Impact of Land Use on Generation of High Flows in the Yarsha Khola Watershed, Nepal

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Abstract

Flood generation has been the focus of discussions in the Hindu Kush-Himalayan region for decades. There are still differences in opinion about whether the land use practices of local farmers are responsible for downstream flooding. The present paper discusses the differences in stream flow generation from lands put to different use, in particular grazing and rainfed agricultural land. The results from sub catchments and erosion plots were compared during different flood events. The results suggest that grazing areas generally make a high contribution to runoff. During events with high rainfall intensities, all types of land use contribute to runoff. This suggests that under present conditions land management and land use has a limited influence on the generation of the highest flood events.

Introduction

Flooding and subsequent stream bank erosion are a severe problem in the foothills and adjacent plains areas of the Himalayas. Although different authors have stressed the importance of the farming practices of Himalayan farmers in the generation of flood events, opinions about their importance in this process differ widely.

This paper is concerned with the generation of high flow events at the watershed scale. Investigation of stream bank erosion, both active destruction like cutting and scoring and deposition within the watershed, is planned for the future. The contribution from different spatial levels (sub-catchments and plots) was determined and compared with the flow events at the main hydrological station. It is of interest to determine to what extent interventions at plot level are successful in preventing flooding. The question of the influence of different land use was addressed and thus the influence of different farming practices investigated.

The Study Area

The Yarsha Khola watershed covers 53.4 sq.km. and is located about 190 km east of Kathmandu on the Lamosangu-Jiri Road in Dolakha District. A network of meteorological and hydrological stations was established within the watershed during 1997 (Figure 68).

The network was set up according to nested approach principles as described in detail in Hofer (1998). For the purposes of this study, the watershed was divided into two sub-catchments, one predominantly on the south facing slope, referred to as the Yarsha Khola sub-catchment, and the other on the north-facing slope, the Gopi Khola sub-catchment. Smaller sub-catchments within these two sub-catchments, with different land use and cover, were monitored. Table 56 shows the key characteristics of these sub-catchments. Erosion plots, each monitoring 100 sq.m. of grazing land or rainfed agricultural land, were established within some of the smaller sub-catchments. The important physical aspects of the Yarsha Khola erosion plots are summarised in Table 57.

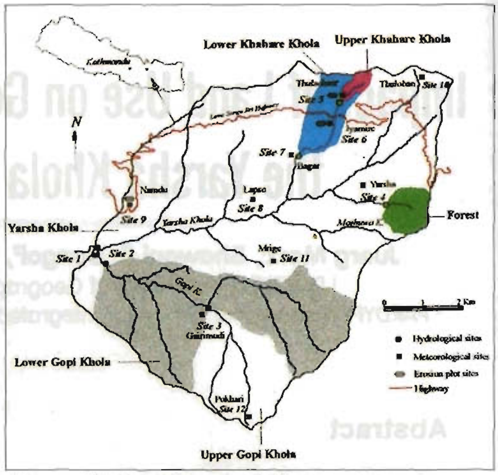

Figure 68: **Location and Measurement Network of Yarsha Khola Watershed**

For reasons of data availability, the present study focused on the hydrological stations along the Khahare Khola (Thulachaur, site 5, and Bagar, site 7), along the Gopi Khola (Gopi

Table 56: Characteristics of the Yarsha Khola Watershed and the Monitored Sub-catchments

Site No.	Catchment (Site Name)	Catchment Size (sq.km.)	Altitude (masl)	Land Cover (%)	
1	Yarsha Khola watershed (Main Hydro Station)	53.4	990-3050	Khet:13.9 Bari:37.4 Forest:31.5	Grass:5.7 Shrub:5.0 Other:6.5
	Yarsha Khola sub -catchment	36.0	990-3050	Khet:14.3 Bari:35.8 Forest:31.6	Grass:6.5 Shrub:5.1 Other:6.8
2	Gopi Khola sub-catchment (Gopi Khola)	17.4	1040-2495	Khet:13.3 Bari:40.8 Forest:31.4	Grass:3.9 Shrub:5.0 Other:5.7
5	Upper Khahare Khola sub-catchment (Thulachaur)	0.3	2280-2730	Khet:0 Bari:15.6 Forest:40.6	Grass:3.1 Shrub:25.0 Other:15.6
7	Lower Khahare Khola sub-catchment (Bagar)	2.1	1740-2730	Khet:0 Bari:50.5 Forest:14.4	Grass:10.1 Shrub:20.2 Other:4.8

Note: *Khet* = irrigated agricultural land *Bari* = rainfed agricultural land

Table 57: Characteristics of Erosion Plots in the Yarsha Khola Watershed

Site No.	Site Name	Land Cover	Soil Type	General Slope (deg)
5	Thulachaur	Grass/shrub land	Dark brown sandy loam	19.1
6	Jyamire	Terrace cultivation	Non red sandy loam	17
9a	Namdu	Terrace cultivation	Red loam	17.5
9b	Namdu	Grassland/fallow	Red sandy loam	17.5

Khola, Site 2), and at the main hydrological station (site 1)—see Figure 68. Sites 4 (Forest) and 3 (Gairimudi) were upgraded during 1998 so that when this study was done there was no complete and reliable data set available for either site. The rainfall data were taken from the sites in the relevant sub-catchments (Gairimudi (site 3; pure rainfall station), Thulachaur (site 5), and Bagar (site 7)), and the meteorological stations close to the erosion plots (Jyamire (site 6), and Namdu (site 9)).

Discharges were determined indirectly by measuring the water level and calculating the discharge using a rating curve. At the main station, the water level is measured digitally by means of a pressure transducer and logger (a Kern FL-2) which records values at five minute intervals during the monsoon (June to September) and at 15 minute intervals during the rest of the year. The other stations are equipped with a hydrograph floater (Ott R-16) that delivers analogue data. The analogue data is then digitalized on a 30 min interval basis for the monsoon season, and on a 60 minute basis during the rest of the year. Readings from the equipment are cross-checked with daily readings from staff gauges by local readers. The discharge used to establish the rating curves was measured using the dilution method. Uranin was used as a tracer at sites 1 and 2, a salt tracer technique was employed at the other stations. The discharge of the Yarsha Khola sub-catchment was determined by subtracting the discharge at the Gopi Khola station from the discharge measured at the main hydrological station.

The rainfall data was derived from 8" diameter tipping buckets with a 0.2mm capacity per tip. Each event of ≥0.2mm is recorded on a HOBO logger. This data was cross-checked with the data from ordinary daily 8" diameter storage rain gauges.

Hydrological Conditions During the Period of Investigation – the 1997 and 1998 Monsoons

More than 80 per cent of the annual rainfall in 1998 fell during the monsoon season (Merz *et al.* 1999). Major high flow events with subsequent stream bank erosion are only expected during this season. Figure 69 shows the daily discharge hydrographs for the two monsoon seasons 1997 and 1998 at the main hydrological station.

The hydrographs of daily discharge at the main hydrological station show only a slightly different picture for the two years. For example, the onset of monsoon discharge was earlier in 1998, beginning in late June to early July, whereas in 1997 the monsoon only resulted in higher discharges in early to mid July. However, the mean discharge of 5.07 cu.m/s in 1997 was slightly higher than that of 4.75 cu.m/s in 1998 (Figure 69). The discharge in 1998 was more homogenous. The minimum discharge during the study period was lower in 1997 than in1998 (0.69 cu.m/s compared to 1.94 cu.m/s) and the maximum discharge higher (16.69 cu.m/s compared to 13.25 cu.m/s). This resulted from the later onset of the monsoon in 1997, and the impact of the 16th and 17th July 1997 when there was an exceptionally big event. The maximum of that event was 56 cu.m/s (Doppmann 1998; corrected value). In

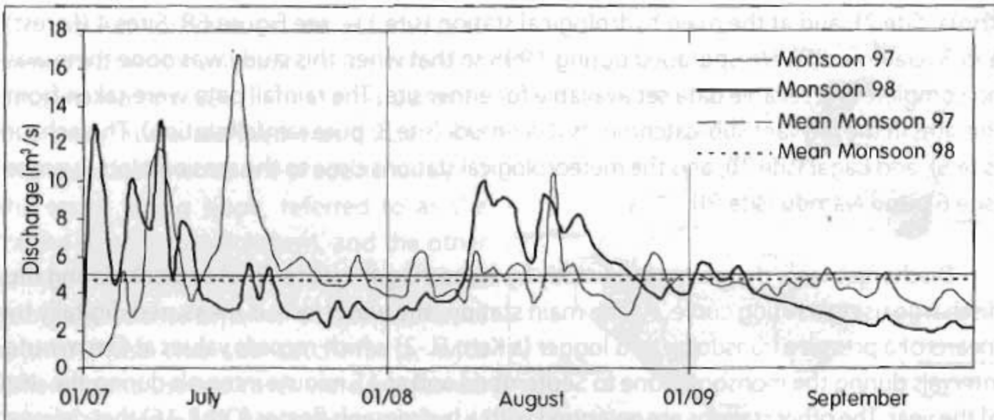

Figure 69: **Daily Discharge Hydrographs for the Monsoon Seasons 1997 and 1998 at the Main Hydrological Station, Yarsha Khola Watershed**

comparison, the highest peak discharge in 1998 was only 28.46 cu.m/s. In both years, the main events happened in early to mid July and mid August with a period of small events in between. September was calm in both years but during the 1997 monsoon the base flow was sustained during the month, whereas in 1998 it fell to post-monsoon flow immediately after the first week of September.

The daily discharge contributions of different sub-catchments to the total discharge at the main hydrological station are shown in Table 58.

The contribution of each sub-catchment depends mainly upon rainfall input. The Gopi Khola sub-catchment receives less rainfall proportionately than the Yarsha Khola sub-catchment, and its contribution to the total output of the watershed was lower than might be expected from the size of the catchment. However, the contributions of the Lower Khahare

Table 58: **Contribution of Different Sub-catchments to Areal Rainfall and Total Discharge of the Yarsha Khola Watershed, the Yarsha Khola Sub-catchment, and the Lower Khahare Khola Sub-catchment; Monsoons 1997 and 1998**

	Yarsha Khola Watershed				Yarsha Khola Sub-catchment				L. Khahare Khola sub-catchment			
	Area	Rain	D97	D98	Area	Rain	D97	D98	Area	Rain	D97	D98
Yarsha Khola sub-catchment	67	80	79	70	–	–	–	–	–	–	–	–
Gopi Khola sub-catchment	33	20	21	30	–	–	–	–	–	–	–	–
L. Khahare Khola sub-catchment	4	5	7	6	6	7	9	9	–	–	–	–
U. Khahare Khola sub-catchment	0.6	1	1	2	1	1	2	2	15	17	21	29

Rain: Average value for monsoons 1997 and 1998 according to Doppmann (1998)
D97: discharge contribution in 1997; D98: discharge contribution in 1998

Khola and the Upper Khahare Khola were slightly bigger (trend) than expected from their area and rainfall input.

One possible reason for these differences could be the different response of the sub-catchments to rainfall events, possibly as the result of different land cover conditions. The main difference between the different sub-catchments is the proportion of land in each under grassland, shrubland, and 'other' land use categories (Table 56). In the Upper Khahare Khola sub-catchment, 43.7 per cent of the land is in these land cover classes, and in the Lower Khahare Khola, 35.1 per cent, compared with 18.4 per cent in the Yarsha Khola sub-catchment as a whole and 14.6 per cent in the Gopi Khola sub-catchment. In addition, the fairly extensive forest in the Upper Khahare Khola sub-catchment is of very low quality and partially degraded and overused. The more than proportional contribution, in terms of both rainfall and area, of the Upper Khahare Khola sub-catchment to the flow of the Lower Khahare Khola measured at Bagar is therefore not surprising. Overall, the water retention capacity of the Lower and the Upper Khahare sub-catchments appeared to be lower than in the other sub-catchments, as indicated by the higher percentage of discharge originating from the two sub-catchments in comparison with the other sub-catchments.

High Flow Events at the Main Hydrological Station

The contribution of the different sub-catchments to total discharge was calculated on a long-term basis. We also investigated whether the same holds true for short-term periods or single events. Tipping bucket rainfall data was only available for 1998, so the generation of high flow events at the main station was only investigated for 1998. There was no big difference in daily discharge between the two monsoon seasons 1997 and 1998, however, so the results for the 1997 season are likely to have been similar. In order to understand the generation of high flow events at the main hydrological station, the five biggest events in 1998 in terms of peak event flow were selected and investigated at different spatial levels. Table 59 shows the characteristics of the selected events at the main hydrological station and Table 60 the rainfall characteristics of the same events across the watershed.

Four of the major events occurred in the period early to mid July and one in mid August. Most of the big events occurred during the night so that establishing the upper part of the rating curves was not easy.

Table 59: **Characteristics of Major Events in 1998 at the Main Hydrological Station, Yarsha Khola Watershed**

Date	Peak flow (cu.m/s)	Specific Discharge ($l/s*km^2$)	Mean discharge (cu.m/s)	Quick Flow (cu.m)	Time of Peak
09/07/98	28.46	530	12.75	25'518	4:00
02/07/98	27.63	520	12.73	28'785	2:00
03/07/98	18.73	350	10.69	21'512	0:00
17/08/98	18.11	340	9.11	13'061	4:00
05/07/98	17.51	330	9.26	25'198	16:00

Table 60: **Rainfall Characteristics of High Flow Events**

Date	Yarsha Khola												Gopi Khola		
	Thulachaur (5)			Jyamire (6)			Bagar (7)			Namdu (9)			Gairimudi (3)		
	P	D	I	P	D	I	P	D	I	P	D	I	P	D	I
09/07/98	43.8	477	5.5	69.0	540	7.7	73.2	640	6.9	66.2	687	4.2	88.2	889	6.0
02/07/98	82.4	496	10.0	81.2	603	8.1	85.8	435	11.8	35.8	378	5.7	41.0	392	6.3
03/07/98	89.0	480	11.1	57.0	482	7.1	54.4	450	7.3	26.2	371	4.2	47.6	331	8.6
17/08/98	49.6	938	3.1	48.2	708	4.1	51.5	780	4.0	18.0	78	4.5	29.2	734	2.4
05/07/98	47.2	289	9.8	58.6	1074	3.3	57.1	205	16.7	15.2	1229	0.7	13.0	58	13.4
Mean*	21.1	540	4.2	18.6	540	3.1	16.0	295	4.5	17.2	499	4.0	15.5	516	4.3
Max*	95.0	-	-	89.6	-	-	85.8	-	-	85.6	-	-	88.2	-	-

P = amount of rainfall during event (mm) D = duration of event (min) I = average intensity of event (mm/h)
* = mean and max for all events during 1998, calculated from whole year data set

The biggest event in 1998 was observed on July 9th. Peak discharge, the most important parameter for the assessment of stream bank erosion and flooding, reached a level of 28.46 cu.m/s. This represents a specific discharge of 530 l/s*km². The mean event discharge was in all cases between two and three times higher than the mean daily discharge of 4.75 cu.m/s during the whole period of the monsoon 1998.

Widespread rainfall over the whole area of the watershed is needed to generate a high flow event. During the first event there was high rainfall in both the major sub-catchments, Gopi Khola and Yarsha Khola. In the July 5th event, the smallest of the five, the amount of rainfall was only high in the upper areas of the Yarsha Khola sub-catchment, as was the case in the other three events, although the differences between the upper and lower areas in these events were smaller. In general, a high flow event is generated by rainfall events above the average amount and below the mean event duration . The average event intensity was above the average for the year in all the five biggest events in 1998.

The instantaneous intensity is also important. Both the maximum 60 minute rainfall intensity and the maximum 10 minute intensity at Bagar (main meteorological station) were high in all five events (Table 61). In the event of July 5th, rainfall amounts in the lower and southern parts of the watershed were comparatively low, but the maximum annual rainfall intensities were recorded for Bagar (main meteorological station).

In all cases, the rapid response of the main station to high rainfall events in the sub-catchments was visible. The rapid response is indicated by the low lag times between the maximum hourly rainfall intensity at Bagar and the peak flow (compare Tables 59 and 61). The peak flow was generally reached within 1 to 2 hours after the maximum 60 minute rainfall intensity was recorded. The lag times between peak flow and maximum 10 minute rainfall intensity of the events show a similar picture.

The discharge from the different sub catchments during the five events is shown graphically in Figure 70. The rapid response of the main station to the events can be seen clearly. Visual comparison shows no obvious similarities between the events. In all cases there was a contribution from both north and south facing slopes. The contribution of the Gopi Khola sub-catchment was generally quite low, except during the biggest event of July 9th. The Lower Khahare Khola measured at Bagar seemed to make a decisive contribution to

Table 61: Instantaneous Maximum Rainfall Intensities at Bagar (Main Meteorological Station), Yarsha Khola Watershed

Date	60min intensity		10min intensity	
	(mm/h)	Time	(mm/h)	Time
09/07/98	29.1	2:50 – 3:50	36.2	2:45 – 2:55
02/07/98	39.0	1:05 – 2:05	60.3	1:40 – 1:50
03/07/98	29.7	21:05 – 22:05	47.0	21:15 – 21:25
17/08/98	25.5	1:55 – 2:55	41.0	2:35 – 2:45
05/07/98	50.5	14:35 – 15:35	92.9	14:50 – 15:00
Annual Maximum	50.5	05/07/98	92.9	05/07/98

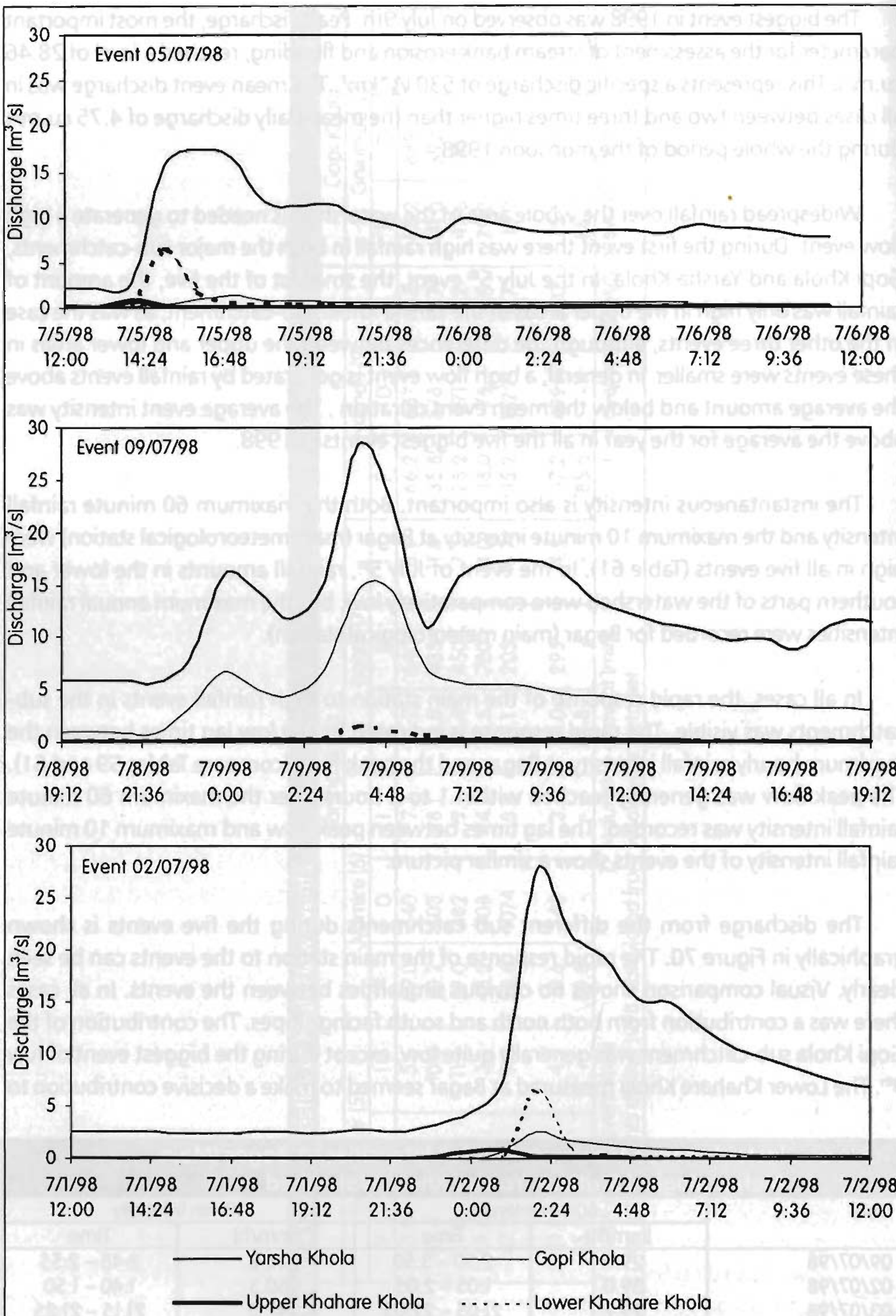

Figure 70: **The Five Biggest Events of 1998 at the Main Hydrological Station in Comparison with Events at Three Selected Sub-catchments, Yarsha Khola**

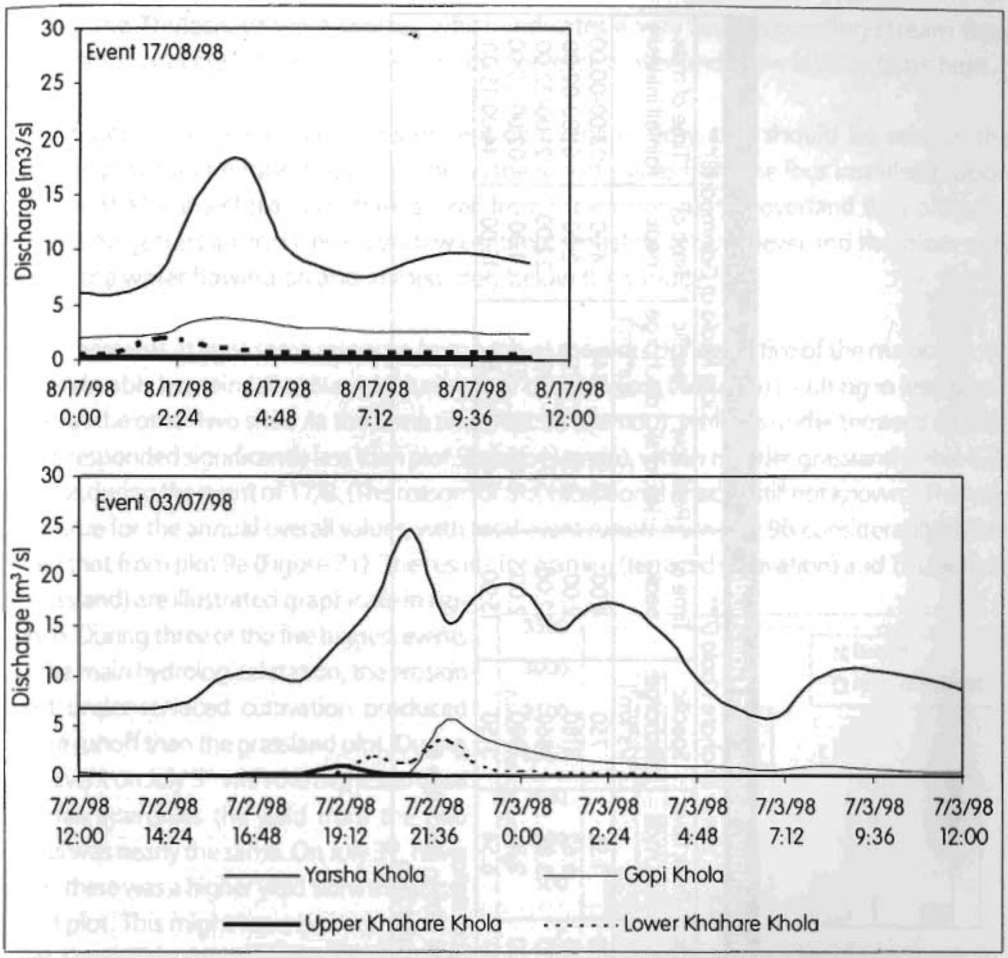

Figure 70: **The Five Biggest Events of 1998 at the Main Hydrological Station in Comparison with Events at Three Selected Sub-catchments, Yarsha Khola (cont'd)**

flood events, with a flood event generally measured at Bagar during flood events at the main hydrological station. The contribution of the Upper Khahare Khola measured at Thulachaur was similar, as also seen from the specific discharge values in Table 62. The specific discharge values (runoff per unit area) were very high in all events at Thulachaur and at Bagar, which indicates a high contribution of the two sub-catchments. The Gopi Khola sub-catchment did not yield any major runoff except during the first event.

The rapid response of the watershed to the rainfall events is indicated by the steep and fast change of the rising limb of the hydrograph. This rapid response indicates simultaneous rapid response to stream flow generation processes such as overland flow and/or subsurface storm flow. According to Anderson and Burt (1990), lag times of one to two hours indicate saturation overland flow at a watershed size of around 50 sq.km.

The lag times of the Gopi Khola showed a similar rapid response to maximum rainfall (Table 7, compare "Time of peak" and "Time of max rainfall intensity"). The lag times at

Table 62: **Characteristics of Selected Events at Sites Thulachaur, Bagar and Gairimudi**

Date	Upper Khahare Khola (5)*				Lower Khahare Khola (7)**			Gopi Khola at Gairimudi (3)***			
	Peak flow (cu.m/s)	Specific discharge (l/s*km²)	Time of peak	Time of max rainfall intensity	Peak flow (cu.m/s)	Specific discharge (l/s*km²)	Time of peak	Peak flow (cu.m/s)	Specific discharge (l/s*km²)	Time of peak	Time of max rainfall intensity
09/07/98	0.14	440	4:00	03:00-04:00	1.56	750	4:00	14.53	840	4:00	23:00-00:00
02/07/98	0.86	2700	1:00	01:00-02:00	6.62	3180	2:00	2.59	150	2:00	01:00-02:00
03/07/98	1.02	3200	19:00	19:00-20:00	3.88	1860	22:00	5.76	330	22:00	21:00-22:00
17/08/98	0.22	700	2:00	02:00-03:00	2.10	1000	2:00	3.69	210	4:00	02:00-03:00
05/07/98	0.84	2630	14:00	14:00-15:00	6.54	3150	15:00	1.46	80	16:00	14:00-15:00

* Rainfall intensity from Thulachaur (Site 5) meteorological station

** For rainfall intensity from Bagar (Site 7) meteorological station see Table 61

*** Rainfall intensity from Gairimudi (Site 3) meteorological station

Bagar and Thulachaur were shorter, which indicates a very fast responding stream flow generation process. The influence of 'infiltration excess overland' flow is likely to be high.

If storm events are mainly dependent on overland flow, this should be seen in the erosion plot data for runoff. Table 63 shows the runoff values from the four installed erosion plots in the Yarsha Khola. Runoff measured from the erosion plots is overland flow only; the collection gutters are inserted only a few centimetres below ground level and therefore only catch the water flowing on and immediately below the surface.

There was at least some response from each of the plots during all five of the major events. Considerably less rain fell at Namdu during four of the events (Table 60) resulting in less runoff than at the other two sites. At the same time, Plot 9a (Namdu), which is under terraced cultivation, responded significantly less than plot 9b (also Namdu), which is under grassland (Table 62), except during the event of 17/8. (The reason for this exceptional effect is still not known.) This was also true for the annual overall values, with total event runoff from plot 9b considerably higher than that from plot 9a (Figure 71). The results for Jyamire (terraced cultivation) and Thulachaur (grassland) are illustrated graphically in Figure 6. During three of the five biggest events at the main hydrological station, the erosion plot under terraced cultivation produced more runoff than the grassland plot. During the event on July 5th with the highest annual rainfall intensities the yield from the two plots was nearly the same. On July 3rd, however, there was a higher yield from the grassland plot. This might have been due to the wet antecedent moisture conditions (from the big event on July 2nd). In contrast, the agricultural plot (Jyamire) reacted less overall than the grassland plot (Thulachaur) during events of average rainfall intensity and

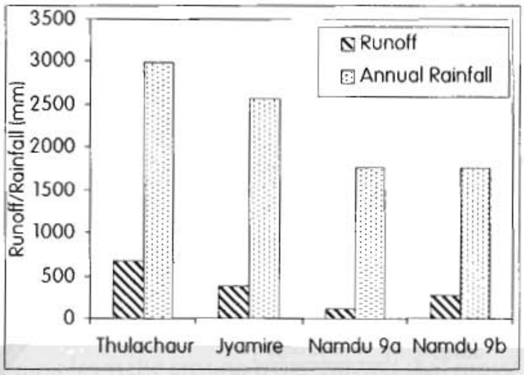

Figure 71: **Total Event Runoff for 1998 from Erosion Plots in Comparison with Total Rainfall Measured at the Sites, Yarsha Khola Watershed**

Table 63: **Runoff from Erosion Plots during the Five Biggest Events at the Main Hydrological Station, Yarsha Khola Watershed (runoff in cu.m/ha)**

	Lower Khahare Khola sub-catchment		Yarsha Khola sub-catchment	
	Thulachaur (5)	Jyamire (6)	Namdu (9a)	Namdu (9b)
	Grass/Shrub land	Terrace cultivation	Terrace cultivation	Grassland
09/07/98	127.7	264.6	27.4	269.8
02/07/98	113.7	281.8	11.0	54.6
03/07/98	295.9	196.4	8.4	53.9
17/08/98	137.6	184.0	88.9	86.6
05/07/98	296.1	278.7	1.6	4.4
Maximum*	297.4	288.5	103.1	269.8
Median*	14.7	6.2	4.9	9.1

* Maximum and median are calculated from the whole year data set, i.e., annual maximum and median

amount, as shown by the annual median value (Table 63) and annual total event runoff, both of which were higher for Thulachaur than for Jyamire (Figure 71).

Figure 72 shows the runoff values for all the events observed in 1998 at the agricultural plot (Jyamire) and the grassland plot (Thulachaur) in one graph. Events of more than 100 cu.m/ha runoff were investigated closely and connected with a line: a thick line when runoff from the agricultural land was higher than runoff from the grassland, and a thin line when runoff was higher from the grassland plot. The runoff from the two plots during the five biggest events at the Main Hydrological Station is shown in Figure 73.

During most of the events (including those below 100 cu.m/ha), the grassland plot yielded more runoff, which led to a higher total annual runoff as shown in Figure 71, and a higher median (Table 63). Thus grassland is more likely to contribute to flood events than rainfed agricultural land, especially during low and medium rainfall events. However, there were a number of situations in which the runoff from the rainfed agricultural land was higher than from the grassland. During the pre-monsoon, the rainfed agricultural land is fallow and infiltration capacity is lower than in areas where vegetation cover exists at this time of the year. Excess water is therefore more likely to run off, as shown during the first two major events in the year. The reason for the reversal on June 3rd has yet to be identified. During the monsoon, the occasions of higher runoff from the rainfed agricultural land coincided with the highest flows at the main station. But there were exceptions. The conditions which lead to these situations during the monsoon need to be investigated further.

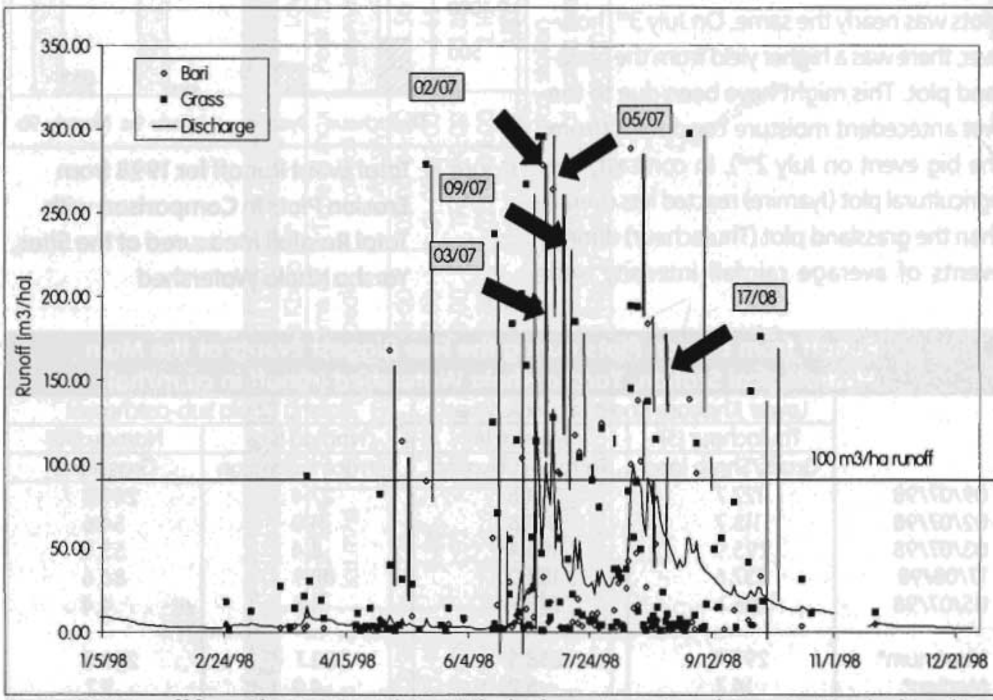

Figure 72: **Runoff from the Erosion Plots at Thulachaur (grass) and Jyamire (agricultural) (event based)**

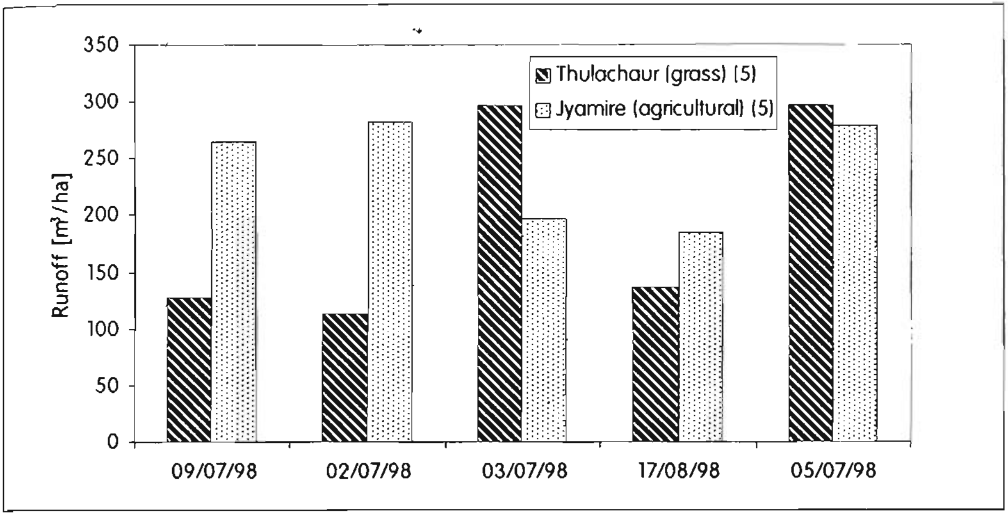

Figure 73: **Runoff from Selected Erosion Plots during the Biggest Events at the Main Hydrological Station**

Discussion

This study showed that there is a difference in the contribution from the different sub-catchments to the total discharge from the watershed. Although there is a difference in rainfall input between the different sub-catchments, this alone does not account for the different contribution.

During the monsoon, the Upper Khahare Khola (measured at Thulachaur), the sub-catchment with the highest portion of grass and shrub land, showed the biggest contribution to total discharge. Similarly, the annual runoff data from the erosion plots showed that grass/shrub land produced more runoff than cultivated terraces. It seems likely that as a result of the lack of cultivation and the relatively compact nature of the soil (a result of intensive grazing and animal trampling), the water retention capacity is lower during the monsoon in the grass/shrub land than in the rainfed agricultural land—which leads to a bigger contribution to discharge by the grass/shrub land dominated sub-catchments.

During high intensity storm events with high rainfall amount, both grassland and sloping agricultural terraces are likely to contribute to discharge as is shown in the erosion plot data. During the biggest events measured in terms of rainfall intensity and amount, rainfed agricultural land reacts intensively, and more than the grass/shrub land. This fact is likely to be important for investigations of high flood generation, and the conditions and reasons for this major response need to be studied closely. During these intense events on the sub-catchment scale, the yield of Bagar, with a high portion of sloping terraces and grass/shrub land, was even higher than that of Thulachaur.

Land cover (grass/shrub land or sloping terraces) clearly has an influence on the occurrence of high flow events, with a larger contribution from sloping terraces especially in the pre-monsoon season and during big events. Overall, however, grass/shrub land yields more than other types of land cover.

Conclusion

The most important events for flooding and stream bank erosion are the major events. The results show that during these events runoff is derived from all types of land cover and land use. Thus the influence of human activity on the generation of these major events in rural catchments is believed to be limited. The same conclusion has been reached in the Swiss Alps. On the other hand, medium-sized events might be influenced by land use changes and differences in land management practices. Carver (1995) reported that indigenous techniques are effective at low and intermediate flows, but less effective at high flows, regardless of land cover and season. A change in the area of agricultural land, as might happen with increasing population pressure and increasing demand from the markets in Kathmandu, might therefore have a major impact on the generation of small to medium flood events, but only a limited effect on big flood events.

However, conclusive remarks cannot be made at this stage as the results are based on the data from only one year, and the influence of forested catchments has yet to be investigated. Future studies will be focused on further understanding of the processes in areas with different land cover during major events, and a comparison of the responses to rainfall events from different types of land cover, land use, and land management practices.

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