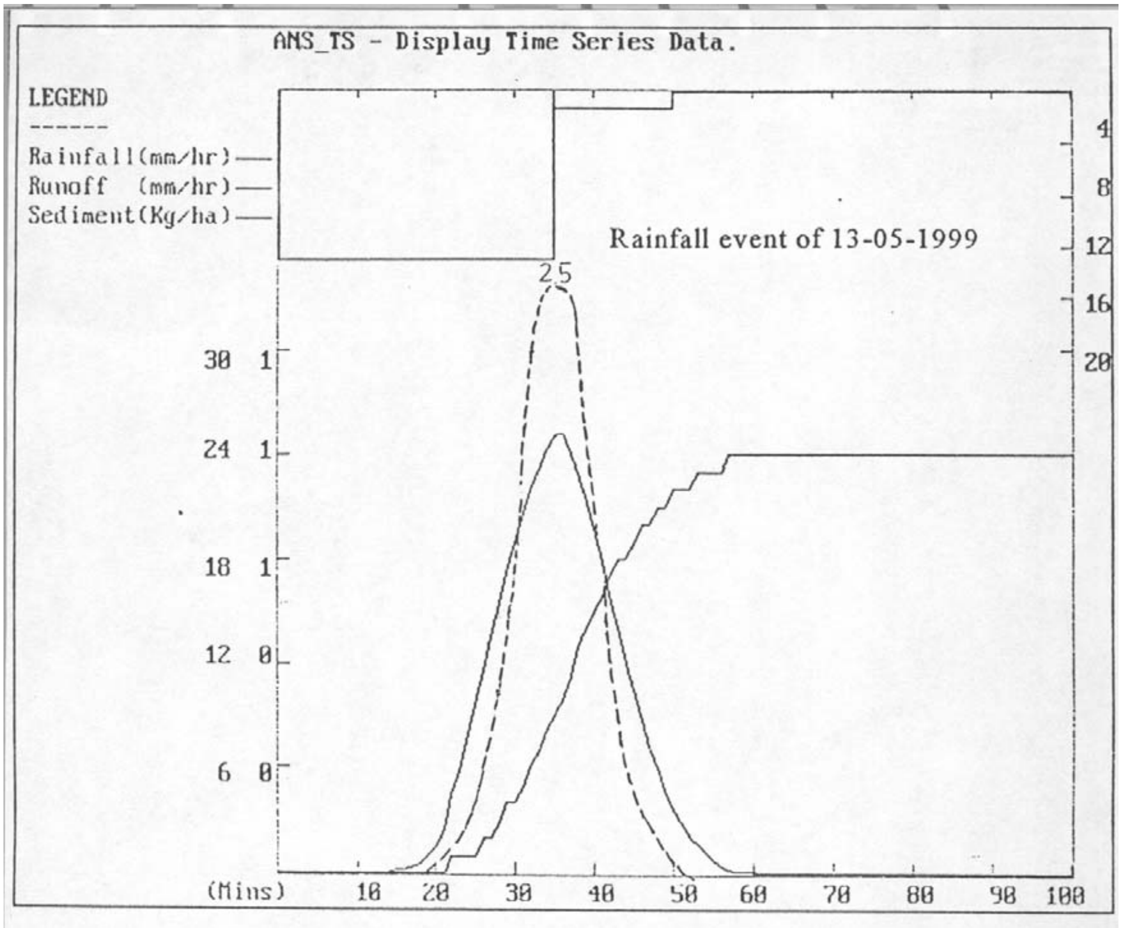
Appendix 17. Multistrata system (Erythrina with dense coffee underground)



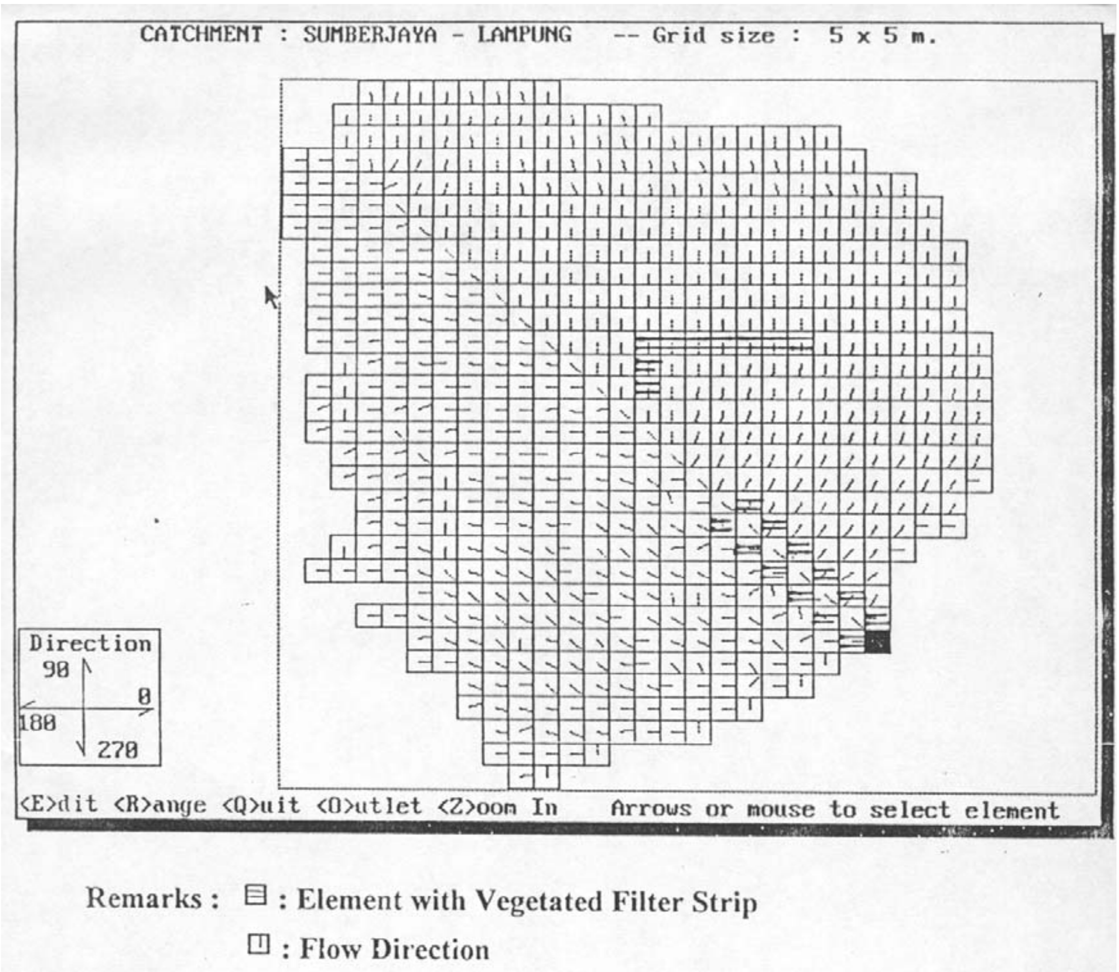
Appendix 18. Predicted and Meaured Run-Off at Outlet of Micro-Catchment for Rainfall Event of 18-02-1999



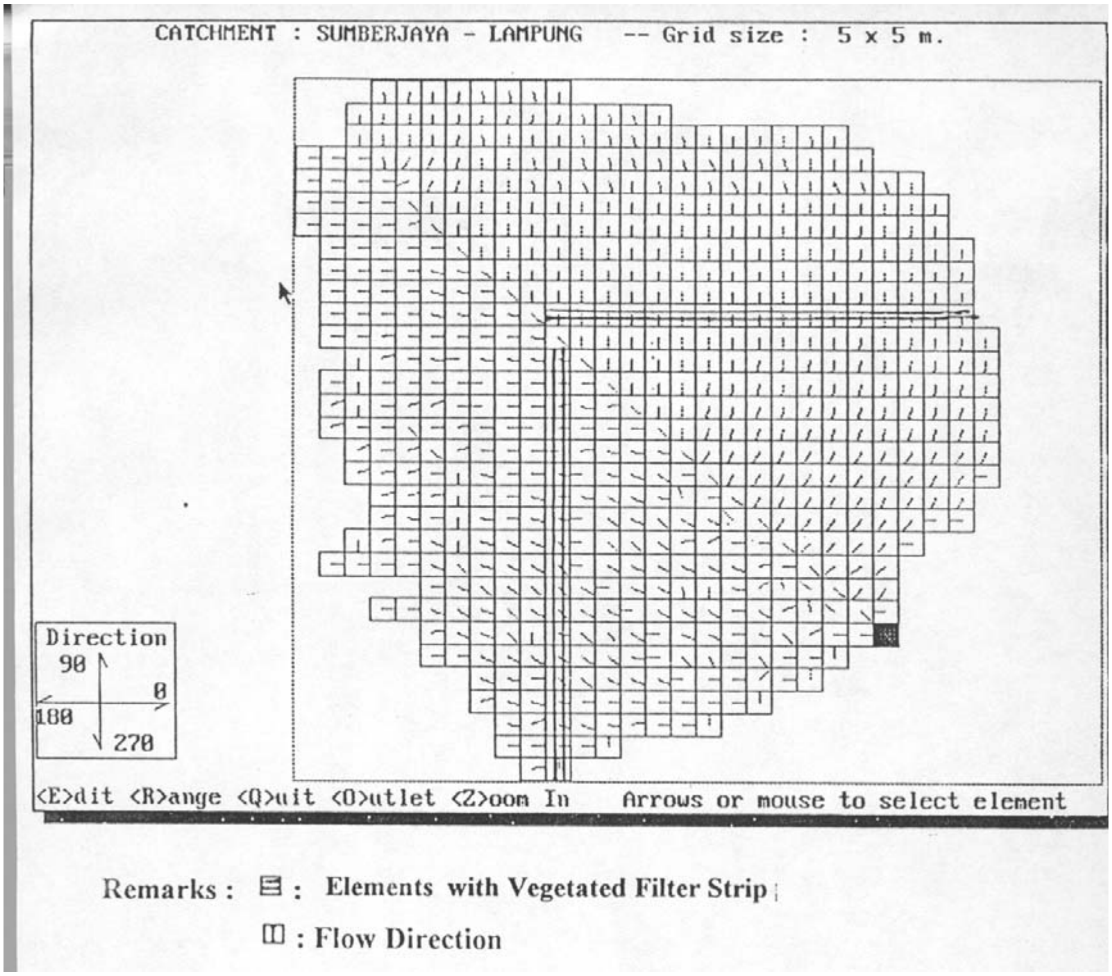
Appendix 19. Predicted and Meaured Run-Off at Outlet of Micro-Catchment for Rainfall Event of 21-02-1999



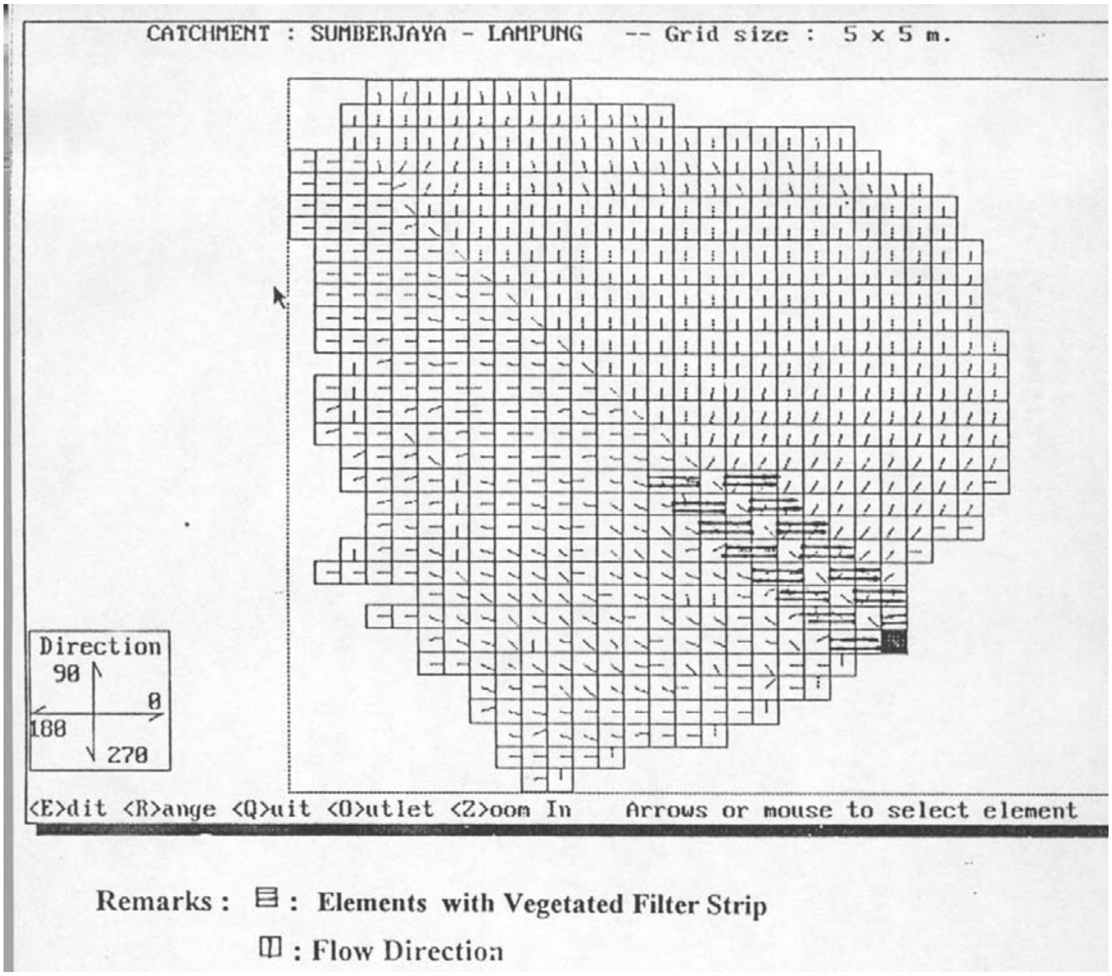
Appendix 20. Predicted and Meaured Run-Off at Outlet of Micro-Catchment for Rainfall Event of 13-05-1999



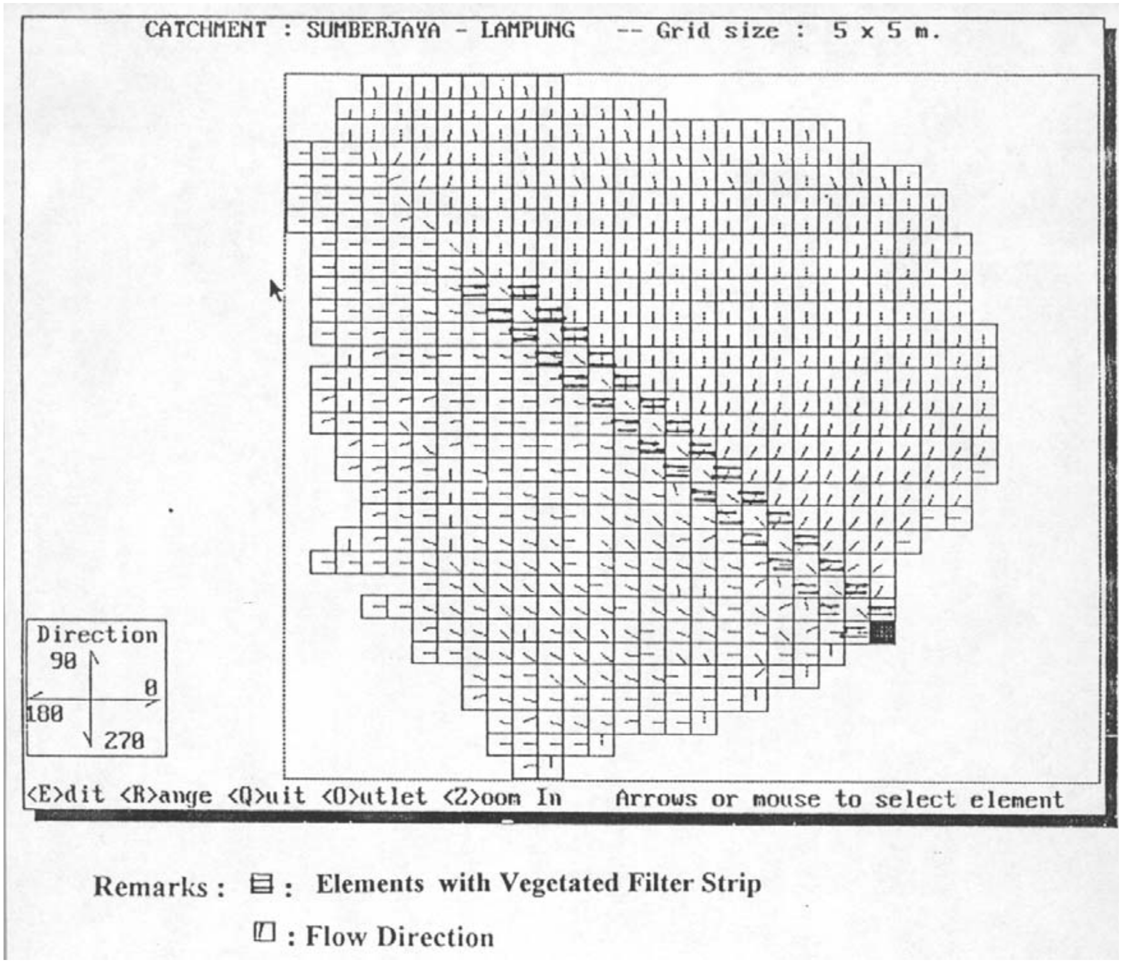
Appendix 21. Spatial Configuration of Existing Field Strip



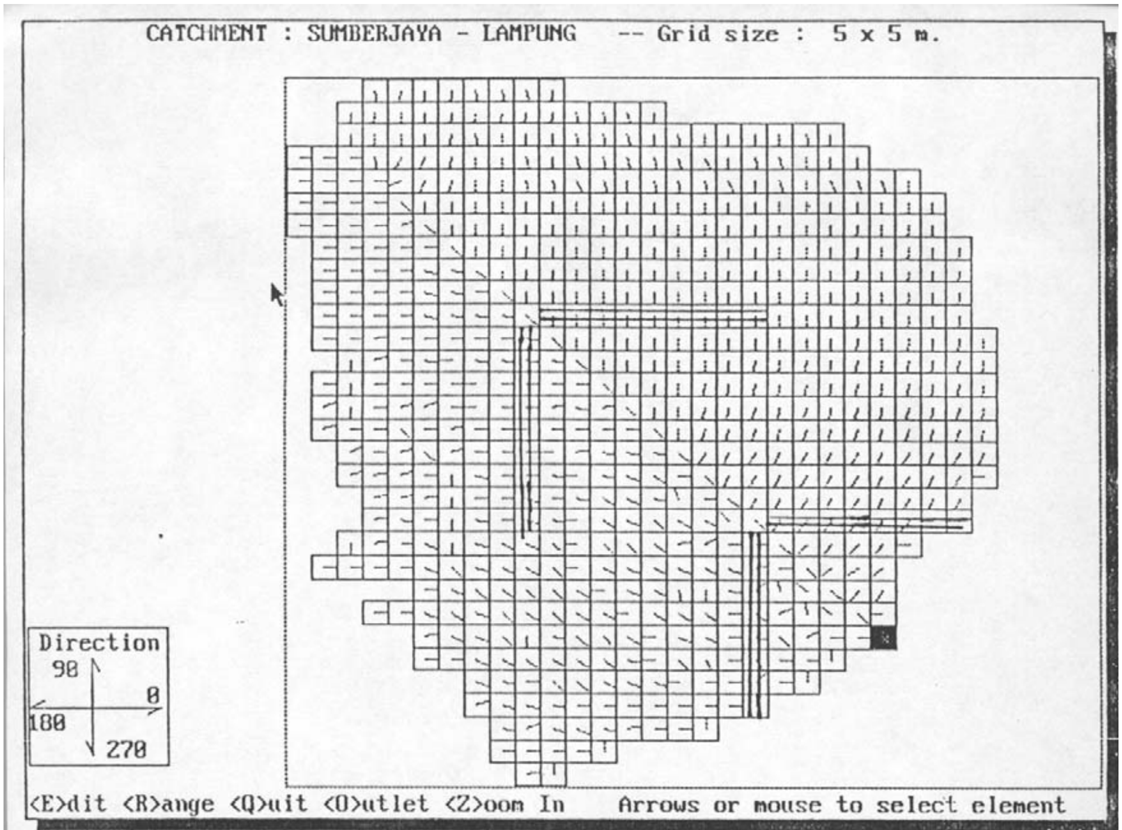
Appendix 22. Spatial Configuration of First Simulated Field Strip



Appendix 23. Spatial Configuration of Second Simulated Field Strip



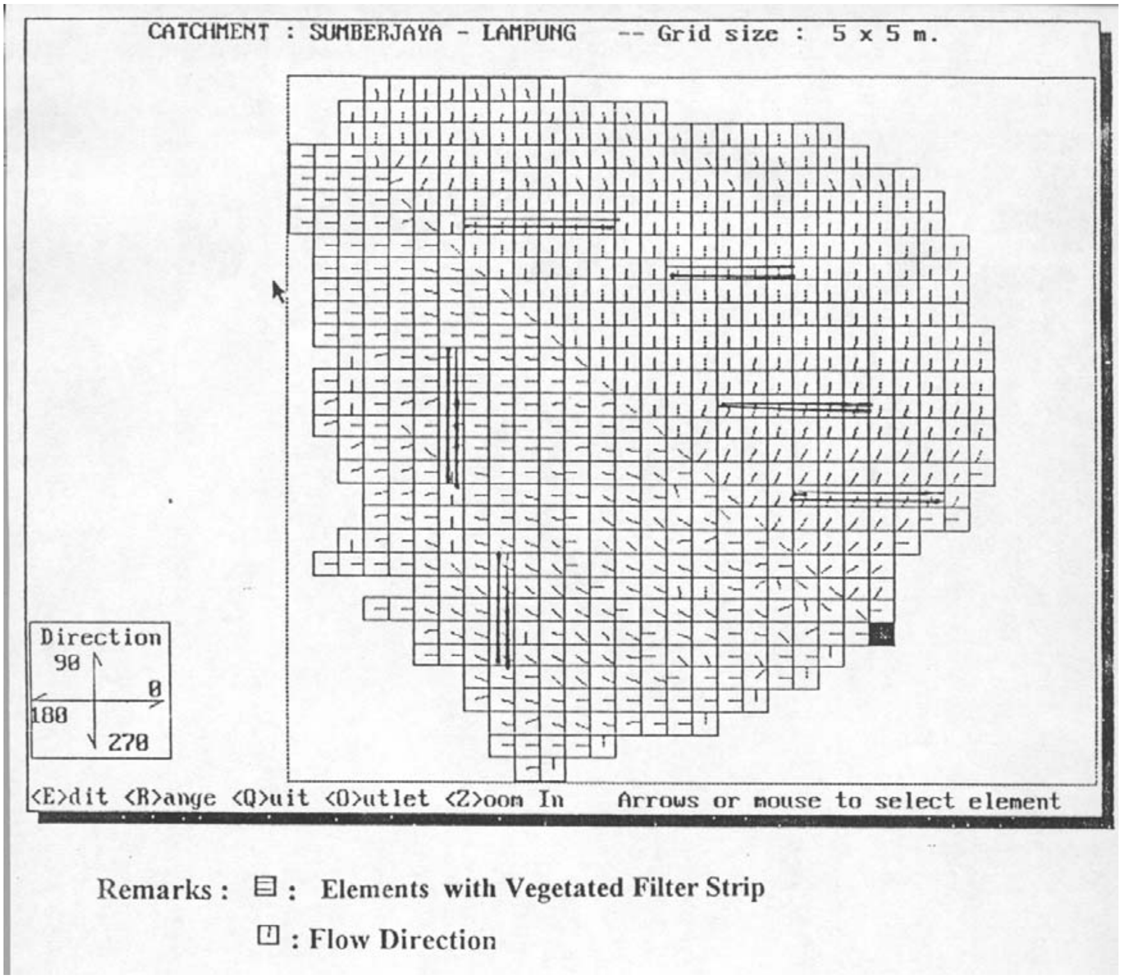
Appendix 24. Spatial Configuration of Third Simulated Field Strip



Remarks : ⊟ : **Elements with Vegetated Filter Strip**

◫ : **Flow Direction**

Appendix 25. Spatial Configuration of Fourth Simulated Field Strip



Appendix 26. Spatial Configuration of Fifth Simulated Field Strip

Appendix 27. Data of sediment yield on small ridge and Multistrata System (Erythrina with Coffee Undergrowth)

Field Land use	Sediment Traps	Depth of Sediment (cm)						
		M1	M2	M3	M4	M5	M6	Total
Small Ridge								
	1		2	1	0.4	1.6	2	
	2							
	3	5	3	0.5		1.7	0.3	
	4							
	5	3	2.5	0.5	2.3		1	
	Average	4	2.5	0.67	1.35	1.65	3.3	25.31
	Dev	1	0.41	0.24	0.95	0.05	0.70	
Multistrata system (Erythrina with coffee undergrowth)								
	1	5	3	0.5		1.7	0.3	
	2							
	3							
	4	3	2.5	0.5	2.3		1	
	5	12	4	0.5	2.6	3.4	8.5	
	Average	6.67	3.17	0.5	2.45	2.55	9.8	25.31
	Dev	3.85861	0.62360	0	0.15	0.85	3.71154	

Appendix 28. Data of sediment yield on small ridge and Horticultural crops

Field Land use	Sediment Traps	Depth of (cm)						
		M1	M2	M3	M4	M5	M6	Total
Small ridge								
	1						2.5	
	2						4.5	
	3						6.5	
	4						12.8	
	5						2	
	Average						5.66	
	Dev						3.90927	
Horticultural								
	1						4.8	
	2						14	
	3						13.3	
	4						13.5	
	5						31.5	
	Average						15.42	
	Dev						8.73553	

Appendix 29. Data of sediment yield on Hedgerow of banana, Horticultural crops and Multisytrata system (Coffee gardens with other trees overgrowth)

Field Land use	Sediment Traps	Depth of Sediment (cm)						
		M1	M2	M3	M4	M5	M6	Total
Hedgerow of banana								
	1			3.5	0	2.5		
	2						3.2	
	3						0.5	
	4			6	1.5	1	0.5	
	5			4	2	1.5		
	Average			4.5	1.17	1.67	1.4	8.74
	Dev			1.08	0.85	0.62	1.27	
Horticultural crops								
	1			28	7.5	26	36.5	
	2			14.5	13.5	72.5	6	
	3			101			96.5	
	4			100			6.2	
	5			102			58.5	
	Average			69.1	10.5	49.25	40.74	169.6
	Dev			39.31	3.00	23.25	34.18	
Coffee Gardens								
	1				0.5	0.8	0.2	
	2				2.5	2.2	5.3	
	3				1	0.5	2	
	4				0	1.3	1.2	
	5				1.5	0.5	5	
	Average				1.1	1.06	2.74	4.9
	Dev				0.86	0.64	2.05	

Appendix 30. Data of sediment yield on hedgerow of banana and mixed gardens

Land use	Sediment Traps	Depth of Sediment (cm)						
		M1	M2	M3	M4	M5	M6	Total
Hedgegrow of banana with small ridge covered by grass								
	1				1	0.8	5.7	
	2	11	4		0.5	1	2	
	3	19	6			1.5	3.5	
	4			1	0.6	1.4	3	
	5				2.5		2	
	6		4	2.5	1	Full	destroyed	
	7				2			
	8	15	2	5	9	Full	destroyed	
	Average	15	4	2.83	2.37	1.18	3.24	28.62
	Dev	3.27	1.41	1.65	2.79	0.29	1.36	
Mixed gardens (Banana with young coffee and Talas undergrowth)								
1					22.5	13.2	14.3	
2					5	3.6	17.4	
3		10	12	2	1.5	9.1		
4		100						
5					4.5	2.5	16.5	
6		11	17	19	0	10.5	14.5	
7		32	8	33	16.5	6		
8		100						
9					10.5	2.5	26	
	Average	50.6	12.33	18	8.64	6.77	17.74	114.01
	Dev	41.09	3.68	12.68	7.68	3.92	4.29	

Appendix 31. Data of sediment yield on hedgerow of banana and unweeded coffee gardens

Land use	Sediment Traps	Depth of Sediment (cm)						
		M1	M2	M3	M4	M5	M6	Total
Hedgegrow of banana with small ridge covered by grass								
							16.5	
							10	
							1	
							3.5	
							8	
	Average						7.75	7.75
	Dev						5.39073	
Unweeded Coffee gardens with sparse Gliricidia and banana								
							0.5	
							1	
							3.5	
							11	
							0	
	Average						3.2	3.20
	Dev						4.08	

Appendix 32. Data of sediment yield on dense woody shrubs and coffee gardens with small ridge along crop rows

Land use	Sediment Traps	Depth of Sediment (cm)						
		M1	M2	M3	M4	M5	M6	Total
Dense woody shrubs								
	1	7	1		0.4	1.1	1	
	2	6	1	0.5	1.8	0.7	0.5	
	3	8	0	0.5	0.8	0.7	0.5	
	4						Destroyed	
	5	5	0	1				
	Average	6.5	0.5	0.67	1	0.83	0.67	10.17
	Dev	1.12	0.5	0.24	0.59	0.19	0.35	
Coffee gardens with small ridge along crops rows								
	1	8	2		1	6	2	
	2	45	2	1				
	3		0.5	2.5	1.7		5.5	
	4		5			3	2.5	
	5	10.5	0.5	0.5	1.5	2.1	3.9	
	6		0			5.5	2.5	
	7	9	2			3		
	8	8.5	3.5		1.8	3.7	2.5	
	Average	16.2	1.99	1.33	1.5	3.88	3.15	28
	Dev	14.42	1.57	0.85	0.31	1.41	1.20	

Appendix 33. Data of sediment yield on dense woody shrubs and unweeded coffee gardens

Land use	Sediment Traps	Depth of Sediment (cm)						
		M1	M2	M3	M4	M5	M6	Total
Dense woody shrubs								
	1			2.5	0.8	0.2		
	2			1.5	0	0	4	
	3			6.5	2.5	4.5		
	4			5.5		3.5	1.5	
	5			6	2.7	0.3	4.5	
	Average			4.4	1.5	1.7	3.33	10.93
	Dev			2.01	1.14	1.91	1.31	
Unweeded coffee gardens with sparse gliricidiae and banana								
	1			28	6.5	2.5		
	2			29.5	7	4.1	2.9	
	3			7.5	1.9			
	4			4.8	1.5	3.2	27.5	
	5			20.5			5	
	Average			18.06	4.23	3.27	11.8	37.4
	Dev			10.23	2.54	0.65	11.13	

Appendix 34. Data of sediment yield on dense grass, young woody shrubs, and clean weeded coffee gardens

Land use	Sediment Traps	Depth of Sediment (cm)						
		M1	M2	M3	M4	M5	M6	Total
Dense Grass								
	1				5.5	0.5	2	
	2				4	0.5	4	
	3				2	1	4	
	4			2.7			destroyed	
	5			0.62				
	Average				3.83	0.67	2.5	7
	Dev				1.43	0.24	1.66	
Woody young shrubs								
	1		14	5	1		3	
	2		4					
	3			1	0	0.5	6.5	
	4							
	5		14		11	5	3.5	
	Average		10.67	3	4	2.75	4.33	24.78
	Dev		4.71	2	4.97	2.25	1.55	
Clean weeded coffee gardens								
	1		9		16.5			
	2		10			4	12.5	
	3		19	3		18.5	57	
	4			9.5	6	6	12.8	
	5		9	9	4.5	4	34.5	
	Average		11.75	7.17	9	8.13	29.2	65.3
	Dev		4.21	2.95	5.34	6.05	18.36	

Appendix 35. Data of sediment yield on terraced land and clean weeded coffee gardens

Land use	Sediment Traps	Depth of Sediment (cm)						
		M1	M2	M3	M4	M5	M6	Total
Terraced land with woody young shrub								
	1		3	0	1	0		
	2		1				1.5	
	3		1	1	0	0.3	1.7	
	4		2			0	1	
	5		9	0	1.6		1.5	
	6		0					
	7		1				2	
	8		6		2	0.5	1	
	Average		2.88	0.33	1.15	0.2	1.45	6.01
	Dev		2.89	0.47	0.75	0.21	0.36	
Clean weeded coffee gardens								
	1		4	0	34.7	1.3	4	
	2			0	3.5	1		
	3			1	2.5			
	4			0	2.5	1.5		
	5		5	97				
	6		8.5	95.5			3	
	7		5	0				
	8		5	0			11	
	Average		5.5	24.2	10.8	1.27	6	37.77
	Dev		1.55	41.61	13.85	0.21	3.56	

Appendix 36. Data of sediment yield on woody shrubs and weeded coffee gardens

Land use	Sediment Traps	Depth of Sediment (cm)						
		M1	M2	M3	M4	M5	M6	Total
Woody shrubs with imperata grass undergrowth								
	1		3	0.5	1	0	0.5	
	2		3	0.5	0.5	0.5	0.5	
	3		5		0.5		0.5	
	4		3		0.5	0.3	4.2	
	5		3	0.5	3.3	0.2	0.5	
	Average		3.4	0.5	1.16	0.25	1.24	6.55
	Dev		0.8	0	1.09	0.18	1.48	
Unweeded Coffee gardens with sparse Gliricidia and banana								
	1		4.5	5	8.3	1.7	22	
	2		5	1.5	29.3			
	3		9	4		2.5	1.5	
	4		8		5	1.5	6.5	
	5		5		0		20	
	Average		6.3	3.5	10.65	1.9	12.5	34.9
	Dev		1.83	1.47	11.17	0.43	8.71	

Appendix 37. Data of sediment yield on Hedgerow of Pisangan and Clean weeded coffee gardens

Land use	Sediment Traps	Depth of Sediment (cm)						
		M1	M2	M3	M4	M5	M6	Total
Hedgegrow of Pisangan								
							1	
							0.5	
							6.5	
							4	
							5.5	
	Average						3.5	3.5
	Dev						2.39	
Clean Weeded Coffee Gardens								
							3	
							51	
							2	
							23.5	
							5.5	
	Average						19.88	19.88
	Dev						18.72	

Appendix 38. Data of sediment yield on Calliandra with coffee undergrowth
(at Kampong Dwikora)

Land use	Sediment Traps	Depth of Sediment (cm)						
		M1	M2	M3	M4	M5	M6	Total
Caliandra with								
	1				2.5	0	1	
	2				0	0	1.6	
	3				2	0.5	0	
	4				1	0	2.5	
	5				0.5	1	1.5	
	Average				1.2	0.3	1.32	2.82
	Dev				0.93	0.4	0.82	
Calliandra with Pinus overgrowth								
	1				3.5	0	1	
	2				2.5	0	1.5	
	3				2	4.5	3.5	
	4				1.5	0	1.5	
	5				1.2	1.5	0.5	
	Average				2.14	1.2	1.6	4.94
	Dev				0.81	1.75	1.02	

Appendix 39. Data of sediment yield on Calliandra with coffee undergrowth (at Kampong Tebo)

Land use	Sediment Traps	Depth of Sediment (cm)						
		M1	M2	M3	M4	M5	M6	Total
Calliandra with coffee undergrowth								
	1	3.5	0.5		0	0		
	2	3.5	0.5		1.5	0	0.5	
	3	1.5	4.5		0	0	1.5	
	4	8	1		2	0.5	5	
	5	6.5						
	6		1.5		0	0		
	7		1.5		0.6	5.4		
	8				0.5	0	2	
	9				0.5	0	0.5	
	Average	4.6	1.58	0	0.64	0.74	1.9	9.46
	Dev	2.33	1.37		0.69	1.77	1.67	

Appendix 40. Data of sediment yield on Clean weeded coffee gardens

Land use	Sediment Traps	Depth of Sediment (cm)						
		M1	M2	M3	M4	M5	M6	Total
Clean weeded Coffee Gardens								
	1	40	6	2	0	3	41.5	
	2	100				2		
	3	16	3	0	3	2.5	11.5	
	4	8	7	17	11.5	4	9	
	5	69.5						
	Average	46.7	5.33	6.33	4.83	3.83	20.67	87.72
	Dev	34.19	1.70	7.60	4.87	0.74	14.77	

Appendix 41. Data of sediment yield on Natural Forest

Land use	Sediment Traps	Depth of Sediment (cm)						
		M1	M2	M3	M4	M5	M6	Total
Natural Forest								
	1	3	1.5	0	3	0	1.7	
	2	0	0.5	0	0	0	0.5	
	4	1	0	0	0	0	0.5	
	5	0	3.5	0	0	0	1	
	Average	1	1.4	0	0.75	0	0.93	4.13
	Dev	1.22	1.34	0	1.30	0	0.49	

Appendix 42. Data of sediment yield on Cleared land with falling trees
(The former natural forest)

Land use	Sediment Traps	Depth of Sediment (cm)						
		M1	M2	M3	M4	M5	M6	Total
Cleared land								
1		-	2	0	0.5	0	0.5	
2		-	0	0	0.5	0	0.5	
3		-	0	0	1	3.2	2	
4		-	2	2	0	0	0.5	
5		-	4	2	0	0.3	1.2	
	Average	-	1.6	0.8	0.4	0.7	0.94	4.44
	Dev	-	1.50	0.98	0.37	1.26	0.60	

Appendix 43. Data of sediment yield on Multistrata System (Erythrina with dense Coffee Undergrowth)

Field Land use	Sediment Traps	Depth of Sediment (cm)						
		M1	M2	M3	M4	M5	M6	Total
Multistrata system (Erythrina with coffee undergrowth)								
	1				2.5	0.5	0.5	
	2	7.5	0.5	1	4.1		1	
	3	8	2	1	0.4	0.5	1.5	
	4	7	1	2	0.6	1.7	2.2	
	5				1	0.5	1	
	Average	7.5	1.17	1.33	1.72	0.8	6.2	18.72
	Dev	0.41	0.62	0.47	1.40	0.52	0.57	

Appendix 44. Data of sediment yield on Tegalan with Horticultural crops

Field Land use	Sediment Traps	Depth of Sediment (cm)						
		M1	M2	M3	M4	M5	M6	Total
Tegalan with Horticultural Crops (clean weeded)								
	1	100.0						
	2	100.0						
	3	64.0	25					
	4	88.5	11.5					
	5	100.0	0					
	Average	90.5	12.2					102.7
	Dev	14.0	10.2					

Appendix 45. Water run-off and soil erosion from some representative land use types

No.	Land Use Type	Water run-off (Liter/plot)						Soil Erosion (gram/plot)					
		1	2	3	4	5	Total	1	2	3	4	5	Total
1	Natural Forest	6.40	5.10	3.65	4.20	2.90	22.25	7.54	7.57	1.85	2.89	4.38	24.23
2	Calliandra	4.80	2.45	1.45	3.35	5.74	17.79	7.73	3.51	2.58	5.63	5.80	25.25
3	Multistrata System	6.30	4.10	3.20	6.50	3.20	23.30	12.46	25.40	16.76	16.19	5.10	70.91
4	Clean weeded coffee gardens	41.60	1.70 ?	2.90	41.20	1.70 ?	89.10	98.68	38.62	12.43	145.69	12.25	307.67
5	Unweeded coffee gardens	8.80	2.20	4.00	4.80	3.90	23.70	9.92	0.92	4.91	8.51	7.90	32.16
6	Unweeded coffee gardens	12.35	9.30	5.55	6.05	2.75	36.00	41.51	11.83	8.40	6.60	6.03	74.94

Note: Area of the plot: 3 x 1 m
1 = sediment collected from 4 - 26 December 1999
2 = sediment collected from 26 - 30 December 1999
3 = sediment collected from 30 December - 3 January 2000
4 = sediment collected from 3 - 13 January 2000
5 = sediment collected from 13 - 24 December 2000

Appendix 46. Soil Profile Description in Micro-Catchment

Field code: B2 **Vegetation:** Coffee **Slope:** 30%		**Field code:** B4 **Vegetation:** Coffee, Maize **Slope:** 13%	
Horizon Depth (cm)	Profile Characteristics	Horizon Depth (cm)	Profile Characteristics
0 – 10	10 YR 4/4, clay, friable	0 - 6	10 YR ¾, loam rather sticky, friable
10 - 45	10 YR 4/6, clay, sticky	6 - 33	10 YR 6/8, clay, mottle : 10 YR 4/8, sticky
45 - 70	10 YR 6/8, clay, sticky mottle: 10 YR 6/4	33 - 70	YR 6/8, clay. mottle: 10 YR 4/8, sticky
70 - 97	7.5 YR 6/8, clay, sticky, coarse particle(white)	70 - 97	5 YR 5/8, clay, mottle10 YR 7/3, sticky
97 -110	7.5 YR 6/8, clay, sticky, gravel plintit 2.5 YR 5/8	97 - 120	10 YR 4/8, heavy clay, very sticky

Field code: C1 **Vegetation:** Coffee **Slope:** 27%		**Field code:** A2 **Vegetaion:** Coffee, Banana (sparse) **Slope:** 18%	
Horizon Depth (cm)	Characteristics	Horizon Depth (cm)	Characteristics
0 - 14	10 YR ¾, clay, friable	0 - 5	10 YR 3/3, clay , sticky
14 - 42	10 YR 3/8, clay, sticky	5 - 23	10 YR 6/8, clay,, sticky
42 - 70	10 YR 6/8, clay, sticky	23 - 67	10 YR 6/8, clay, white mottle/ coarse particle
70 - 115	10 YR 6/8, clay, mottle10 YR 4/8	67 - 95	7.5 YR 5/8, clay, sticky
115 - 120	10 YR 6/8, clay, mottle10 YR 4/8	95 - 105	5 YR 5/8, clay, sticky
		105 - 120	5 YR 5/8, clay, 10 YR mottle

Field code: C4 **Vegetation:** Coffee **Slope:** 4%		**Field code:** C5 **Vegetation:** Coffee **Slope:** 15%	
Horizon Depth (cm)	Characteristics	Horizon Depth (cm)	Characteristics
0 - 20	10 YR 3/3, clay loam, friable	0 - 11	10 YR 3/3, clay loam, friable
20 - 45	10 YR 5/6, clay, sticky	11 - 35	10 YR 5/6, clay, sticky
45 - 73	10 YR 6/8, clay, sticky	35 - 72	10 YR 6/8, clay, sticky
73 - 120	10 YR 6/8, clay, sticky	72 - 95	10 YR 6/8, clay, sticky
		95 - 115	7.5 YR 6/8, clay, sticky

Appendix 46 (cont'd)

Field code: D5 **Vegetation: Coffee** **Slope: 22%**		**Field code: D3** **Vegetation: Coffee** **Slope: 37%**	
Horizon Depth (cm)	Characteristics	Horizon Depth (cm)	Characteristics
0 - 11	10 YR 3/3, clay loam, friable	0 - 5	10 YR 3/3, clay, sticky
11 - 32	10 YR 5/6. clay, sticky	5 - 34	10 YR 5/8, clay, sticky
32 - 47	10 YR 5/8, clay loam, sticky	34 - 72	10 YR 6/8, clay, sticky
47 - 105	10 yR 6/8, clay, sticky	72 - 110	10 YR 6/8, clay; 2.5 Y 6/6, mottle
105 -120	7,5 YR 5/8 clay, sticky,	110-120	10 YR 6/8, clay; 2.5 Y 6/6, mottle
Field code: D6 **Vegetation: Coffee** **Slope: 29%**		**Field code: D7** **Vegetation: Coffee** **Slope: 19%**	
Horizon Depth (cm)	Characteristics	Horizon Depth (cm)	Characteristics
0 - 14	10 YR 3/3, clay, friable	0 - 7	10 YR 3/3, clay, friable
14 - 42	10 YR 5/8, clay, sticky	7 - 35	7.5 YR 5/8, clay, sticky
42 - 75	7.5 YR 5/8, clay, sticky	35 - 67	7.5 YR 5/8, very sticky
75 - 115	7.5 YR 5/8, clay, sticky	67 - 95	7.5 YR 6/8, clay , very sticky
		95 - 115	7.5 YR 6/8, clay
Field code: D8 **Vegetation: Coffee** **Slope: 26%**		**Field code: D9** **Vegetation: Coffee** **Slope: 20%**	
Horizon Depth (cm)	Characteristics	Horizon Depth (cm)	Characteristics
0 - 9	10 YR 3/3, clay, friable	0 - 11	10 YR 3/3, clay, friable
9 - 34	10 YR 5/8 - 6/8, clay, sticky	11 - 43	10 YR 6/8, clay, sticky
34 - 72	10 YR 6/8, clay, sticky	43 - 70	10 YR 5/8, clay, sticky
72 - 110	10 YR 6/8, clay, sticky	70 - 115	10 YR 5/8, clay, sticky

Appendix 47. Soil Physical Characteritics of Micro-Catchment

No.	Field Code	Layer	Bulk Density (g/cc)	Porosity (% Vol.)	Field Capacity (% Vol.)
1	1	I	1.03	61.13	40.52
2	2	I	0.93	64.91	46.23
3	3	I	1.10	58.49	51.13
4	4	I	1.06	60.00	42.73
5	5	I	1.07	59.62	45.82
6	6	I	0.99	62.64	44.47
7	7	I	1.13	57.36	52.94
8	8	I	0.89	66.42	41.91
9	9	I	0.92	65.28	44.68
10	10	I	0.93	64.91	40.04
11	11	I	0.94	64.53	43.85
12	12	I	0.99	62.64	37.97
13	13	I	0.93	54.91	46.39
14	14	I	0.85	67.92	41.00
15	15	I	1.02	61.51	47.65
16	16	I	1.02	61.51	46.12
27	17	I	1.11	58.11	45.75
18	18	I	1.01	61.89	47.26
19	19	I	1.12	57.74	47.03
No.	**Filed Code**	**Layer**	**Bulk Density (g/cc)**	**Porosity (% Vol.)**	**Field Capacity (% Vol)**
1	R 1	II	0.86	67.18	50.48
2	2	II	0.91	65.66	51.94
3	3	II	1.12	57.74	50.49
4	4	II	1.09	58.87	54.77
5	5	II	1.00	62.26	52.20
6	6	II	1.02	61.51	53.89
7	7	II	1.02	6151	52.90
8	8	II	0.78	70.00	50.52
9	9	II	0.85	67.56	54.02
10	10	II	0.94	64.53	51.85
11	11	II	0.97	63.40	52.88
12	12	II	1.06	60.00	54.26
13	13	II	0.93	64.91	50.34
14	14	II	0.95	64.15	51.27
15	15	II	1.00	62.26	58.78
16	16	II	1.04	60.75	53.13
17	17	II	1.05	60.38	40.16
18	18	II	1.00	64.91	53.48
19	19	II	0.93	64.91	53.48

Remark : Layer I = 0-20 cm; Layer II = 20-40 c

Appendix 48. Hydraulic Conductivity Data of Micro-Catchment as a Basis for Determining Infiltration Descriptions of ANSWER Models

Soil Group	**Hydraulic Conducivity (cm/H)**
I	0.2
I	0.2
I	0.3
I	0.7
I	1.5
I	1.6
I	1.8
I	3.1
I	4.9
I	4.9
I	6.2
I	7.5
I	13.8
I	24
IV	0.2
IV	0.58
IV	0.61
IV	0.73
IV	1.37
IV	1.96
IV	2.08
IV	2.2
IV	2.71
IV	3.58
IV	3.84

Soil Group	**Hydraulic Conducivity (cm/H)**
II	0.1
II	0.1
II	0.2
II	0.5
II	0.5
II	0.7
II	0.7
II	0.8
II	1.1
II	1.4
II	1.5
II	1.6
II	3.6
II	4.2
II	4.6
II	6.1
II	6.5
II	8.3
II	10.3
II	10.8
III	0.2
III	0.4
III	0.4
III	1
III	2.1
III	2.4
III	2.8
III	5
III	28.4

Appendix 49. Excerpt of Subroutine Struct in ANSWERS Model

```
SUBROUTINE STRUCT
C
C ****** SUBROUTINE TO ADJUST PARAMETERS TO REFLECT STRUCTURAL
PRACTICES
C ****** INSTALLED WITHIN AN ELEMENT.
C
      DIMENSION IEL(3,JMAX,NPAR2), NSTRUC(ISTRUC), WID(10), CN(10)
      DIMENSION IELC(3,JMAX,2)
      INTEGER CHAN,PRACT
      LOGICAL STRUC
      CHARACTER*2 IELC
C
C **** SWITCH TO APPROPRIATE HANDLER FOR EACH STRUCTURAL TYPE.
C
      PRACT=IEL(2,J,9)
      IF (PRACT.GT.ISTRUC.OR.PRACT.LT.0) GO TO 90
      STRUC=.TRUE.
      NSTRUC(PRACT)=NSTRUC(PRACT)+1
      GO TO (10,60,70,80), PRACT
C
C **** HANDLE PONDS AND TILE-OUTLET TERRACES BY USING A TRAP EFFICIENCY
C **** APPROACH, FOR BOTH SEDIMENT AND WATER.
C
C **** CASE 1 IS FOR A PTO.
C
   10 TRAP=.90
C
C **** CHECK FOR A POSSIBLE SHADOW CHANNEL ELEMENT.
C
   20 IF (CHAN.EQ.0) GO TO 40
C
C **** IT'S A CHANNEL ELEMENT, DOES IT REQUIRE DIAGONAL FLOW?
C
      IF (ANG.LT..3926991.OR.ANG.GT.1.178097) GO TO 40
C
C **** FLOW IS DIAGONAL, CHANGE DESTINATION ELEMENT NUMBERS.
C
      IF (NR.LT.I) GO TO 30
      NR=NC+1
      NC=NC+1
      GO TO 40
   30 NR=NC-1
      NC=NC-1
C
C **** THE PREDOMINANT OVERLAND DIRECTION IS MAINTAINED AND THAT
C **** ELEMENT WILL RECEIVE THE UNTRAPPED FLOW AND SEDIMENT.
C
   40 IF (RFL.GT..5) GO TO 50
RFL=TRAP
```

```
      NR=NMAX+1+PRACT
      RETURN
   50 RFL=1.-TRAP
      NC=NMAX+1+PRACT
      RETURN
C
C **** PONDS ARE SIMILAR TO PTO'S, BUT HAVE A HIGHER TRAP EFFICIENCY.
C
   60 TRAP=.95
      GO TO 20
C
C **** GRASSED WATERWAYS DIRECTLY AFFECT ONLY THE VEGETAGED AREA OF
C **** THE ELEMENT IN WHICH THEY ARE LOCATED, BUT THEY MUST ALSO ASSURE
C **** THAT THIS ELEMENT HAS A SHADOW CHANNEL ELEMENT.
C
   70 IF (CHAN.NE.0) GO TO 80
C
C **** CURRENT ELEMENT DOES NOT HAVE A SHADOW CHANNEL ELEMENT, MAKE
ONE.
C
      CHAN=IEL(2,J,11)
      IF (CHAN.EQ.0) CHAN=1
      II=II+1
      CWID=WID(CHAN)
      PIV=CONST/CN(CHAN)/X*(DX/CWID/X)**.6667*SQRT(SSI)
      SSII=SSI
      IF (SSI.LT.SCMIN) SCMIN=SSI
      IF (SSI.GT.SCMAX) SCMAX=SSI
      SCBAR=SCBAR+SSI
C
C **** NOW ACCOUNT FOR VEGETATED AREA BY REDUCING THE SEDIMENT
C **** DETACHMENT BY FLOW FOR THIS ELEMENT BY AN AMOUNT PROPORTIONAL
C **** TO THE VEGETATED AREA.  SINCE FLOW DETACHMENT IS DIRECTLY
C **** PROPORTIONAL TO THE OVERLAND SLOPE, ADJUST THAT PARAMETER.
C
C **** FIELD BORDERS HAVE A SIMILAR EFFECT TO THE VEGETATED AREA
C **** OF GRASSED WATERWAYS.
C
   80 TRAP=FLOAT(IEL(2,J,10))/DX
      IF (TRAP.GT..5) TRAP=.5
      SL=SL*(1.-TRAP)
      RETURN
C
C **** CHECK TO SEE IF IT'S A MANAGEMENT PRACTICE BEFORE SPOUTING OFF.
C
   90 IF (PRACT.GT.10.AND.PRACT.LT.13) RETURN
      WRITE (6,100) IEL(2,J,9),IEL(2,J,1),J
      RETURN
C
  100 FORMAT (14H  PRACTICE NO.,I3,7H IN ROW,I4,5H, COL,I4,20H ILLEGAL A
     1ND IGNORED)
      END
```

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