Soil Erosion Management at the Watershed Level for Sustainable Agriculture and Forestry in Vietnam

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Introduction

Watershed management is an important concern in Vietnam not only to protect the existing forest, but also to conserve agricultural lands for sustainable agriculture and biological diversity. It is the best way to minimize land surface runoff and soil loss and prevent frequent and intense flash floods. For the last three years, the Management of Soil Erosion Consortium (MSEC) has supported catchment research and capacity building in Vietnam to better understand and manage land and water resources for sustainable agriculture and improved income of farmers.

The Dong Cao Catchment in Tien Xuan commune, Luong Son district, Hoa Binh Province, 50 km from Hanoi, inside the Red River Basin, is the site of the MSEC project in Vietnam (Figure 1). The catchment of about 45 has a mean slope of 45% and the steepest slopes are around 120%. The steepest slopes are situated in the middle part of the basin and are largely cultivated by farmers from Dong Cao village to crop cassava and fodder in association with some trees (*Venitia montana*, *Acacia mangium*); there is also some husbandry of cows. The farmers (around 40 farm households of 200 inhabitants) share their work time between the lowlands to crop irrigated rice and also to use the uplands to increase their revenue.

The catchment was instrumented for soil erosion and hydrological monitoring to evaluate the interactions between rainfall, runoff, groundwater, topography, soil quality, land cover, and climate (Figure 2). These data are necessary to assess and predict the impact of land use and land management on soil losses, soil fertility, and solute transport in and through the watershed.

The results of three years of research and monitoring showed a high inter-annual variability of soil loss (from 1 to 15 t ha^{-1} $year^{-1}$). Moreover, this variation depends on both the amount and intensity of rainfall and the kind of land use. The project has proved to be very useful for farmers, not only in terms of understanding soil erosion and nutrient loss, which cause land degradation and reduce productivity, but also in terms of farmers' enhanced capacity and improved information dissemination strategies.

To further understand the hydrological processes and land use changes in the catchment and their interactions, the project continued to monitor rainfall, runoff, erosion, land use and other parameters in 2003. This report highlights the activities conducted during the year and the results obtained from them.

Materials and Methods

Five gauging stations, three (W1, W2, W3) built on three streams before their intersection with the main stream, one (MW1) on the main stream at the outlet of the catchment, and another one (W4), on the upper part inside the catchment above W3,

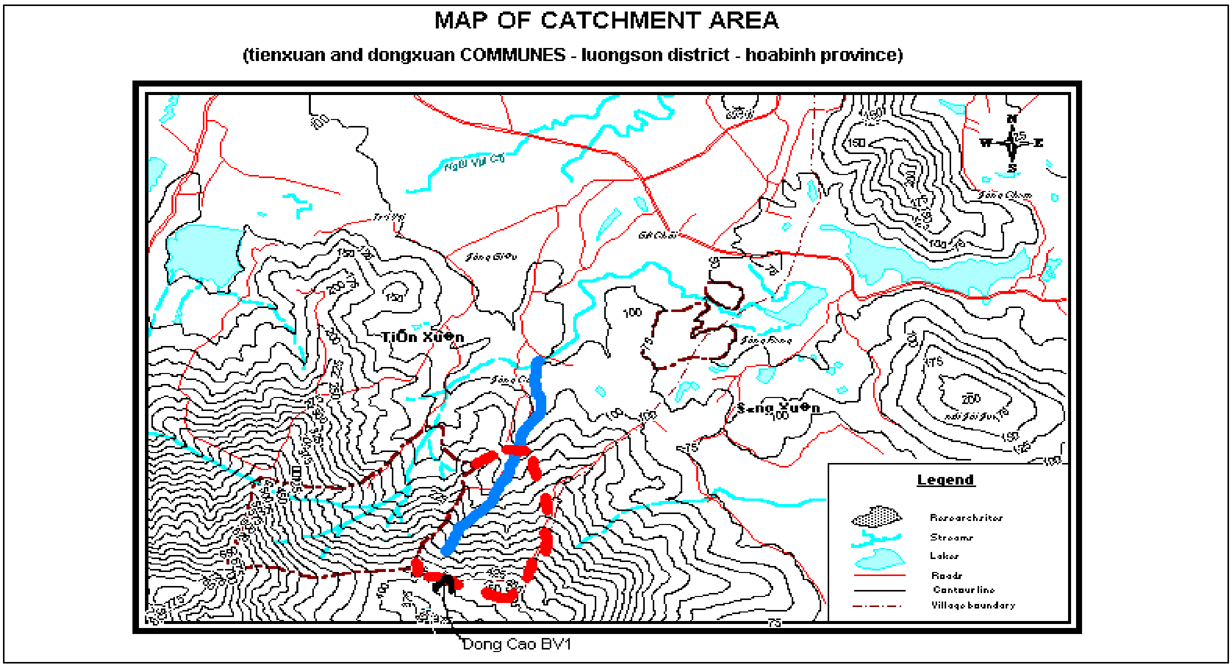

Figure 1. Map of catchment area (Source: MSEC program, IWMI, 2002)

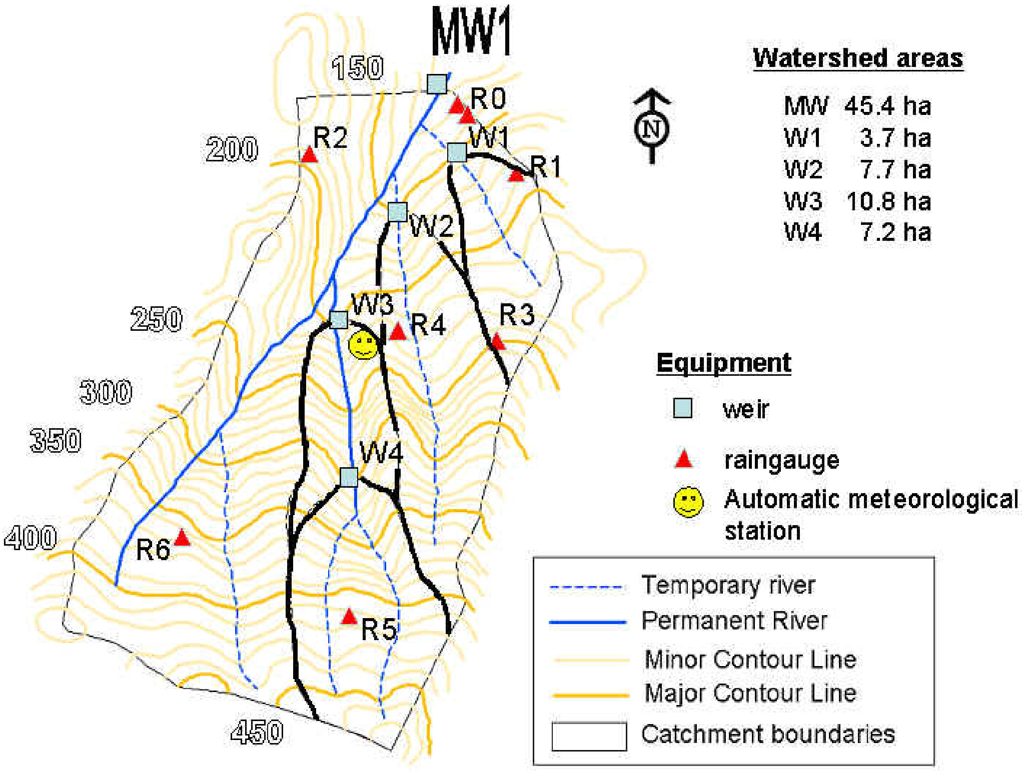

Figure 2. Location of equipment in the Dong Cao catchment.

were used to measure runoff and discharge during rainfall events. The water level in each weir was recorded automatically using Thalimedes type automatic water level recorders. Bed load sediments from each weir trap were entirely weighed after every flood. Some water samples from the weirs were taken for water chemistry and isotopic analyses. In 2002, three automatic suspended sediment samplers (ASS) were installed at the main weir, weir 2 and weir 4. Because of the problems with the ASS, it was impossible to collect the water samples from all weirs. As such, data for suspended load were collected from the main weir during the big storm events (end of July) only. Rainfall was measured by an automatic weather station and seven manual rain gauges distributed within the whole catchment. The use of manual rain gauges and automatic weather station reduces errors in measurement. Groundwater level monitoring, more detailed soil characterization and land use change evaluation were also done during the year.

Results and Discussion

Hydrological Characteristics

Rainfall

The rainy season started at the beginning of April and ended in late October. April was relatively wet in 2003 than in the same month in 2002 (Figure 3). The months of May and June were similar in both years, but July was especially humid (575 mm against 300 mm in an average year). It should be noted that in July, two typhoons passed by north Vietnam between 21 and 25 July, bringing rains amounting to 420 mm. During this big storm event (typhoon Koni), the water level rose to over 1 meter (Figures 4 and 5), and the stream discharge carried more than 20 g/l of suspended matter measured at 0700 on July 23.

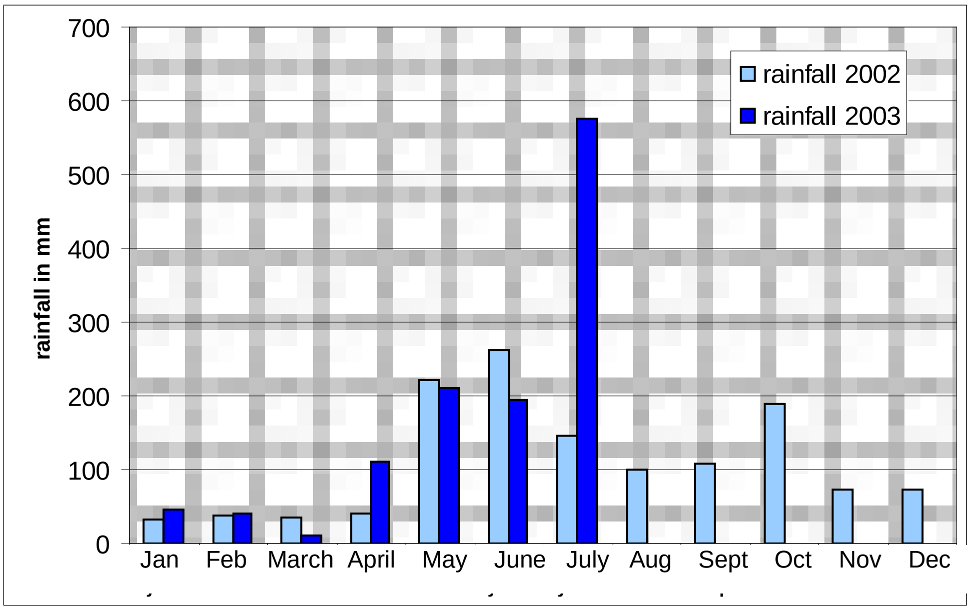

Figure 3. Monthly rainfall (in mm) in the Dong Cao catchment from January 2002 to July 2003.

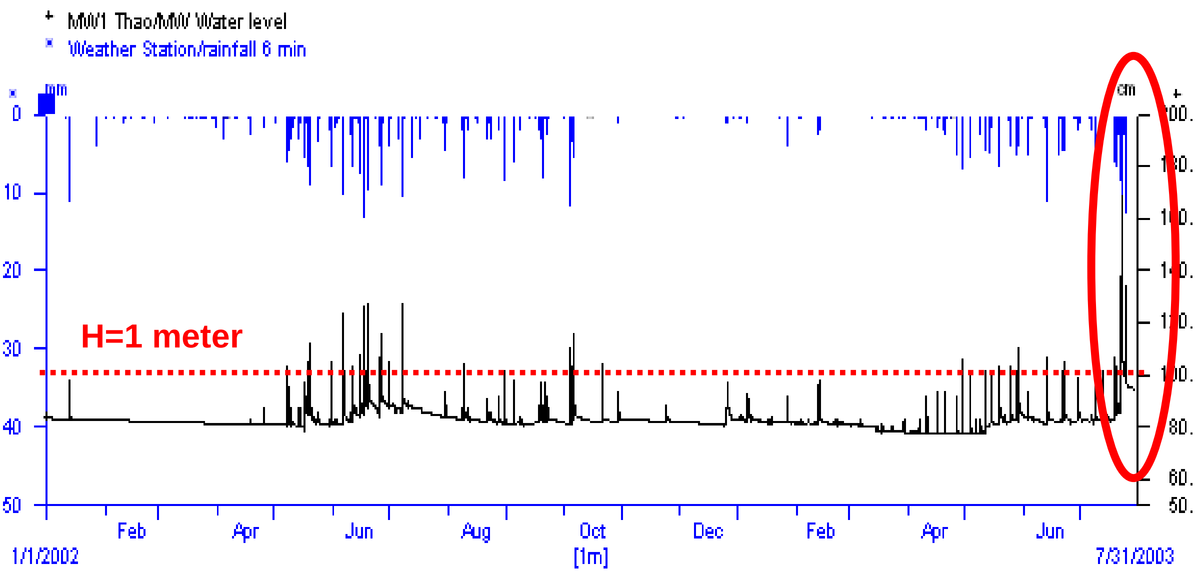

Figure 4. Water level at the main weir showing the increase during the time of the storm in July 2003.

Figure 5. Exceptional storm event (typhoon Koni) from 21 to 25 July 2003

There were fewer rainfall events in 2003 than in 2002, two times less in the month May. There were more events in the month of April although there were only small rains (Table 1. It was also observed that there were more rains falling at night (between 6 PM and 6 AM) (Figure 6). Of the 15 rainfall events that occurred during April to June, 11 events occurred at night or during weekends. These conditions made field measurement of runoff difficult.

Table 1. Rainfall monthly distribution, rainy season 2002 and 2003.

Rainfall (mm)	April 2002	April 2003	May 2002	May 2003	June 2002	June 2003	July 2002	July 2003
0-10	6	14	5	2	8	5	10	3
10-20	2	0	7	1	2	1	3	1
20-30	0	1	2	1	2	1	1	1
30-40	0	0	0	2	3	0	0	3
40-50	0	0	1	2	0	3	1	0
50-60	0	0	0	0	1	0	0	1
60-70	0	1	0	0	0	0	0	1
>100	0	0	0	0	0	0	0	2
Total monthly amount (mm)	**40,5**	**110**	**221**	**212**	**262,5**	**194,4**	**147**	**575**
No. of events	**8**	**16**	**15**	**8**	**16**	**10**	**15**	**12**

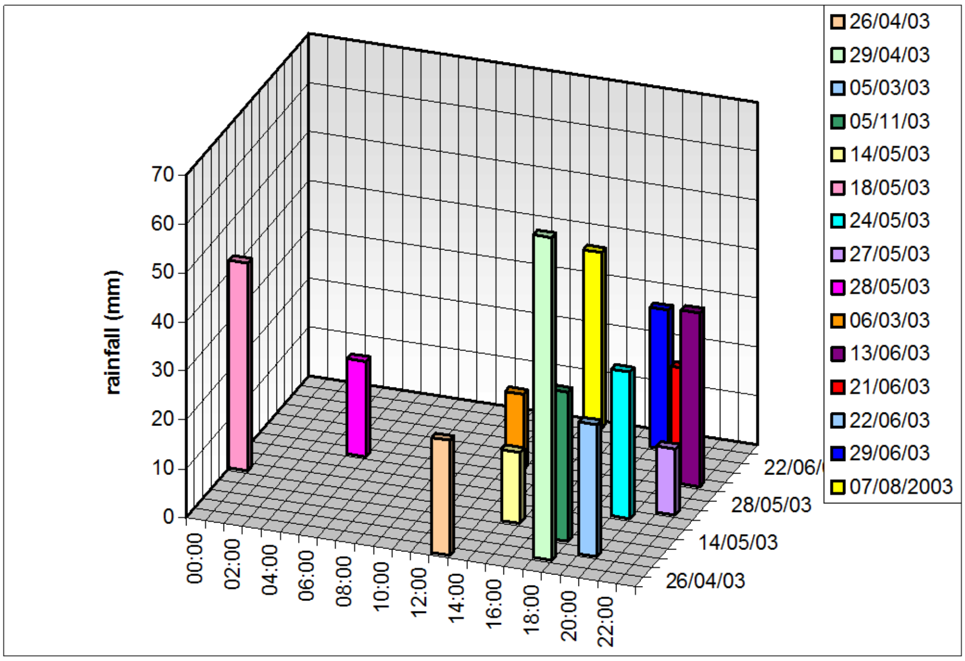

Figure 6. Daily rainfall distribution over Dong Cao catchment, April to June 2003

Runoff

Before any analysis, database cleaning is necessary to have more accurate data. The estimated discharge using the corrected data for 2002 and 2003 (until end of July) is shown in Figure 7. It was observed that there were fewer big floods (> 100 cm) in 2003 than in 2002.

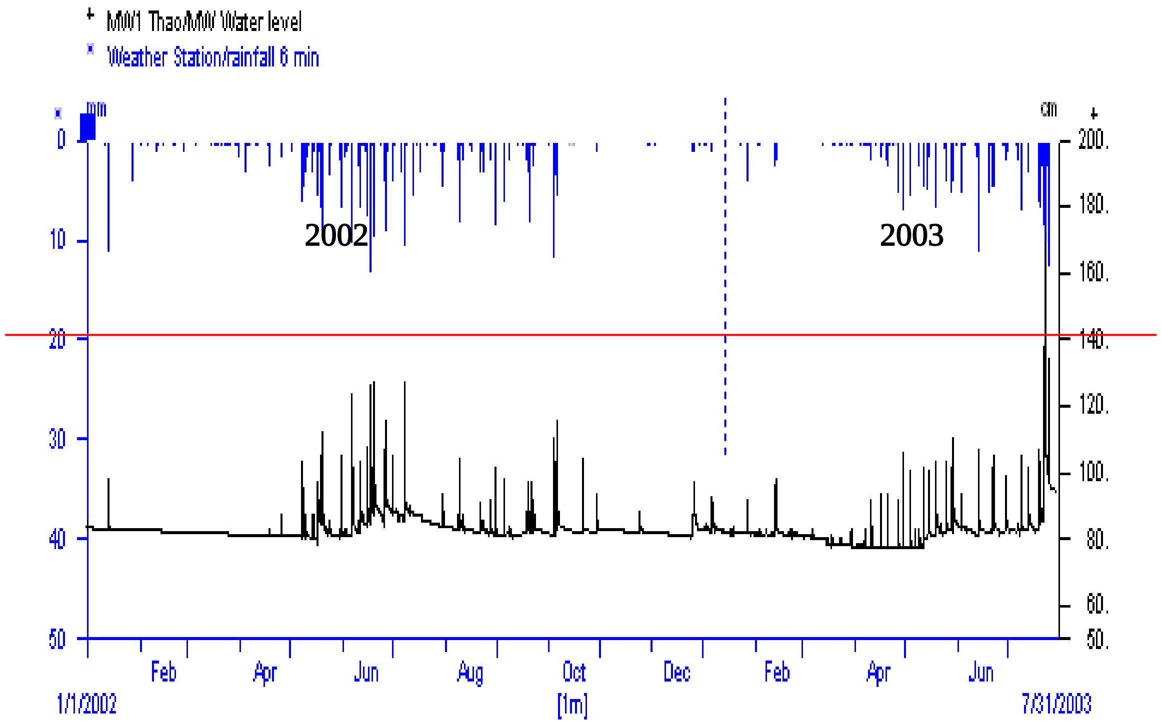

Figure 7. Observed rainfall and water level for 2002 and 2003 (until July)

The flow coefficient which represents the ratio of the total flow and the total rainfall over a certain period was estimated at 30% for 2002 and 40% for 2003 (Table 2). During the dry season, the streamflow in the main outlet is permanent, even if rainfall is limited. The flow coefficient at this period is higher but the flow volume is low. During the wet season, the flow coefficient decreases but the flow volume increases. This shows the important role of ground water on the hydrological process in Dong Cao Catchment. In 2003, the typhoon rains contributed 2/3 of the flow or 40% of rain. During this week, the flow coefficient exceeded 80%. The soil and sub surface horizon were saturated with rain water.

To measure runoff coefficient, the different storage tanks were first determined by doing logarithmic hydrogram separation (Figure 8). This method permits to determine different slopes. Each straight-line intersection shows a new water storage tank. The runoff volume and runoff coefficient were then estimated (Table 3). Runoff in Dong Cao catchment is low (10% for 2002). During the rainy season, the monthly runoff coefficients varied from 0 to 17% except during the typhoon in July 2003 when the soil becomes saturated and runoff coefficient reached 64%.

Table 2. Calculated flow coefficient on the main outlet of the Dong Cao catchment during 2002 and 2003

MW 2002	No. of rainy day > 50mm	Rainfall mm	Effective rainfall (90% of total rain) mm	Surface m^2	Effective rain volume m^3	Flow volume m^3	Flow coefficient %
Jan	0	31.5	28.3	455000	12899.2	10963	85
Feb	0	36.7	33.0	455000	15028.6	8323	55
March	0	36.0	32.4	455000	14742.0	7610	52
April	0	40.5	36.4	455000	16584.7	5677	34
May	0	221.0	198.9	455000	90499.5	12188	14
June	1	262.5	236.2	455000	107493.7	36229	34
July	0	147.0	132.3	455000	60196.5	25921	43
August	0	100.5	90.4	455000	41154.7	11102	27
Sept	0	107.5	96.7	455000	44021.2	8641	20
Oct	1	188.0	169.2	455000	76986.0	16770	22
Nov	0	74.0	66.6	455000	30303.0	9250	31
Dec	0	73.0	65.7	455000	29893.5	9152	31
Total 2002		1318.2	1186.3		539802.9	161826	30

MW 2003		Rainfall mm	Effective rain (90% of total rain)	Surface m^2	Effective rain volume m^3	Flow volume m^3	Flow coefficient %
Jan	0	45.5	40.9	455000	18632.2	10351	56
Feb	0	39.2	35.3	455000	16052.4	6987	44
March	0	10.0	9.0	455000	4095.0	3698	90
April	1	114.0	102.6	455000	46683.0	3915	8
May	0	211.0	189.9	455000	86404.5	13839	16
June	0	194.0	174.6	455000	79443.0	12434	16
July	4	575.0	517.5	455000	235462.5	159030	68
Until June		613,7	552,3	455000	251310.1	51224	20
Until July		1188,7	1069,8	455000	486772.6	210254	43
Flood 21-25/07		420,0	378,0	455000	171990.0	139873	81
Flood 22-24 July		320,0	288,0	455000	131040.0	117000	89

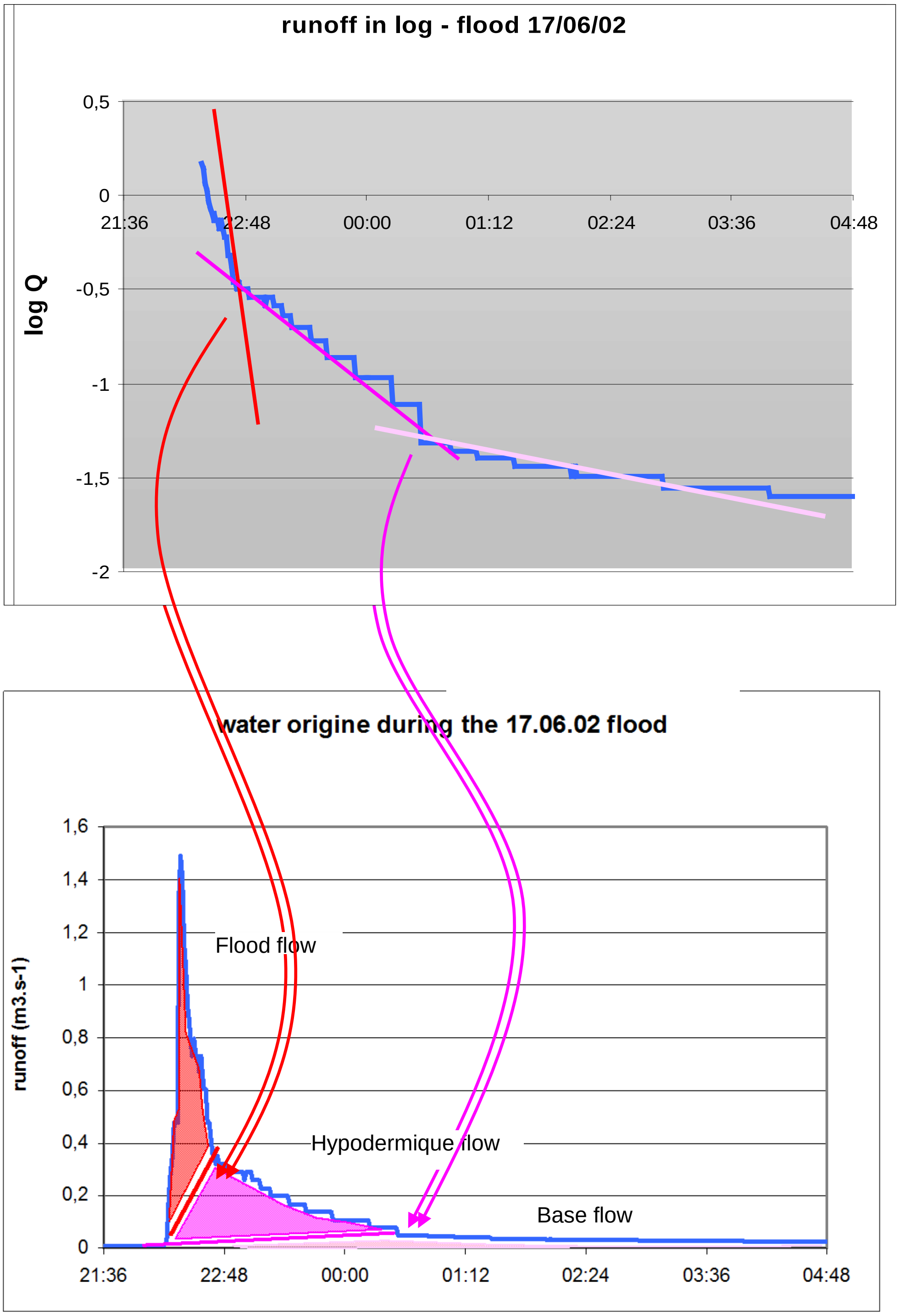

Figure 8. Logarithmic water storage tank separation method.

Table 3. Runoff coefficient in Dong Cao main outlet in 2002 and 2003

MW 2002	Rain (with runoff) mm	Effective rainfall (with runoff) mm	Surface m^2	Effective rainfall volume m^3	Runoff volume m^3	runoff coefficient (%)
Jan	0	0	455000	0	0	0
Feb	0	0	455000	0	0	0
Mrch	0	0	455000	0	0	0
April	0	0	455000	0	0	0
May	112	100	455000	45500	1860	4
June	235	212	455000	96000	14153	15
July	44	40	455000	18200	3053	17
August	44	40	455000	18200	503	3
Sept	0	0	455000	0	0	0
Oct	157	141	455000	64155	5614	9
Nov	0	0	455000	0	0	0
Dec	0	0	455000	0	0	0
Total	592	532		242055	25183	10
MW 2003	Rain (with runoff) mm	Effective rainfall (with runoff) mm	surface m^2	Effective rainfall volume m^3	Runoff volume m^3	runoff coefficient (%)
Jan	0	0	455000	0	0	0
Feb	0	0	455000	0	0	0
March	0	0	455000	0	0	0
Apr	70	63	455000	28665	470	2
May	176	158	455000	71890	5004	7
June	80	72	455000	32760	1209	4
July	490	441	455000	200655	127741	64
Total end June	326	293	455000	133315	6683	5
Total end July	816	734	455000	333970	134424	40
flood 21-25 July	420	378	455000	173810	125843	72
flood 22-24 July	320	288	455000	131040	116207	88

Sediment yields

The yearly bed load measured at the main weir was estimated at 0.5 t ha^{-1} $year^{-1}$ (Table 4, Figure 9). It was observed that the bed load was relatively lower in 2002. This observation can be explained by the lower rainfall and the denser grass cover in 2002. Because 2002 was a relatively dry year, the area that was cultivated was smaller than the previous years and the areas earlier cultivated had been left with wild grasses. The highest bed load was observed in W2 (2.7 t ha^{-1}) where cassava was planted. The other sub-catchments had bed loads of not more than 1 t ha^{-1}.

Table 4. Sediments collected in the different weir during the rainy season of 2003.

Date	MW (kg)	W1 (kg)	W2 (kg)	W3 (kg)	W4 (kg)
6-Apr-03	632	0	28	185	74
3-May-03	253	0	3 745	210	74
5-May-03	162	0	0	0	0
15-May-03	401	0	129	0	0
22-May-03	125	0	422	389	39
28-May-03	621	0	3 440	230	0
29-May-03	0	0	4 087	0	0
6-Jun-03	1 135	0	201	69	42
18-Jun-03	857	0	1 427	261	75
24-Jun-03	632	0	1 480	0	0
2-Jul-03	944	0	439	428	0
11-Jul-03	1 398	0	1 455		0
19-Jul-03	814	0	530	252	124
24-Jul-03	6 263	1 450	0	0	0
25-Jul-03	0	0	2776	2409	1 501
27-Jul-03	2 974	0	0	0	0
13-Aug-03	1 071	0	278	508	156
28-Aug-03	731	0	124	220	69
19-Sep-03	5 599	0			
20-Sep-03		0	580	314	121
Year total	**24,612**	**1,450**	**21,142**	**5,475**	**2,274**
Area (ha)	49.7	2.64	7.71	9.92	8.36
In 2003	**0.54**	**0.39**	**2.75**	**0.51**	**0.32**
In 2002	0.46	1.30	1.90	0.79	0.60

6250 : Amounts of sediment collected after the exceptional heavy rains of the 22/23 of July.

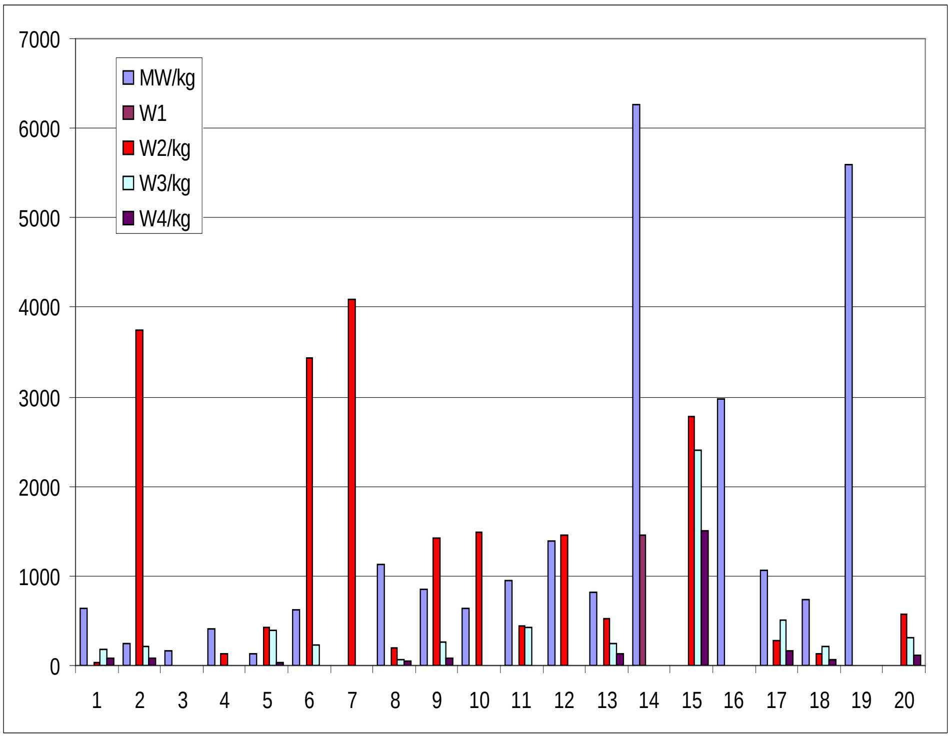

Figure 9. Bed load yields for each rainfall event in Dong Cao watershed, 2003

The analysis of the results points to several observations as follow:

- There is no direct relation between the amount of rainfall and the production of sediments;
- After land clearing, in the month of May, weir 2 shows the highest amount of sediments. Figure 10 shows that in May, watershed 2 had a totally bare soil surface and steep slopes. Erosion occurred as proto-rills.
- After the growth of *Bracharia* on watershed 2, the amounts of sediments collected in weir 2 decreased significantly in August and September;
- Weir 1 with a complete forest cover and weir 4 with degraded forest and under long fallow had little amounts of sediments.

Groundwater table and geology

Since May 2003, ground water level had been recorded. The water level was about 9.50 m from the ground surface in the beginning of May and increased to about 9 m in May and June (Figure 11). Underground water in this part (downstream from main weir), increase two or tree days after a big rainfall event. For the 20-25th rainfall event, the underground water level increased to near 5 m. Normally, for a “normal” rain, underground water level increase by few centimetres. Indeed, this year, for the first time the water level in a well near the main watershed outlet was observed. These records prove the direct connection between rainfall and the rapid change of the groundwater table.

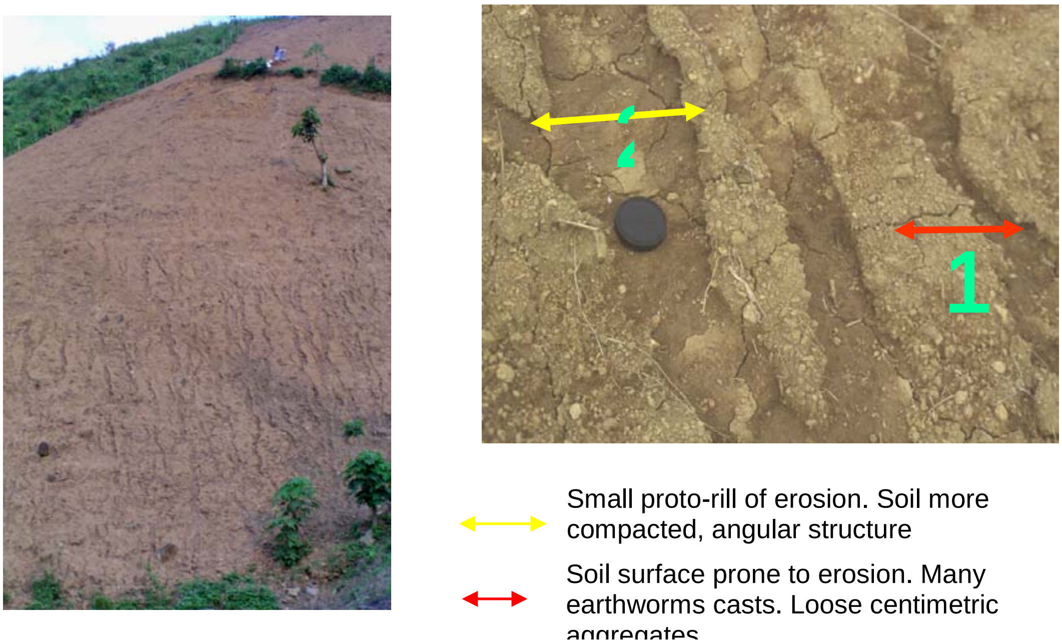

Figure 10. Proto-rills in steep slopes of watershed 2 (left); details of these proto-rills (right)

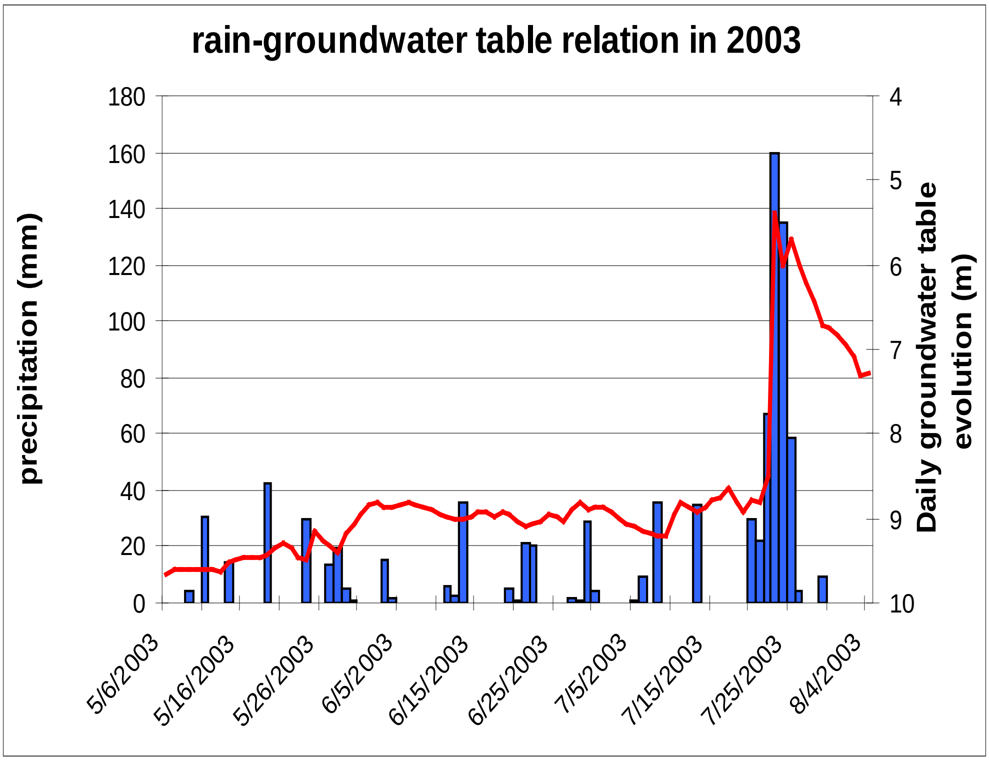

Figure 11. Groundwater table daily evolution in a well near the main watershed outlet of Dong Cao.

During big rainfall, Dong Cao catchment spring have a bigger runoff. Impacts of ground water in Dong Cao catchment seem important, without any hydrogeological analysis, we can only put forward hypothesis. Ground water seems to have a great impact on surface flow.

Field studies and data analysis had shown that geology and groundwater appeared to largely explain the hydrological processes in Dong Cao catchment. Figure 12 shows some geological information about the catchment. It is observed that soil characteristics are similar in the whole catchment. There are temporary streams in sub catchments 1 and 2 and permanent streams in sub catchments 3, 4 and 5 (River near W3). There are aquifers with springs at different places (downstream W2 and MW). Ground water feeds into stream 3 and stream 5 and this is confirmed by isotopic analysis and flow coefficient.

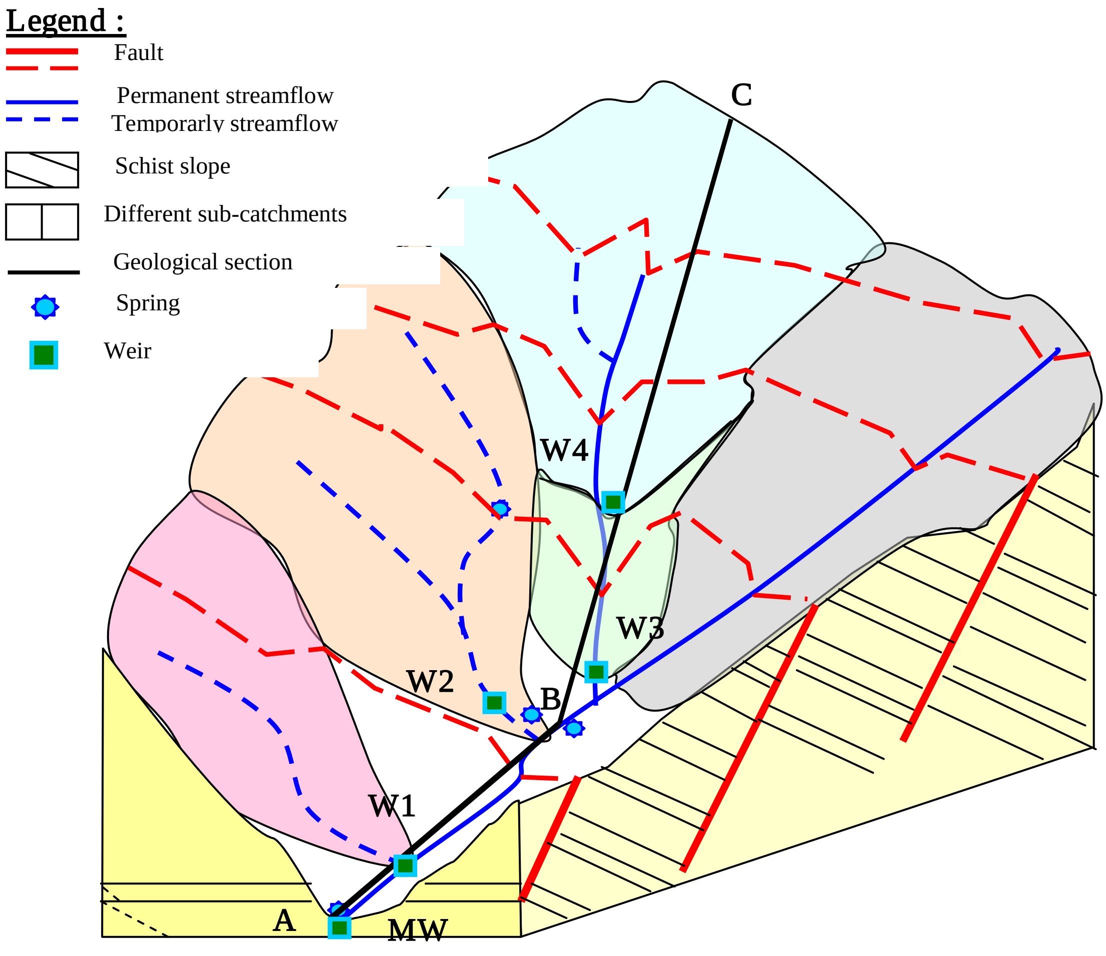

Figure 12. Dong Cao catchment geological diagram.

From the above observations, it can be hypothesized that streamflow begins at the first base of the fault stairs and at the spring in others. In permanent flow catchment, fault layer slope and schistosity cut at right angle to the streamflow and infiltration is low. In temporary flow catchment, fault layer slope and schistosity cut parallel to the streamflow and infiltration is high. Without any hydrogeological analysis, the effect of ground water can not be clearly explained, except by isotopic analysis and determination of flow coefficient.

Isotopic analysis

Isotopic analysis of the water showed three groups. More water is evaporated from the rainfall, followed by the reservoir and then from the Dong Cao streamflow (Figure 13). All the Dong Cao streamflows look similar, and can be considered of the same water family. These initial information suggest the possibility of using isotopic analysis to trace the pathway of surface runoff in the Dong Cao watershed. Dong Cao stream flow appears to come from both rainfall and ground water.

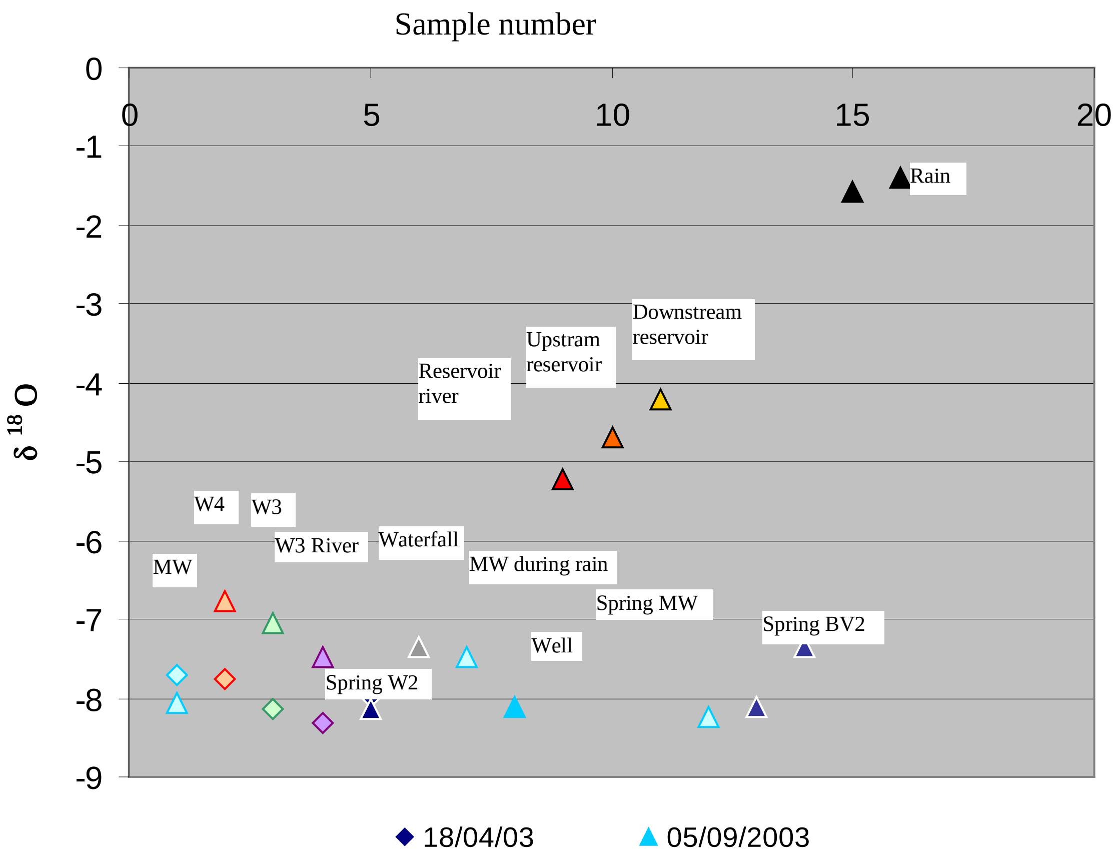

Figure 13. Isotopic water chemistry assessment (oxygen-18 in isotopic delta) in Dong Cao catchment, 2003.

Soils

Orientation of the landscape

The Dong Cao catchment is surrounded by hills with a general slope of over 30%, sometimes reaching 100%. The hills are scaled in space with steps and alternate occurrence of gentle slope (15-20%) and very steep slopes (over 80%) (Figure 14) . This disposition is probably linked to a series of faults oriented to the north (in the same direction of the main flow).

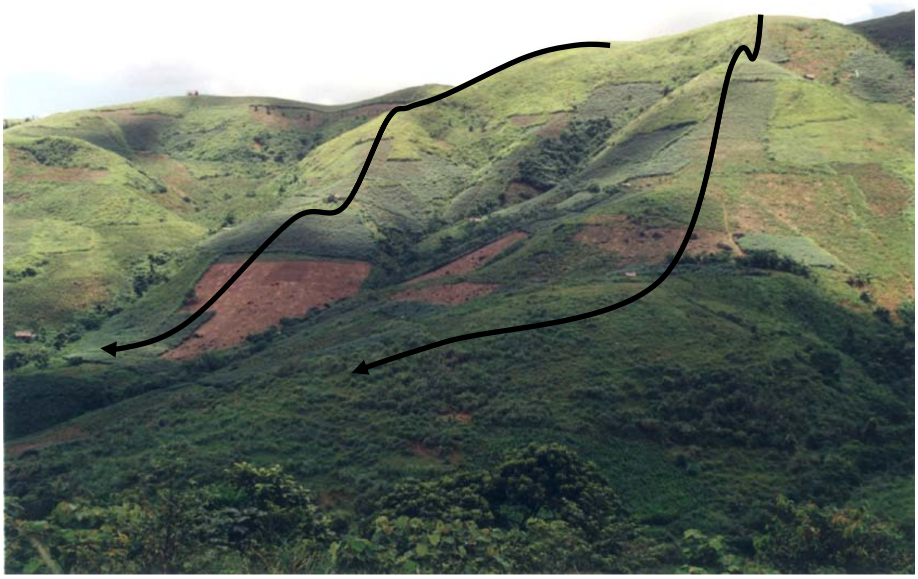

Figure 14. Step-form steep slopes on Dong Cao watershed

Orientation of the parent rock

The parent rocks are schists in centimetric layers with a steep dip oriented to the south, opposite the slope (Figure 15). For this reason, the soil depth will depend on the weathering rate of the schist layers. Therefore the succession of hills will have different soil depth.

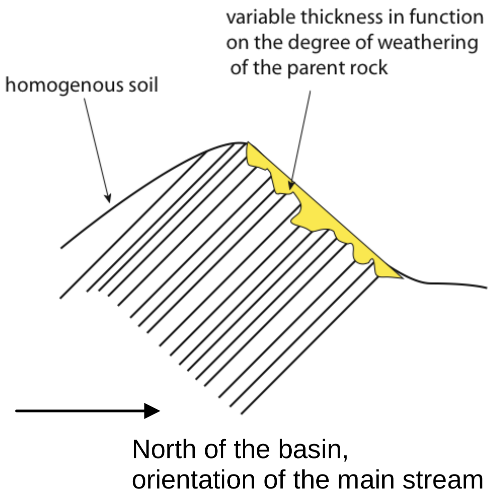

Figure 15. Orientation of the schist dip in the watershed.

Distribution of the soil types

Acrisols

The general soil type in the landscape is an Acrisol (FAO, 1998) or Ultisol (SSS, 1999). Soils are generally thick, over 1.0 m deep, clayey, very porous, with micro aggregates on the topsoil resulting from a strong biological activity of termites and ants. They show a homogenous brown colour 10YR4/4 to 7.5 YR 4/6 with a weak differentiation. The general clay type is kaolinite with low CEC; pH is low, below 5.0 (Tables 5 and 6). The soils present a small clay enrichment at 40-cm depth with a Bt horizon (Table 7), some cutans are visible. Along the main slope, there are four different kinds of soil profiles (Figure 16).

Table 5. Chemical data of soil surface horizon of different soil types

	C	N	C/N	pH	pH	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CEC	S/T	P_2O_5T	KT
	g kg^{-1}	g kg^{-1}		H_2O	KCl	Cmol$^{(+)}$ kg^{-1}					%	%	%
STA1	11.1	1.46	7.42	5.2	3.7	0.40	0.36	0.04	0.10	7.0	12.9	0.140	0.036
STA2	44.5	2.97	14.83	4.8	3.9	2.88	1.12	0.04	0.41	13.4	33.2	0.147	0.054
STA3	23.7	2.24	10.79	4.9	3.9	1.80	0.11	0.04	0.08	11.2	18.1	0.101	0.066
STA4	24.9	3.19	7.77	4.9	4.0	2.78	1.79	0.04	0.21	13.8	34.9	0.140	0.527
Dcao 1.1	28.9	4.26	6.73	4.4	3.8	2.67	0.18	0.09	0.26	18.2	17.6	0.100	0.451
Dcao 4.1	34.5	3.64	9.58	4.3	3.7	1.91	0.19	0.09	0.46	14.6	18.2	0.108	0.211
Dcao 14.1	27.8	2.97	9.28	4.2	3.7	3.43	1.21	0.09	0.13	15.6	31.2	0.204	0.385
Dcao 17.1	32.1	2.97	10.70	4.3	3.8	3.74	2.35	0.09	0.26	11.8	54.6	0.114	1.791
Dcao 22.1	25.9	2.86	8.93	4.5	4.0	6.69	2.26	0.09	0.26	14.6	63.7	0.247	0.247
Dcao 23.1	36.7	3.36	10.80	4.3	3.8	8.72	5.75	0.09	0.18	22.5	65.5	0.214	0.163
Dcao 25.1A	30.8	3.40	9.06	4.1	3.9	3.60	1.73	0.04	0.28	16.6	34.0	0.211	0.069
Dcao 25.1B	27.8	7.39	3.76	4.1	3.9	2.80	2.34	0.04	0.10	17.6	30.0	0.234	0.066
W2-4/5/03	27.3	2.35	11.39	4.1	3.8	3.95	1.77	0.04	0.28	18.4	32.8	0.096	0.078
LAC13	29.2	3.25	8.85	5.3	4.9	9.14	4.19	0.04	0.15	18.2	74.3	0.224	0.385

STA1: deep Acrisol soil without clast;STA 2: earthworm clast; STA 4: compacted Acrisol close to bamboo plantation; STA4: Cambisol below forest.
Dcao 1.1: Acrisol top of hill; Dcao 4.1: Acrisol on steep slope below forest; Dcao 14.1: shallow Acrisol below cassava; Dcao 17.1 Leptosol below opened forest; Dcao 22.1: Arenosol; Dcao 23.1: Cambisol on fallow ; Dcao 25.1A : Acrisol on steep slope, erodible aggregates of Fig. 12; Dcao 25.1B: Acrisol on steep slope, not eroded soil of Fig. 12;
W2: Sediments of weir 2 the 4th of May; LAC13: surface sediments collected in the reservoir.

1. On the top of the hills, soils are moderately deep, and laying directly on parent rock (Figure 17).
2. On slopes, soils develop on former colluvial material (Figure 18). This colluvium is composed of free stones and gravels embedded in a clayey matrix similar to the Bw horizon matrix, with the same geological origin than the parent rock but removed in different directions. The clayey horizon is over 70 cm thick and the colluvium is at least 50 cm thick (profile 02, 05, 07, 09)
3. When the slope decrease on the more horizontal part of the steps forming the landscape, the colluvium became very thick (over 1.0) and the soft soil without stones becomes shallower, >0.50 cm (profile 04, 08, 12).

Table 6. Soil grain size composition in Soil sequences n°1 (on the left bank) and in watershed 3

Sample	Hz	CS	FS	CSi	FSi	C
Cao 11.1	A	2.79	1.86	15.09	36.79	43.47
Cao 11.2	Bw1	2.79	1.92	17.15	36.21	41.92
Cao 11.3	Bw2	3.62	1.74	14.20	35.96	44.49
Cao 11.4	Bw3	2.34	2.65	28.51	21.85	44.65
Cao 12.1	A	1.43	1.22	11.68	30.18	55.49
Cao 12.2	Bt	1.53	0.89	7.80	22.44	67.32
Cao 12.3	Bw1	1.75	0.89	9.74	28.23	59.39
Cao 12.4	Bw2	1.07	0.72	14.73	28.48	55.00
Cao 13.1	A	1.57	0.98	7.79	39.95	49.70
Cao 13.2	B	4.07	0.80	15.22	19.98	59.92
Cao 14.1	A	3.54	1.08	10.50	32.43	52.46
Cao 14.2	AB	2.81	0.68	7.73	24.12	64.67
Cao 14.3	Bw	2.37	0.64	7.50	27.19	62.29
Cao 15.1	A	4.20	2.37	12.14	36.44	44.85
Cao 15.2	Bt	3.30	1.78	7.60	23.73	63.59
Cao 15.3	Bw1	1.67	0.71	20.50	27.33	49.78
Cao 15.4	Bw2	0.40	0.29	31.78	33.77	33.77
Cao 16.1	A	13.13	7.06	12.77	30.33	36.71
Cao 16.2	Bt	8.14	6.59	7.68	34.11	43.48
Cao 16.3	Bw1	12.95	7.40	7.97	34.25	37.44
Cao 16.4	Bw2	9.61	5.85	5.07	31.28	48.18
Cao 31.1	A	5.26	4.21	9.05	27.16	54.32
Cao 31.2	AB	2.47	1.65	10.54	32.60	52.74
Cao 31.3	Bw	5.69	4.48	6.29	37.73	45.82
Cao 32.1	A	9.85	7.24	10.74	28.53	43.64
Cao 32.2	AB	5.66	3.57	15.43	33.58	41.75
Cao 32.3	Bw	6.98	3.21	9.88	29.64	50.29
Cao 33.1	A	5.47	3.75	12.71	29.05	49.02
Cao 33.2	AB	0.87	1.84	16.54	53.51	27.24
Cao 33.3	Bw	7.95	3.51	14.16	31.87	42.50

CS: Coarse sand; FS: Fine sand; CSi: Fine silt; Fsi: Fine silt; C: Clay
Data obtained in 2002, after the 1st soil survey made by Pascal Podwojewski in 2001.

Cao 11, 12, 14: deep Acrisols on parent rock; Cao 15 and Cao 16: deep Cambisol on colluvium; Cao 13 and Cao 31: shallow eroded Acrisol; Cao 32 Cambisol on colluvium; Cao 33 deep Acrisol on colluvium on very steep slope

Table 7. Soil surface grain size composition in Soil sequences made for ^{137}Cs measurements

Sample	CS	FS	CSi	FSi	C
DC1	17.56	11.47	9.39	30.73	30.85
DC3	6.02	4.52	6.26	26.84	56.36
DC4	2.11	1.85	6.73	27.85	61.46
DC5	4.09	3.15	6.49	27.83	58.44
DC6	4.57	5.34	5.66	29.56	54.88
DC7	6.35	7.88	5.96	25.70	54.10
DC8	6.37	6.98	8.67	29.46	48.53
DC9	6.07	6.51	7.00	29.72	50.70
DC10	13.94	8.49	9.30	34.14	34.14
DC11	14.06	9.88	6.08	29.67	40.32
DC12	16.28	10.50	5.60	31.71	35.91
DC13	12.31	9.00	8.66	30.69	39.34
DC14	2.82	4.27	5.04	31.81	56.05
DC15	2.07	2.22	5.74	24.88	65.09
DC16	3.08	1.55	7.63	28.61	59.13
DC17	2.90	1.73	10.49	29.57	55.31
DC18	3.40	2.03	13.24	36.88	44.45

Data obtained in 2002, after the ^{137}Cs prospection in year 2000.

DC1 to DC13 correspounding to the Soil sequence n°0 ;
DC14 to DC18 are localized in the sequence 1, on the left bank of the watershed.
DC10, 11, 12 and 13 correspound to eroded and shallow Acrisols

4. At the lower part of the hills, in the concave and rectilinear part of the slope, when the slope decreases, soils are shallower, developing on old colluvial material, and with a probable erosion of their upper part (Figure 19). This erosion occurred probably during the last decades after cultivation and tillage (profiles 13 and 14).

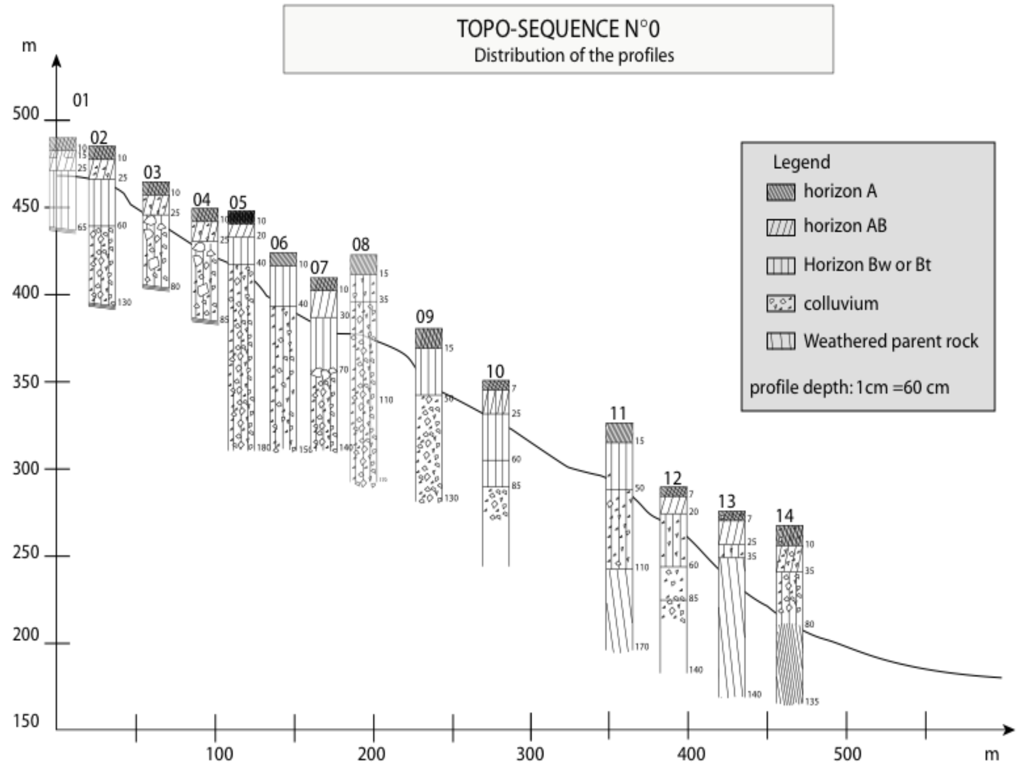

Figure 16. Main soil sequence from the top of the watershed to weir 3

Figure 17
Acrisol on parent rock

Figure 18
Acrisol on colluvium Shallow

Figure 19
Acrisol on colluvium

Cambisols

In the main drainage pathways, on recent colluvium, the soils present cambic horizon characteristics with darker color and no evidence of clay accumulation (Figure 20, profile 23). On the water pathways, soils are often shallower and with coarse material. These soils have often an enrichment in organic matter, water and nutrients.

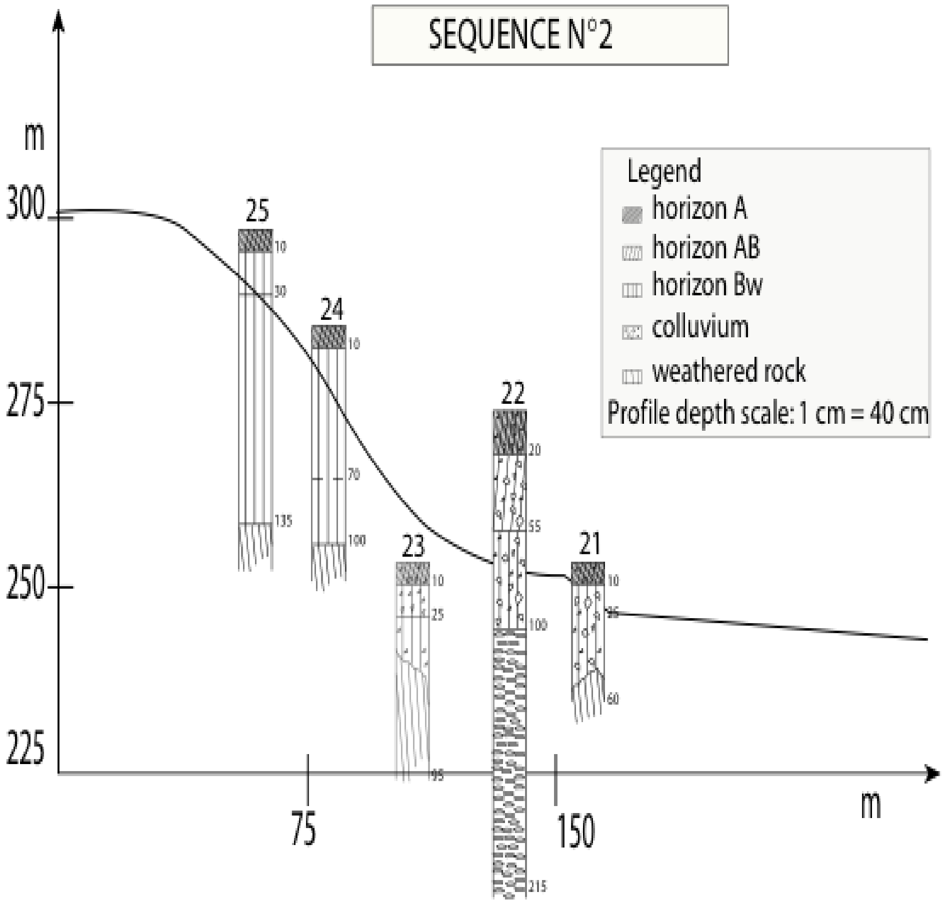

Figure 20. Soil distribution in the sequence2, located in the watershed 2

Regosol on Fluvisol

Just downstream weir 3 and upstream of weir 2, there are big colluvial rounded blocks over 50 cm in diameter outcrops. Between these blocks, deep Fluvisol with arenic properties are formed. These areas have limited area (Figure 20, profile 22).

Leptosols

In some places where the schist layers are harder, soils are very shallow, < 30 cm thick, and with a high stone content > 20%. Soil surface is covered with stones 1-15 cm long. This narrow area (20 m) is localised close to the main weir and is oriented perpendicular to the main drainage way (Figure 21).

Figure 21. Contact between deep Acrisols (brown-orange colour) and Leptosol (grey colour) close to the main weir.

Carbon sequestration in the landscape

To measure the effect of the slope on the general carbon content, and to appreciate the evolution of the carbon content before and after land use changes, soil samples were taken from two horizons at a depth of 0-10 and 15-25 cm in 75 sites and arranged in 11 soil sequences. The selected samples were from watershed 2, watershed 3, and a smaller trial on main weir site. The land use represents an intensive cassava cropping (watershed 3), grass cover after bare fallow (watershed 2), and eventually bamboo and *Tephrosia sp.* hedgerows plantations (main weir) after cassava cropping and young fallow.

The land use changes that have occurred in these areas are as follow:

- In 2002, the main part of watershed 2 was cultivated with cassava and then maintained in bare fallow (Figure 22), while close to main weir and watershed 3 were fallow after cassava cultivation in 2001 and several years before. Cassava cropping generates intense erosion in the early stages of the development of the vegetation, at the beginning of the rainy season (April and May) with bare soils and tilled soil surface.

- During the year 2003, watershed 2 and 3 and also a plot close to Main weir changed their land use.

  - Close to the main weir, on the right bank of the river, the LUSLOF project (University of Uppsala, Sweden) leads a bamboo crop trial associated to *Tephrosia candida* (Fabaceae) hedgerows along the slope.
  - In Watershed 2, the MSEC programme decided to plant a new cover crop, *Bracharia ruziziensis*, a Poaceae with a C4 chlorophyll cycle (Figure 23) to provide the farmer fodder for the cow raised for milk, to improve the soil carbon content, and to reduce the soil erosion,

Figure 22. Watershed 2, bare soil, month of May

Figure 23. Same site in August, grass cropping

- Watershed 3 was cultivated with a cassava crop, with less soil cover than grass and less effects on the soil carbon. To maintain the soil fertility especially in nitrogen, *Stylosanthes guyanensis* (Fabaceae) was planted with cassava.

- End of the year 2003 ,

  - In Watershed 2, *Bracharia* was cut two times, first in mid-August with a yield of 2.5 t ha^{-1} and second in October yielding 3.8 t ha^{-1} in dry matter. The water content was around 80%. Half of the *Bracharia* cover was cut for fodder for the cow of the farmers, the other half left on soil as a mulch to maintain the soil fertility and improve the soil carbon content.
  - In Watershed 3, the cassava was harvested end of November. Yields varied with the soil depth (water and nutrient reserves).

In 2004, it is planned to measure the carbon content in the same locations. In watershed 2, the effect of the grass cover should be a rapid increase of carbon content which is expected after regular cuttings to be higher than in the fallow land. The amount of carbon eroded from the grassland soil cover can be measured by the C13 content of the sediment deposits in weir 2.

Earthworm activity

In Don Cao watershed, earthworm activity is very high. The earthworm casts may have an important role in the erosion process. The casts formed are very hard and are composed of rounded centimetric sub-aggregates that are prone to erosion on steep slopes. Many rounded aggregates have been found in weir 2 when bare soil of watershed 2 was exposed to water erosion before the grass cover. In addition, the earthworm may concentrate some elements in their casts. Blanchard *et al* observed that carbon, nitrogen and exchangeable calcium and magnesium are higher in the cast than in the soil. The first results of chemical analysis confirm this observation (see Table 5).

Therefore, earthworms play an important role in the redistribution of soil and soil nutrients from upslope to down slope. The earthworms seemed to be very important on recently transformed lands. In front of the MSEC house, the hill was earlier planted to forest trees (*Acacia mangium*, Eucalyptus). After 10 years, the trees were cut and the area was cleared. On this cleared land the earthworm activity was very high as evidenced by accumulation of the casts (Figure 24).

Figure 24. Earthworm casts at soil surface

Using three observation plots of 20 m^2 (20m x 1 m) along the slope of the cleared forest, all casts from each plot were collected, air-dried and weighed. The earthworm cast density varied from 5 m^{-2} in the upstream portion to 20 m^{-2} downstream. The cast measured about 9 cm long and 3 cm in diameter and 90 g in weight on the average. Some casts reached as long as 15 cm and 160 g (Figure 25). They are composed of the aggregated rounded centimetric hardened pellets. The bulk density is about 1.6 kg dm^{-3} and moisture content of fresh casts of 25% (250 g kg^{-1}), and 3 %(30 g kg^{-1}) for the air-dried sample.

Soil structure stability

The soil morphology of the soil sequence 0 or on the sequence 2 (see Figure 20) shows that the eroded soils are located at the foothills at less steep slopes decrease (profile 21), while on steep slopes, the soil depth is over 1.0 m. This soil evolution could be attributed to 3 factors:

- Tillage of the soil especially for land clearing and weeding;
- Expose bare soil surface especially during the first stages of the cassava cropping;
- Decrease of soil organic matter content which reduces the stability of aggregates.

Figure 25. Earthworm cast in Dong Cao

The soil structure stability is an important parameter for understanding of erosion processes. Many samples have been taken in 2003 and we must measure the aggregate structure stability. The stability of aggregates can be affected by different land uses, mineral composition of the soils, and activity of the earthworms.

Organic matter is an important factor affecting aggregate stability, and therefore it will be important to compare the situation under different land uses, i.e., fallow, cassava fields, former cassava fields and new grass cover and compare them with the soil carbon storage. Shallow Acrisols are more eroded and their clayey composition shows an increase in interstratified material coming from the early stages of rock weathering. These soils may have a different aggregate stability than the deep Acrisols.

Land Use and Land Ownership

Land use and land use changes were monitored by actual ground survey and interviews. The watershed was divided in 41 plots in 2002, 40 belonging to 18 different households, and one state owned. In June 2003, the watershed was occupied by only six owners, including the State. All or some part of the watershed lands of 14 farmers had been bought by one farmer of Dong Cao (Mr.Bon). Land use maps were prepared showing the plots and the owners.

Land use changes between 2002 and 2003

Between 2002 and 2003, the areas of *Acacia mangium*, secondary forest and *Venicia montana* remained the same (Table 8). The fallow area decreased by 4%, while the area of cassava decreased by 65%. The arrow root was completely stopped and 55% of the Eucalyptus was cut down. A small area was planted to bamboo and *Tephrosia candida* (by LUSLOF project).

The main changes on the MSEC watershed was the cultivation of fodder crops (by MSEC program), and the planting of trees (by one farmer of Dong Cao, Mr Bôn). Thus, 4.3 ha was planted to *Bracharia ruziziensis*, a fodder grass, and 1.1 ha to *Stylosanthes guyanensis*, a leguminous fodder, in association with cassava (Figure 26). In the lower part of the watershed, 4.1 ha was planted to *Canarium trandenus*, 13.8 ha to *Chukrasia tabularis*, mainly in the middle part of the watershed, and 22 ha to Styrax, mainly in the upper part of the watershed. These trees were planted on areas already covered by other crops, or in fallow areas, on almost all the watershed (Table 9). At the end of 2003, 80% of the watershed was thus planted to these trees.

Table 8. Area (ha) per kind of crop in 2002 and 2003

CROP	2002	2003
Acacia Mangium	7.4	7.4
Arrow root	0.5	0
Bamboo	0	0.3
Bracharia Ruziziensis	0	4.3
Canarium Trandenus	0	4.1
Cassava	4.4	1.5
Chukrasia Tabularis	0	**13.8**
Eucalyptus	6.4	2.9
Fallow	**24.9**	**24.0**
Secondary forest	9.4	9.4
Stylosanthes Guyanensis	0	1.1
Styrax	0	**22.0**
Tefrosia Candida	0	0.8
Venicia Montana	0.8	0.8

(Source : Koïkas J. Renaud J. & al. Dong Cao GIS Arcview project, with former inquiry, 2003)

Table 9. Area per land use in 2003

LAND USE	Area (ha)
Acacia Mangium in fallow 1 year + Chukrasia Tabularis	1.7
Acacia Mangium in fallow 1,5 year + Chukrasia Tabularis	1.4
Acacia Mangium + Styrax	1.1
Acacia Mangium + Canarium Trandenus	0.5
Acacia Mangium	1.2
Acacia Mangium in fallow 7 months	0.5
Bamboo + Tefrosia Candida	0.3
Bracharia Ruziziensis + Styrax	0.4
Bracharia Ruziziensis + Chukrasia Tabularis	3.3
Bracharia Ruziziensis	0.6
Canarium Trandenus	3.5
Cassava & Stylosanthes + Acacia + Chukrasia Tabularis	1.1
Cassava + Tefrosia Candida	0.5
Eucalyptus	2.9
Fallow 1,5 year + Chukrasia Tabularis	0.8
Fallow 10 years + Styrax	14.1
Fallow 10 years + Chukrasia Tabularis	1.0
Fallow 12 years + Chukrasia Tabularis	2.2
Fallow 3 years + Chukrasia Tabularis	0.6
Fallow 6 months + Chukrasia Tabularis	0.2
Fallow 7 months + Chukrasia Tabularis	1.5
Secondary forest	3.0
Secondary forest + Styrax	6.4
Venicia Montana + Canarium Trandenus	0.1
Venicia Montana	0.7
TOTAL	49.5

(Source : Koïkas J. Renaud J. & al. Dong Cao GIS Arcview project, with former inquiry, 2003)

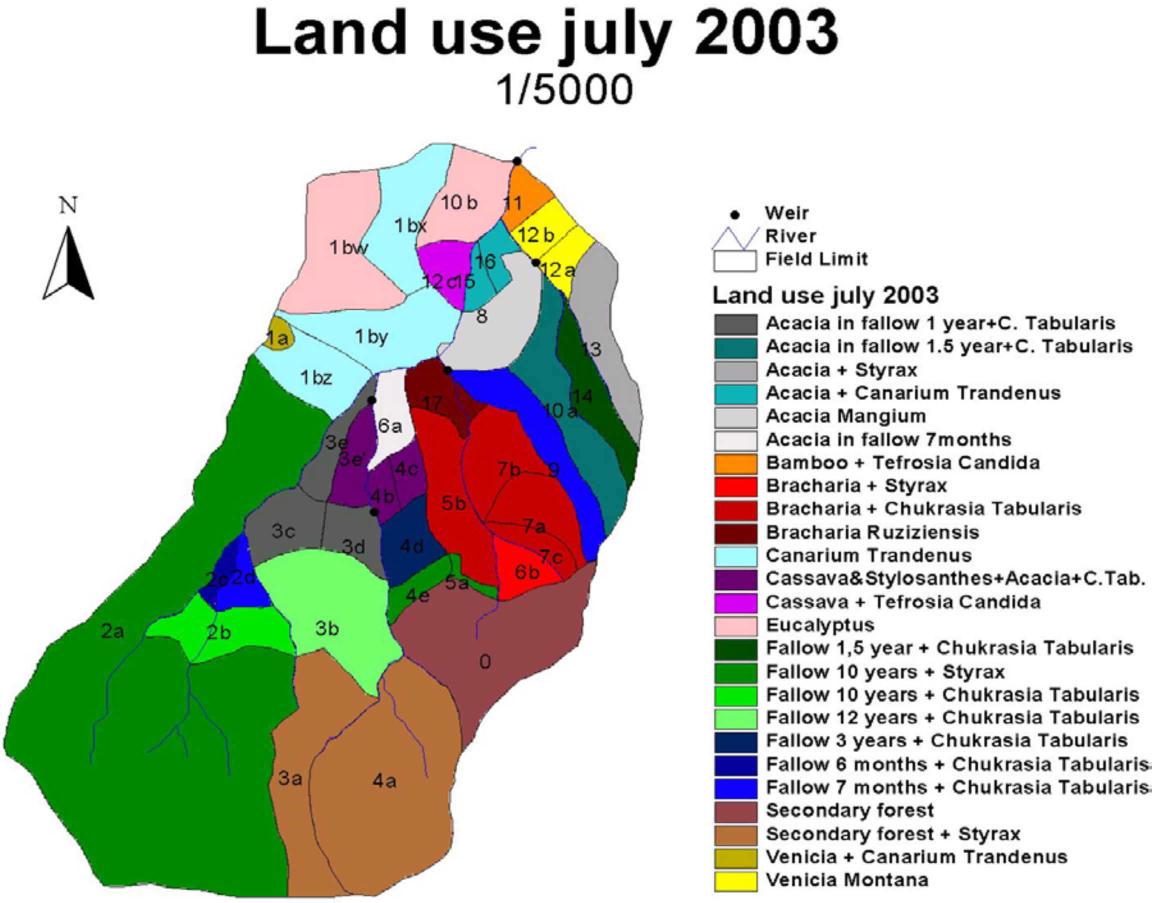

Figure 26. Land use map of the catchment in 2003 showing the plots

Land ownership in 2002 and 2003

In 2002, there were 19 different owners of the land in the watershed (Tables 10 and 11 and Figures 27, 28, and 29). The biggest owner was the chief of the village, Mr Tuoi, with 15.3 ha (31%). There were 3 farmers owning between 5 and 7 ha (between 11 and 13%), 3 ha was owned by the state. In the upper part of the watershed, 9 farmers owned between 1 and 3 ha (2 to 4%), and 5 farmers owned less than 1 ha.

In 2003, one farmer, Mr Bôn, who owned 5.5 ha (11%) in 2002, bought 75% percent of the rest of the watershed, bringing his ownership to 86% of the watershed or 42.5 ha. As a a result, there were only six owners on the watershed, including the State. The four other remaining farmers owned between 0.7 and 1.2 ha or 2% or less of the total area.

Table 10. Area per owner on MSEC watershed in 2002 and 2003

Owner 2002	Area (ha)	%	Owner 2003	Area (ha)	%
Tuoi	15.3	31	Bôn	42.5	86
Tháo	6.5	13	State	3.0	6
Cân	5.8	12	Phú	1.2	2
Bôn	5.5	11	Khuyen	1.1	2
State	3.0	6	Nhón hô	1.0	2
Luc	2.1	4	Bûi	0.7	1
Tám	1.4	3	Tuoi	0.0	0
Bây	1.4	3	Tháo	0.0	0
Bûi	1.2	2	Cân	0.0	0
Phú	1.2	2	Bây	0.0	0
Quý	1.1	2	Lý	0.0	0
Khuyen	1.1	2	Luc	0.0	0
Nhón hô	1.0	2	Quý	0.0	0
Lý	1.0	2	Tám	0.0	0
Tiên	0.8	2	Xuân	0.0	0
Hien	0.6	1	Tiên	0.0	0
Xuân	0.3	1	Hoi	0.0	0
Tho	0.3	1	Tho	0.0	0
Hoi	0.2	0	Hien	0.0	0
TOTAL	49.5	100	TOTAL	49.5	100

(Source : Koïkas J. Renaud J. & al. Dong Cao GIS Arcview project, with former inquiry, 2003)

Table 11. Land owners in Dong Cao watershed in 2002 and 2003

Reference	Plot	Area (ha)	Owner 2002	Owner 2003
1	0	3.03	State	State
2	1A	0.12	Bôn	Bôn
3	1Bw	1.86	Bôn	Bôn
4	1Bx	1.25	Bôn	Bôn
5	1By	1.35	Bôn	Bôn
6	1Bz	0.93	Bôn	Bôn
7	2A	13.72	Tuoi	Bôn
8	2B	1.01	Tuoi	Bôn
9	2C	0.18	Tuoi	Bôn
10	2D	0.34	Tuoi	Bôn
11	3A	2.06	Tháo	Bôn
12	3B	2.15	Tháo	Bôn
13	3C	0.72	Tháo	Bôn
14	3D	0.54	Tháo	Bôn
15	3E	0.47	Tháo	Bôn
16	3E'	0.51	Tháo	Bôn
17	4A	4.35	Cân	Bôn
18	4B	0.25	Cân	Bôn
19	4C	0.29	Cân	Bôn
20	4D	0.61	Cân	Bôn
21	4E	0.29	Cân	Bôn
22	5A	0.10	Bây	Bôn
23	5B	1.27	Bây	Bôn
24	6A	0.51	Lý	Bôn
25	6B	0.44	Lý	Bôn
26	7A	0.77	Luc	Bôn
27	7B	0.95	Luc	Bôn
28	7C	0.35	Luc	Bôn
29	8	1.15	Phú	Phú
30	9	1.11	Quý	Bôn
31	10A	1.40	Tám	Bôn
32	10B	1.04	Nhón hô	Nhón hô
33	11	0.33	Xuân	Bôn
34	12A	0.34	Bûi	Bûi
35	12B	0.38	Bûi	Bûi
36	12C	0.45	Bûi	Bôn
37	13	1.05	Khuyen	Khuyen
38	14	0.83	Tiên	Bôn
39	15	0.21	Hoi	Bôn
40	16	0.27	Tho	Bôn
41	17	0.55	Hien	Bôn

(Source : Koïkas J. Renaud J. & al. Dong Cao GIS Arcview project, with former inquiry, 2003)

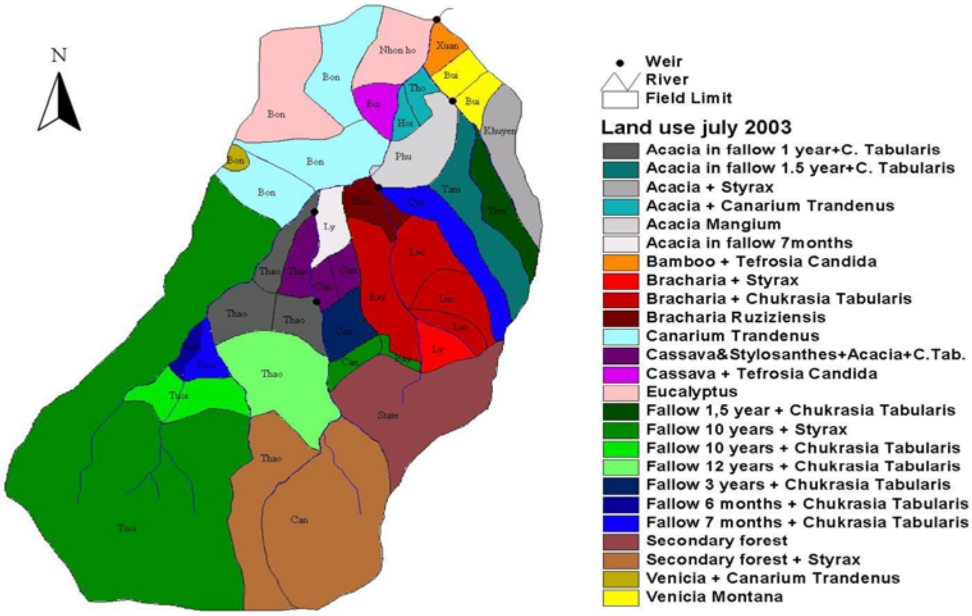

Figure 27. Land use map in 2003 showing the owners in 2002 (1/5000)

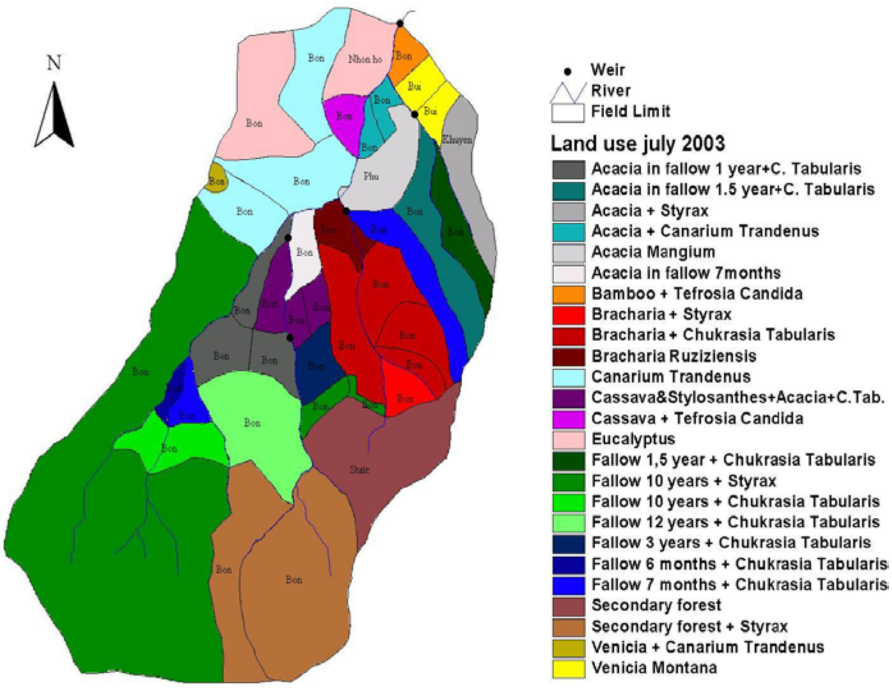

Figure 28. Land use map in 2003showing owners in 2003 (1/5000)

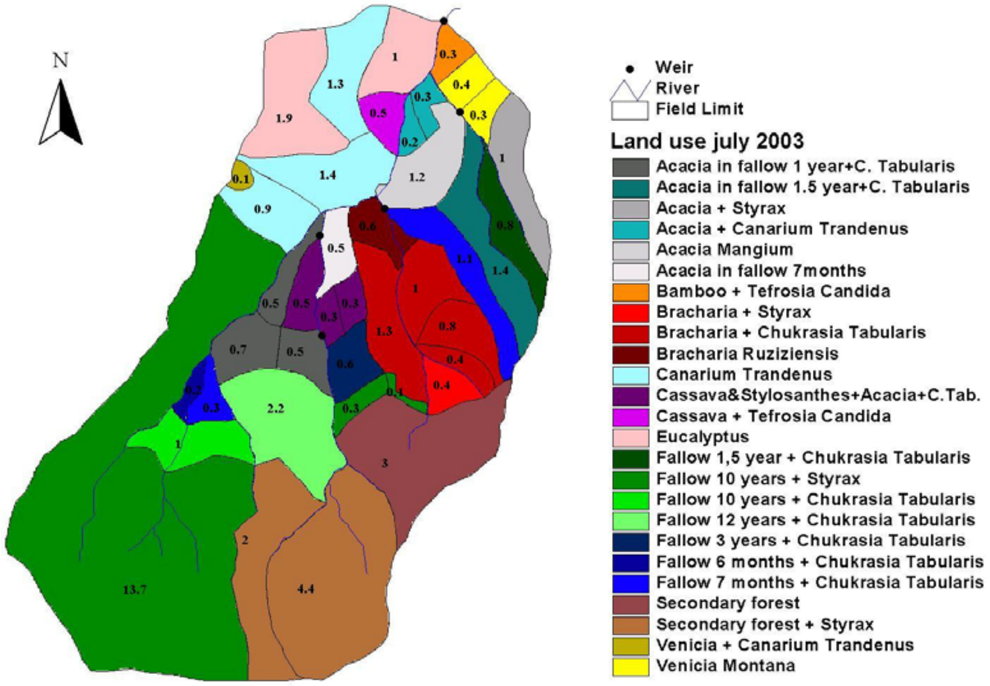

Figure 29. Land use map in 2003 showing plot areas (1/5000)

Conclusion

The results of three years of research and monitoring showed a high interannual variability of soil loss in the Dong Cao Catchment in northern Vietnam. Moreover, this variation depends on both the amount and intensity of rainfall and the kind of land use. Soil loss in 2001 was six times more than in the other years. It is notable that during this year, the total annual rainfall was highest and a large proportion of the catchment was cropped with cassava. There was relatively less erosion in 2002 when the rainfall was lower and the land use was significantly changed to fallow and natural grass.

During the rainy season of 2003, studies permitted to understand better the hydrology of this catchment. The results show that hydrology in Dong Cao catchment depends principally on geology. Permanent streamflow in catchment 3 and 5 show the impact of underground water and geology. In theses catchments, streamflow cut geological structure, dip and schistosity perpendicularly. Rivers collect underground water and infiltration is limited by schistosity. In others catchments, streamflows are in same side than dip and schistosity. Infiltration is maximal and so rivers non-permanent. These results are confirmed by isotopic and chemical analysis. These studies are required to understand better hydrological process on Dong Cao catchment and also are a database to measure soil erosion. It is also necessary to manage field modelisation in south East Asian sloppy catchment.

The project has proved to be very useful for farmers, not only in terms of understanding soil erosion and nutrient loss, which cause land degradation and reduce productivity, but also in terms of farmers' enhanced capacity and improved information dissemination strategies. The farmers are now more aware of the need to conserve soil fertility to sustain high agricultural productivity. Some of the technologies they have become aware of include contour hedgerow farming, agroforestry, intercropping systems, etc. Dialogue with farmers and different stakeholders from the local government, agricultural institutes, and research programs has been conducted to develop better understanding of how river basins respond to socio-economic changes. With this program of research and development, it is expected that the local government will change their thinking on soil management. The research activities in the Dong Cao Watershed have demonstrated to farmers, policy-makers, and extension workers how much sediment yield and bedload would be lost if appropriate soil and water management technologies were not used.

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Capacity Building

Students

In 2003, there were four Vietnamese students (two in first level of Bsc, two in second level of Bsc) and two French students (one in DESS, one in MSc). The four Vietnamese students will continue in 2004.

- -Do Duy Phai for a Msc in Hanoi University, supported by IRD/IWMI during 2004 and 2005.

Study work : Hydrological modeling in a small agricultural watershed.

- -Three students from SLU in collaboration with Luslof project and ICRAF-Bogor

The research activities and the *focus for the thesis work* for the three students are agreed as follows:
As one team, the three students will support each other in the fieldwork in Vietnam as well as in the simulation work, together with the ICRAF modelling team in Bogor and in closely exchange with the MSEC team in Vietnam (by email with D. Orange). The focus of the thesis work of the three the students are as follow:

- ***La Nguyen*** *thesis with focus on role of Bamboo as filter species in transect 1 and simulation with WaNuLCAS.*
- ***Lina Norlin*** *thesis with focus on (1) Calibration of WaNuLCAS and (2) the "on-site" effects of trees as filter using WaNuLCAS in transect 2,*
- ***Carina Ortiz*** *thesis with focus on (1) Calibration of GenRiver and (2) "on-site" and "off-site" effects of trees as filter, simulation with GenRiver on watershed leve*

- -Co-coordination of a doctoral thesis in Paris VI (Miss Le Thi Phoung Quynh) with Josette Garnier (Paris VI) and Minh Van Chau (NCSTV) supported by CNRS (2002-2005).

Study work: *Hydrological modeling and matter flux transport in a large river basin : the Red River Basin.*

- -Three French students.

Study work1: *GIS assisted modeling: PLER model for MSEC Vietnam study.*
Study work2: *Modelling of event-based soil erosion in North Vietnam.*
Study work3: *Agricultural land-use and hydrological behavior in a small farming watershed in the North Vietnam.*

Training

- Training on Hydrological data management with Hydras-3 software, in IWMI-Bangkok, coordinator: J-P Bricquet and **the participation of D. D. Phai as trainer**.
  Vietnamese trainees: N. D. Phuong, P.H. Hai An (student)

Capacity building.

Information Dissemination

Scientific Papers

Erosion control within a cultivated sloping land in North Vietnam. 2003. Tran Duc Toan, Orange D., Podwojewski P., Do Duy Phai, Thai Phien. *Oral paper presented at the Symposium on Soil quality and evolution mechanism and sustainable use of soil resources, ISSAS / Yingtan, Jiangxi Province, China September 23-28, 2003*

An environmental DSS for a large tropical flooded ecosystem: the inner Delta Niger River. 2004. Didier ORANGE, Marcel KUPER, Christian MULLON, Yveline PONCET , *International Environmental Modelling and Software Society, IEMSs : "Complexity and Integrated Resources Management", Osnabrück, 14-17 June 2004*

Reports

Bayer A., 2003. Comportement hydrologique d'un petit bassin versant agricole sur fortes pentes au Nord Vietnam. Memoire DESS, Universite de Grenoble.

Renaud J., 2003. Cartographie des sols de la région de Dong Cao (bassin du fleuve rouge, Vietnam du Nord) Creation d'un SIG et modélisation de l'érosion sur des basins versant à fortes pentes. Mémoire de Maîtrise. IUP Montagne CISM, Université de Savoie, Le Bourget du Lac.

Workshop, Congress, Seminar

1. "Dialogue", Water and Food, IWMI, Hanoi, October 2002
2. Scientific Seminar on "Water quality and treatment in Hanoi", NCSTV-CNRS, Hanoi, February 2003
3. "National workshop for pro-poor project", VIWRR-IWMI, Hanoi, May 2003
4. "MSEC meeting" in Laos, October 2003
5. Seminar on "Information Technology and Communication for Natural disaster warning and mitigation", ISTED-MARD, Hanoi, November 2003

Collaboration and Opportunities

Visitors to Vietnam

- Vincent Chaplot (IRD/IWMI Laos), 1 week
- Sylvain Huon (Univ. Paris VI), 2 weeks
- Matthew Kurian (IWMI-SEA), 1 week
- Christian Valentin (IRD/IWMI Laos), 3 days
- Jean-Pierre Bricquet (IRD/IWMI Bangkok), many times
- Jean-Louis Janeau (IRD/IWMI Bangkok), 1 week
- Guillaume Lestrelin (IRD Laos), 1 week
- Norbert Silvera (IRD/IWMI Laos), many times
- Jean-Pierre Thiebaux (IRD/IWMI Laos), many times
- Josette Garnier (CNRS, Paris VI), 1 week

Trips Abroad

- Tran Duc Toan: Sweden, Laos, Thailand, China
- Do Duy Phai: Thailand, Laos
- Pham Ha Hai An: Thailand
- Pascal Podwojewski: Laos, Thailand, China
- Didier Orange: Laos, Thailand, China, France

Faculty of Chemistry,Univ. of Hanoi

Scientific purpose: Nitrogen and carbon cycle in the rural environment.
Four students.

Institute of Chemistry, NCSTV

Scientific purpose: Particulate and Dissolved Organic Carbon in the streams, matter flux transported by the rivers.
One student (doctoral thesis) and one BSc in detachment..