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COMPARISON OF RUNOFF AND SEDIMENT YIELD FOR TWO NEIGHBOURING CATCHMENTS IN THE PHILIPPINES

SUE WHITE

Instituto Pirenaico de Ecología (CSIC), Apdo. 202, 50080 Zaragoza (Spain)

Abstract. During the 1980's two river catchments in the mountains of northern Luzon, Republic of the Philippines, were studied in varying detail (White, 1987; Amphlett and Dickinson, 1989; Dickinson et al, 1990; White, 1992). In one, the Magat catchment, a detailed field programme lasting several years was carried out. This included measurement of runoff and sediment yield rates from small, single use, catchments, together with a series of nested river monitoring sites where discharge and sediment transport rates were recorded, and a survey of sedimentation in the reservoir at the downstream end of the catchment. In contrast, for the neighbouring Casecnan catchment few sediment yield data were available, but discharge and rainfall were monitored for a period of six years. In addition, maps of land use, geology/geomorphology, soils and elevation/slope were available for both catchments. This paper provides a comparison of the physical characteristics, the discharge and the sediment yield in the two catchments, with possible explanations for the differences observed. Potential for increasing discharge and sediment yield in the, as yet undeveloped, Casecnan catchment is discussed.

Key Words: Sediment yield, discharge,catchments,land use, cyclones, Philippines

Resumen. Durante los años 80 se han estudiado dos cuencas en las montañas del norte del Luzón, Republica de las Filipinas (White, 1987; Amphlett and Dickinson, 1989; Dickinson et al, 1990; White, 1992). En una de ellas, la cuenca de Magat, se ha desarollado un programa detallado de trabajo de campo, que incluye medidas a diferentes escalas: caudal y aporte de sedimentos en pequeñas cuencas con uso de suelo uniforme, medidas de caudal y tranporte de sedimentos en ríos, y control de la sedimentación en el embalse a la salida de la cuenca. En contraste, para la cuenca de Casecnan, al lado de Magat, se disponía de pocos datos de transporte de sedimentos, pero existían datos diarios de caudal y lluvia durante seis años. Además, había mapas de uso del suelo, geología/geomorfología, suelos y altitud/pendiente para ambas cuencas. En este articulo se comparan las caracteristicas físicas, el caudal y el aporte de sedimentos de las dos cuencas, con posibles explicaciones de las diferencias. Se discute asimismo el potencial aumento del caudal y del aporte de sedimentos en la cuenca de Casecnan, todavía no desarollada.

Palabras claves: Aporte de sedimentos, caudal, cuencas, uso de suelo, ciclones, Filipinas

1. Introduction

The Philippines are located in the Pacific Ocean between China, Vietnam and Indonesia. The physical environment of the country is very fragile. The islands are located in an area of active mountain building with frequent earthquakes and volcanic eruptions. Geologically, the mountains are mainly formed of basic rock types of the Mesozoic period, although a significant proportion consists of Tertiary volcanic formations. Evidence of geologically recent and pronounced movement can be seen in the coralline limestone at considerable elevations in Palawan, Mindanao, Cebu and Northern Luzon. Elevations range from sea level to around 3000 m over distances of 30 km. Slopes are, therefore, extreme, frequently exceeding 50%. The natural vegetation of the islands is forest (mossy, Dipterocarp or Mangrove). However, a land use survey in 1988 (Swedish Space Corporation, 1988) showed only 25% of the country under forest, with 41% under extensive cultivation (mainly grasslands) and 34% under intensive cultivation (mainly arable crops and coconut plantations). Of the remaining forest only 14% is primary undisturbed forest (Barbier, 1993). The majority of soils are shallow and, once disturbed, are easily degradable.

Population growth has been rapid since 1900, with an average annual increase from 1980 to 1987 of 2.4% (World Bank, 1988). This population is very unevenly spread with only 8 persons per square kilometre in Palawan, between 60 and 160 in Mindanao and most of Luzon, and 32,000 in Manila. Population growth in rural areas has tended to fall in recent years as more young people move to the cities in search of work. However, clearance of forest still continues due to the activity of timber companies, largely for the export market.

Climatically, the Philippines has an ideal combination of intense rainfall and extreme flood events for accelerated soil erosion and sediment transport. Annual rainfall ranges from 1000 mm to over 4000 mm, with between 100 and 240 rain days per year. Of these rainy days, between 30 and 80 have convective thunderstorm activity, with rainfall intensities often exceeding 100 mm hr^{-1}. The islands also lie in the area of the world most affected by tropical cyclones, with a long-term annual mean of 19.4 (Flores and Balagot, 1969). There is no real dry season in most of the country, but a large proportion of mean annual flow can be supplied by one cyclone event. This irregular distribution of rainfall, coupled with the need for irrigation to provide sufficient of the staple food crop of rice, means that reservoirs are necessary.

In addition, the Philippines, like many other Asian countries, suffers from its dependence on oil for energy. Thus, reservoirs can serve a two-fold purpose, supplying water for irrigation and generating power.

The fragility of the physical environment, linked with the clearance of large areas of forest, and lack of soil conservation measures, means that reservoir sedimentation has been much more rapid than expected, and is an increasing problem. Sedimentation rates double those estimated before construction are not uncommon (Abernethy, 1984; Wooldridge, 1986), and of more concern, appear to be increasing at around 50% per decade (Abernethy, 1987). The only long-term solution is good catchment management, although engineering measures may provide a short-term solution in some locations. However, in order to manage a catchment well, the hydrology and processes of erosion, sediment transport and deposition must be understood.

2. The Magat and Casecnan catchments

The Magat catchment is situated on the main island of Luzon, Republic of the Philippines (Fig. 1). In December 1982 construction of a dam across the Magat river at Ramon was completed. The catchment area to the dam is approximately 4143 km^2. The dam was constructed to provide both power and irrigation water and other benefits include the development of fisheries in the reservoir.

The population of the Magat catchment is increasing, but not as fast as the rate predicted for the Philippines as a whole. In 1977 the projected population growth rate for the Philippines was 2.0% per year. In fact from 1975 to 1980 the Magat catchment showed a population increase of only 0.3% per year. Many young people are leaving the area to try to find employment in Manila or overseas. This is clearly demonstrated in the north of the catchment, where the renowned Banaue rice terraces are falling into disrepair because the older people who remain in the area are unable to maintain them.

Before the detailed study in Magat commenced, two main studies had been carried out to assess discharge frequency and likely maximum river discharges. The Magat Watershed Feasibility Study

(National Irrigation Administration and Engineering Consultants Inc., 1978) was primarily concerned with the reliability of water supply for the proposed reservoir. The work in this report therefore concentrated on monthly and annual discharges. In addition, daily discharge data were available for Baretbet (Fig. 1), for the periods 1977-1981 and 1983-1984 inclusive.

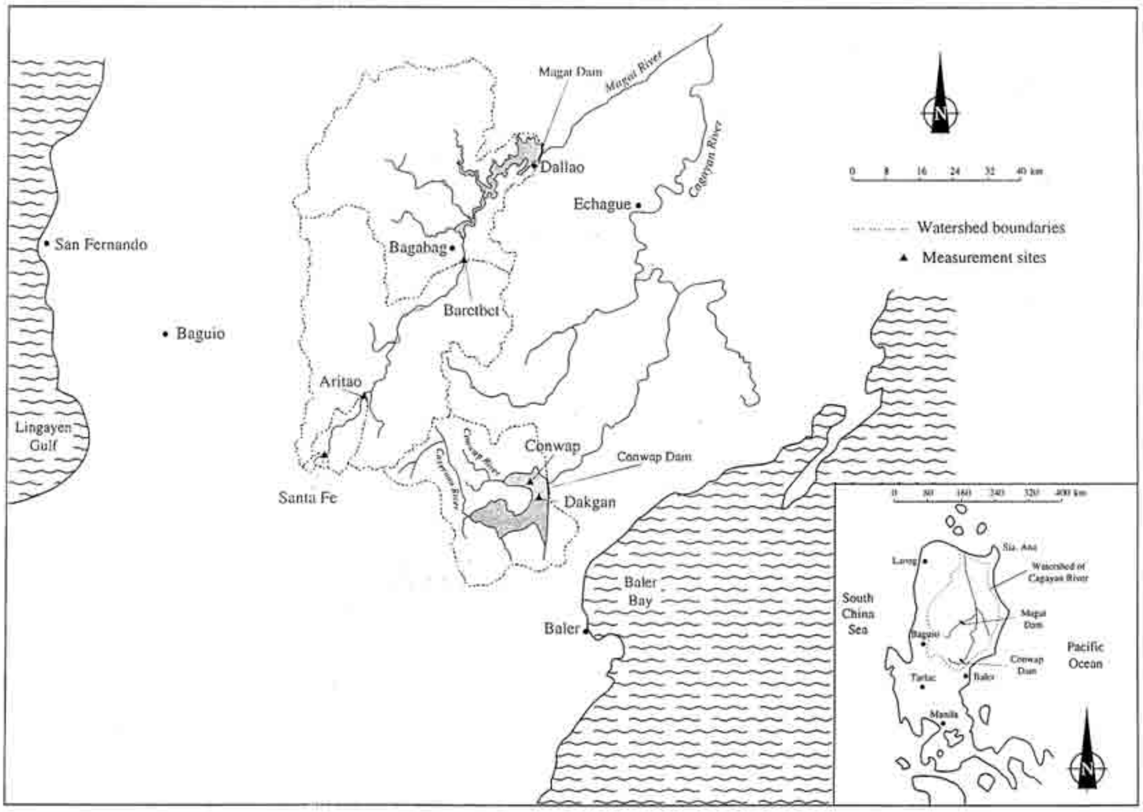

Fig. 1. The Magat and Casecnan catchments
(Las cuencas de Magat y Casecnan)

In the original Magat Watershed Feasibility Study sedimentation of the reservoir was not considered to be a problem. Sediment yields were estimated at 0.5% of reservoir capacity per year, a figure which is acceptable for reservoirs in the USA. It was considered that such a rate of sedimentation would not pose a serious threat to reservoir operations within 50 to 100 years. The sediment yield to the reservoir was calculated from a flow exceedance curve at 20 t ha^{-1} yr^{-1}. This figure was later revised by Hall (1982) using an extra six years of discharge data for the dam site on the Magat River. These flows appeared to show a trend towards higher discharges at Magat, although these six years also showed higher rainfall, which could have been the sole cause for the increase in discharge observed. Using rating curves and a flow duration curve for Magat, Hall predicted sediment yields to the reservoir of between 30 and 40 t ha^{-1} yr^{-1}.

Of much more concern to the authors of the Feasibility Study was the loss of fertile soil from the catchment. Previous measurements from plots under various land uses in other catchments had shown excessive erosion rates. The need was therefore seen for a catchment management programme to protect the soil resources. This work was updated for a Benchmark Resources Inventory (National Irrigation Administration and MADECOR, 1982) and again in 1987 (David, 1987). In this latest report, tables of values for the K, C_m and C_p factors in the USLE are given, together with formulae for calculating the erosivity factor, R, from daily rainfall figures.

As part of the feasibility study for the Magat dam, and the subsequent plans for a watershed management programme, three small agricultural catchments at Aritao were instrumented in 1978. The three small sites were chosen to represent three common land uses in the Magat catchment. Data collection from these sites was intermittent, with only 2, 3 and 4 storms being monitored on catchments 1, 2 and 3 respectively. The system of sediment sampling, and the requirement to dig all sediment out of the settling basins between storms meant that the information collected was not reliable, but gives some indication of possible sediment yield rates under degraded catchment conditions (White, 1992).

The first joint study involving Hydraulics Research (HR) and the National Irrigation Administration (NIA) in the Magat catchment started in 1984. This was aimed at quantifying the rate of sedimentation in the recently impounded Magat reservoir, and assessing the effectiveness of reforestation in reducing erosion, and thus sedimentation. In addition to a reservoir survey, two small reforested catchments near to the Magat reservoir were selected for monitoring during the first phase of the study. The catchments, Dallao B and Dallao C, cover areas of 26.5 ha and 15.3 ha respectively. Both catchments were reforested in 1982; catchment B with Ipil-Ipil and Yemane (rapid growth, short, leguminous trees)and catchment C with Ipil-Ipil and Japanese Acacia. The ground cover on both catchments is very good, and has been so since measurements commenced in July 1984.

In a further phase of the HR and NIA study, three 'nested' river sites were selected for monitoring at Santa Fe, Aritao and Baretbet (Fig. 1). Catchment areas increase by an order of magnitude from one site to the next, with each increased area including the smaller catchment. At each of the river sites a programme of measurements was initiated in 1985. This included the development of stage-discharge curves, the recording of water level, cross-sectional surveys, analysis of bed samples, sediment sampling from various points in the flow, and the development of sediment rating curves. These sediment rating curves have been used to estimate sediment yield for all available daily discharge data.

Using the data obtained in the field monitoring programme it was possible to derive annual runoff and sediment yield figures for the small reforested catchments, discharge and sediment rating curves for the river sites, annual discharge and sediment yield at the river sites, and an average annual sedimentation rate for the reservoir. In addition a few data were available for individual storms at the small agricultural catchments. Estimated sediment yields ranged from less than 1 t ha^{-1} yr^{-1} for the small reforested sites, to 38 t ha^{-1} yr^{-1} from the reservoir survey, with figures from the river sites ranging from 0.6 t ha^{-1} yr^{-1} to 33.5 t ha^{-1} yr^{-1}.

The Casecnan catchment is located in the provinces of Nueva Vizcaya and Quirino on the island of Luzon, Republic of the Philippines (Fig 1). It is situated between the basins of the Magat and Pantabangan reservoirs. The proposed Casecnan reservoir will impound an area of 1150 km^2, with two main tributaries, the Conwap (drainage area 255 km^2 to Conwap site) and the Casecnan (drainage area 873 km^2 to Dakgan site) (Fig. 1). The dam-site is located in the northeast of the catchment, just below the confluence of these two rivers.

The construction of the dam and consequent reservoir impoundment is planned to provide both power and irrigation water. One of the important features of the project is a trans-basin tunnel to transfer water from Casecnan to the neighbouring Pantabangan catchment. This water will then be used for irrigation in the central Luzon plain. During transfer along the tunnel the water will be passed through turbines to generate hydro-electric power. Power generation will also take place at Pantabangan (ELC et al., 1985).

At present, access to the catchment is difficult, as there are no good roads. Consequently development has been very slow, with only few areas of forest being cleared for agriculture by the local inhabitants. There has, however, been some logging activity and this is bound to accelerate as access to the catchment becomes easier.

Comparatively few data were available for the assessment of sediment yield to the proposed Casecnan reservoir. This was especially true in the case of sediment measurements, where data were only collected on a few days and in a limited range of discharge. These data were used in comparison with those for the Magat catchment to allow derivation of sediment rating curves. The accuracy of these relationships are questionable, but did allow an estimate of sediment yield to the proposed reservoir to be made (White, 1987). All parameters about which uncertainty existed were subjected to senstivity analysis, thus enabling a range of possible sediment yields and associated reservoir life to be identified.

Using discharge and sediment rating curves derived for the Dakgan and Conwap measurement sites and longer term discharge data, average annual sediment yield to the proposed reservoir could be predicted under a range of possible future conditions. Annual discharge at the Dakgan site varied from an equivalent of 0.87 m to 1.90 m over the catchment between 1977 and 1982. The sediment yields associated with these flows varied from 0.27 t ha^{-1} yr^{-1} to 4.23 t ha^{-1} yr^{-1}.

3. Comparison of physical characteristics of the two catchments

The geology of this area of northern Luzon is dominated by volcanic and metamorphic rocks, and these two groups form the majority of the two catchments. The northern and western zones of the Casecnan catchment are formed by the same mountain ranges which bound the south and east of the Magat catchment - the Mamparang and Caraballo mountains. These mountain ranges are mainly comprised of metamorphic rocks and the dominant soils are clay loams. Both catchments also include areas of metamorphic limestone and sandstones. These are located to the centre west of the Magat catchment and the centre north of the Casecnan catchment. Intrusions of quartz diorite are also to be found in both basins. The major difference geologically speaking between the two basins are the extent of volcanic rocks and volcanic breccia, and the amount of alluvial deposition in the valleys. Volcanic rocks and breccia dominate the Dakgan sub-catchment in Casecnan, but only cover a very small area, downstream of Baretbet in Magat. However, the soils developed on this area of volcanic rocks in Magat differ little from those found throughout the catchment. Most of the soils are clay loams, with some silt loams in the valleys. Alluvial deposition in the Magat catchment is extensive, and can be clearly identified from satellite imagery (White, 1992). However, in Casecnan deposition has only occurred so far in two small areas in the headwaters of the Casecnan river, and on a small tributary to the west (Dakgan catchment), and to some extent in the proposed reservoir area. Both headwater deposition zones are located immediately downstream from areas where forest has been cleared and replaced by open grassland.

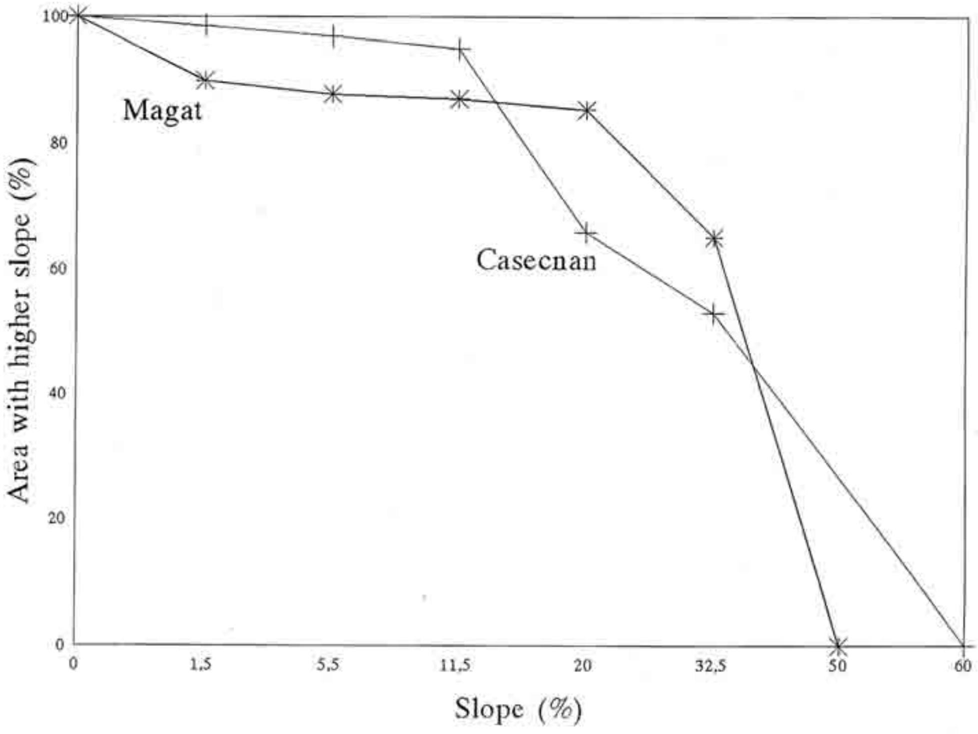

Fig. 2 Distribution of slopes in Magat and Casecnan
(Distribución de pendientes en Magat y Casecnan)

Both catchments are mountainous with extremely steep slopes in the majority of areas. In Casecnan, elevations range from 240 m asl in the reservoir area to 1500 m asl in the east. Corresponding figures for the Magat catchment are 300 m asl to 2500 m asl. For Magat the highest reported slope class is >40%, whilst for Casecnan it is >50% (Table 1). Fig. 2 shows the cumulative percentage of slopes in different slope classes. In general, the Casecnan catchment has a lower percentage of low slopes than the Magat catchment, perhaps due to the lack of extensive deposition in the valleys. This suggests a higher erosion potential due to slope in Casecnan.

Rainfall in this region is high and often occurs as high intensity, short duration storms, as a result of orographic lifting. Average annual rainfall for the Magat catchment is estimated at 2500 mm, with rainfall increasing from south-east to north-west. The predicted annual rainfall is greatly affected by both elevation and aspect, with the higher, south-easterly facing slopes in the north of the catchment receiving maximum rainfall, and the central valley, in part shadowed by the Mamparang mountains, receiving least. The Magat catchment shows no real dry season, although the months of January to April are relatively dry. The wettest months are from June to November, the southwest monsoon season, when there is also a high possibility of cyclones crossing the catchment. September is the wettest month with about 15% of the total annual rainfall. An estimate of annual rainfall data, coincident with the available discharge data, was made using elevation and area weighted averages of data from around the basin.

Table 1. Classification of the Magat and Casecnan catchments by slope
(Clasificación de pendientes en las cuencas de Magat y Casecnan)

Magat		Casecnan			
			Dakgan	Conwap	Total
Slope (%)	Area (%)	Slope (%)	Area (%)	Area (%)	Area (%)
0 - 3	10.06	0 - 3	1.77	0.0	1.43
3 - 8	2.10	3 - 8	2.05	0.0	1.66
8 - 15	0.71	8 - 15	0.23	9.2	1.92
15 - 25	1.70	15 - 30	25.48	44.25	29.04
25 - 40	20.28	30 - 50	11.42	18.84	12.83
> 40	65.15	> 50	59.04	27.71	53.12

Table 2. Rainfall in the Magat and Casecnan catchments
(Precipitación en las cuencas de Magat y Casecnan)

Year	Magat		Casecnan	
	Santa Fe	Baretbet	Dakgan	Conwap
	Rainfall (mm)	Rainfall (mm)	Rainfall (mm)	Rainfall (mm)
1977	-	1542	-	-
1978	2444	2200	2720	2250
1979	1792	1824	1840	1310
1980	3185	2218	2510	1780
1981	2691	2144	2240	1660
1982	-	-	1190	1260

Long-term average annual rainfall in the two catchments is expected to be similar, although rainfall does increase towards the east coast, meaning that the Casecnan catchment may show slightly higher totals. Both catchments have around 140-180 rain days per year, and of these 60-70 are thunderstorm days. Thunderstorms are usually very localised, rainfall intensities may exceed 100 mm hr^{-1}, and rainfall total at a point during storms may be high. Thus, both the erosivity of the rainfall, in cyclones and thunderstorms, (White, 1990) and the sediment transporting capacity of overland and river flow, mainly in cyclones, (White, 1992) are high. Table 2 shows available, comparative rainfall data for the measurement periods in Magat and Casecnan. For the period 1983-1987, data are only available for Baretbet, with annual totals of 1156, 1868, 1044, 1000 and 966 mm respectively.

The Philippines also lies in the area of the world most affected by tropical cyclones. On average 19.4 cyclones per year affect the weather conditions of the islands and of these, 8.8 per year cross the islands. The north-east of Luzon is one of the areas of the Philippines with highest cyclone frequency, with between 31% and 40% of all cyclones directly crossing this area, thus giving an expected cyclone frequency of 2.7 to 3.5 per year. Cyclones can result in both intense rainfall and high rainfall totals, with subsequent extreme flood peaks, especially when a cyclone stalls for several days. Table 3 shows cyclone occurrence for the two catchments during the monitoring periods; Casecnan, 1977-1982 inclusive and Magat, 1986-1988 inclusive.

Table 3. Observed cyclone frequency 1977-1982 and 1986-1988
Frecuencia observada de ciclones (1977-1982 y 1986-1988)

Year	Philippines	Dakgan	Conwap
1977	6	2	1
1978	9	3	4
1979	10	0	0
1980	14	4	4
1981	8	2	2
1982	8	1	0
Mean	9.17*	2+	1.8+
	Philippines	Magat	-
1986	11	6	-
1987	10	1	-
1988	7	7	-
Mean	9.3*	4.7+	-

* LOng term mean 8.8 per year
+ Expected mean 2.7 - 3.5 per year

In terms of land use development (Table 4) the two study catchments offer an opportunity to consider the difference human intervention can make to runoff and sediment production. Much more detailed (although often contradictory) information is available for the Magat catchment, but in Table 4 an attempt has been made to put the 1983 Magat data into similar classes as those reported for Casecnan. Around 53% of the Magat catchment has been cleared of the natural forest cover. Of the 47% of forested land, 22% is secondary forest which has regenerated after cutting. For Casecnan a high forest cover (72%) is still maintained. Fig. 3 shows the percentage of land under different land uses in the two basins.

Much of the forest in Magat, which was the natural vegetation of the catchment, has been cleared both by legal and illegal logging activity, and by the 'kaingineros' - farmers who practice slash and burn agriculture. Most of this former forest is now open grassland, much of which is overgrazed and/or burnt annually to generate growth of fresh grass shoots.

Land-use maps for Casecnan show that most of the cleared land is immediately surrounding the rivers, although there is a limited amount of slash-and-burn subsistence (kaingin) farming in the mountains.

Much of the cleared land is open grassland, and it is here and in the kaingin areas that the worst erosion has already occurred. There is moderate erosion even in areas of secondary forest, which shows the susceptibility of the catchment to erosion.

The difference in forest cover between the two basins can largely be attributed to the difficulty of access to the Casecnan basin, and the corresponding ease of access to Magat. Extensive clearance of reservoir catchments in undeveloped areas often follows on from dam construction (Abernethy, 1987) because access is facilitated during the construction process. Although the Magat dam was only completed in 1982, the catchment also includes the main north-south Luzon highway. Thus, access to land, and the subsequent clearance of land for farming or timber, has taken place in Magat over a number of years. Until recently, access to the Casecnan catchment was possible only on foot or by helicopter. Now, roads have been cut to the proposed dam site and to the northern boundary. Forest clearance around these roads was already occurring in 1987, when the dam was still at the feasibility study stage. Clearance is likely to continue, and possibly to accelerate without strict management of land use.

Table 4. Land use in the Magat and Casecnan catchments
(Uso de suelo en las cuencas de Magat y Casecnan)

Land Use	% of catchment area			
	Magat	Dakgan	Conwap	Total
Forest	47.47	72.16	68.37	71.54
Grassland	38.30	24.88	31.13	26.05
Rice	12.13	2.64	0.0	2.07
Kaingin	1.60	0.31	0.49	0.33
Built-up areas	0.50	< 0.01	< 0.01	< 0.01

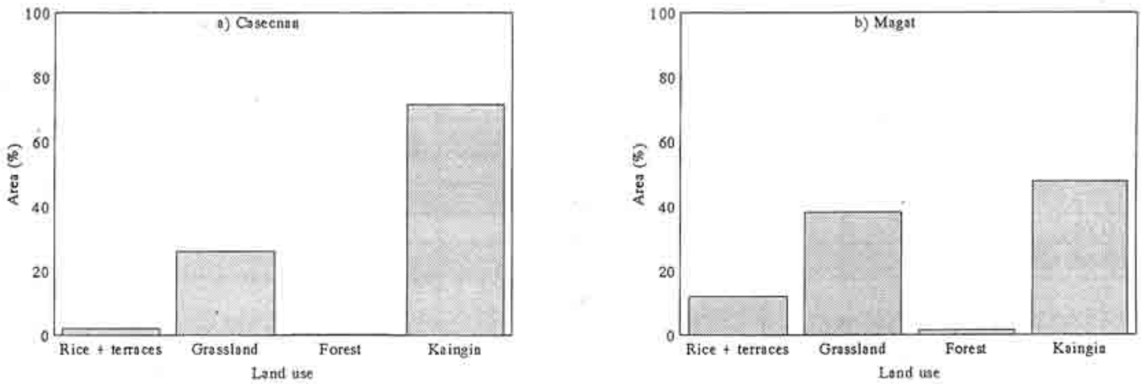

Fig. 3. Land use in Magat and Casecnan
(Uso de suelo en Magat y Casecnan)

Worldwide, many of the problems of erosion have been blamed on shifting agriculture and the fact that few farmers actually own the land that they farm. In Magat it seems that tenure cannot really be blamed for the farmers lack of enthusiasm for soil conservation measures. During the 1971 census survey 62% of farmers questioned owned the land they farmed, and another 16% were part-owners. This land accounted for 84% of the farmed land. Also, on 31 July 1978 the area under kaingin was assessed as 12,180 hectares, or 2.95% of the total catchment area.

The clearance of forest leads to an extremely unstable situation in terms of soil erosion. In 1978, some 83% of the Magat catchment area was assessed as having severe, very severe or excessive erosion rates (Table 5). These terms represent removal of between 75% of the A horizon and 25% of the B horizon, all of the A horizon and up to 75% of the B horizon, and all of the A and B horizons to part of the C horizon respectively (Barrera, 1961).

Existing erosion in the Magat catchment is more extreme than that in Casecnan. Fig. 4 shows the percentage of catchment areas in different erosion classes. Given that the geology, and hence soils, are similar, land use in Magat is conducive to erosion, and slopes in Casecnan are steeper, the potential for future erosion in the latter is possibly greater than that in Magat.

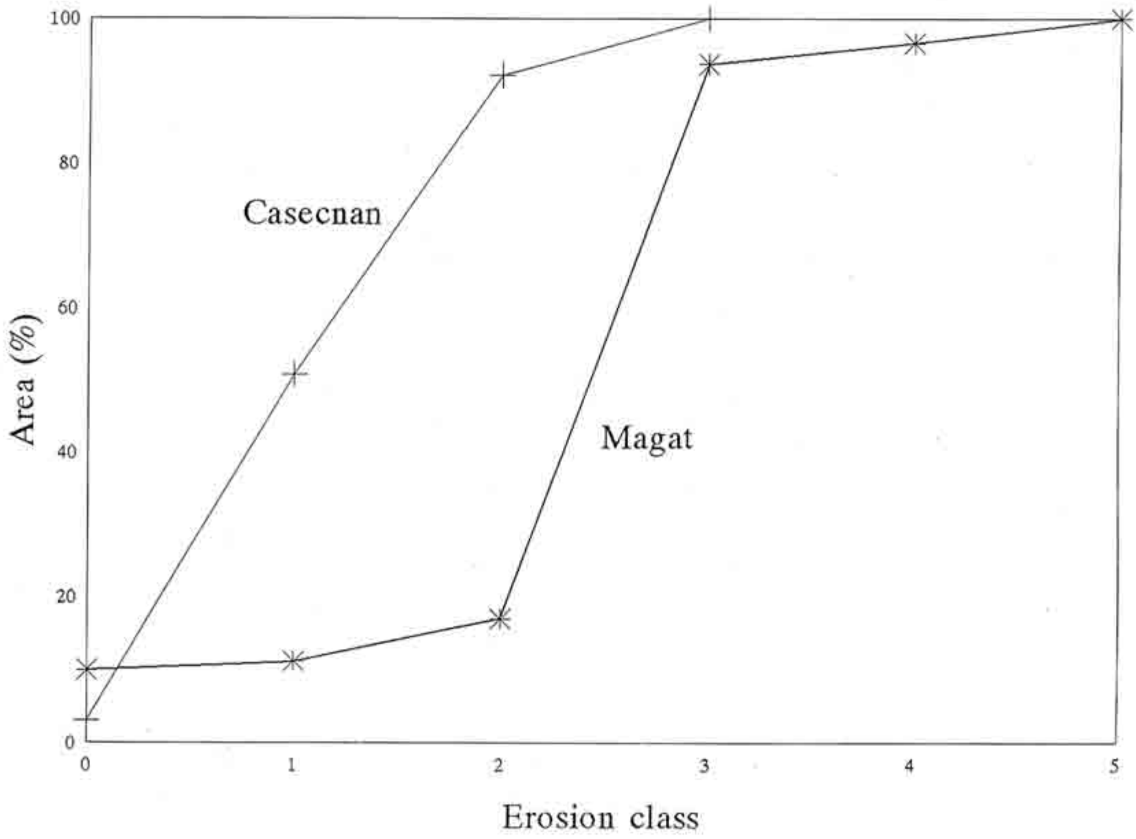

Fig. 4. Current erosion status in Magat and Casecnan
(Estado de la erosión actual en Magat y Casecnan)

Table 5. Existing erosion in the Magat and Casecnan catchments
(Erosión actual en las cuencas de Magat y Casecnan)

		Magat	Casecnan		
			Dakgan	Conwap	Total
Erosion class	Degree of erosion	Area (%)	Area (%)	Area (%)	Area (%)
0	No apparent erosion	9.98	3.67	0.97	3.09
1	Slightly eroded	1.19	44.88	58.36	47.77
2	Moderately eroded	5.83	42.37	37.84	41.37
3*	Severely eroded	52.80	9.07	2.83	7.77
36*	Severely eroded with catsteps and shallow gullies generally present	23.93	-	-	-
4	Very severely eroded	2.91	-	-	-
5	Excessively eroded	3.36	-	-	-

* Plotted together on Fig. 4

4. Discharge patterns - comparisons and contrasts

The Magat reservoir capacity is 1080 x 10^6 m^3, of which 810 x 10^6 m^3 is live storage. Average annual inflow is 6700 x 10^6 m^3, just over six times reservoir capacity. Average flow at the dam site is 200 m^3 s^{-1}, although a peak flow of 20 x 10^3 m^3 s^{-1} has been recorded. It was estimated that the probable maximum flood at the dam (used for design purposes) is of the order of 34.5 x 10^3 m^3 s^{-1} (National Irrigation Administration and Engineering Consultants Inc., 1978). The large variation in flows is due to the occurrence of cyclones, which produce high magnitude short duration floods. Flow can increase by a factor of 100 from one day to the next, and can just as quickly return to pre-flood levels. This results in extremely spiky discharge hydrographs, which present problems in terms of monitoring and prediction.

Discharge data are available for various sub-catchments, and for Magat for the catchment as a whole. The Magat reservoir drains an area of 4143 km^2, river measurement sites are located at Baretbet (2041 km^2), Aritao (159.2 km^2) and Santa Fe (18.9 km^2). Two small reforested experimental catchments at Dallao cover areas of 26.5 ha and 15.3 ha. The proposed Casecnan reservoir will drain an area of 1150 km^2, with data available from the two main rivers at Dakgan (873 km^2) and Conwap (255 km^2). Table 6 gives a summary of the available data.

The impact of cyclones on the discharge pattern and totals is paramount. In cyclone related floods, peak flows of between 100 and 300 times normal baseflow occur (National Water Resources Council, 1980; White, 1992). Thus the number of cyclones per year crossing a catchment is important, as is the path which the cyclone follows. Runoff from a cyclone affected area can appear completely incongruous compared with other sites in the catchment and even with measurement stations downstream. This means that very long time series of flow are needed to make sense of any pattern in flows. Statistically, cyclone related events are extremes in the distribution of discharge, and are best treated as a separate distribution (White, 1987; White, 1992). Even though a number of cyclones may occur in a given year, this may not be immediately obvious from the annual rainfall totals. A study of the cyclone reports (published annually (PAGASA, 1975-1985)) is necessary to interpret the rainfall and discharge correctly. In both of the study areas data are only available for a relatively short time, but do cover a range of cyclone frequency. Thus it is possible to look at ranges of discharge at the various sites.

Table 6. Discharge for the Magat catchment
Caudal en la cuenca de Magat
(Amphlett and Dickinson, 1989; Dickinson et al, 1990)

	Annual runoff (mm $year^{-1}$)
Dallao reforested sites	
B - 1985	336.16
B - 1986	245.27
B - 1987	129.36
C - 1985	341.41
C - 1986	203.77
River sites	
Santa Fe - 1986	3600
Santa Fe - 1987	1010
Santa Fe - 1988	2170
Aritao - 1986	1670
Aritao - 1987	450
Aritao - 1988	940-1230*
Baretbet - 1986	1980
Baretbet - 1987	1080
Baretbet - 1988	2250

* Uncertainty due to shift in channel configuration

The measurement period at Casecnan had a below average cyclone frequency, although for the Philippines as a whole these years were near or above average (Table 3). Thus, it is unlikely that the years 1977-1982 represent the most extreme conditions possible at Casecnan. Given this, and the already severe response of Dakgan, there is obvious cause for believing that peak observed discharge may be exceeded by a factor of two or more in the long term. If forest is cleared from the catchment this situation may be exacerbated.

Cyclone frequency in the Magat catchment over the measurement period 1986-1988 was higher than the long-term average, as was the national figure for these years. 1988 was exceptional in that all cyclones which directly crossed the Philippine islands affected the Magat catchment. Thus, the sediment transporting capacity in the measurement period may have been higher than the long-term average, although this depends on peak flow as well as frequency.

For both catchments, as would be expected, total runoff increases with area (Fig. 5). However, considering runoff as a depth over the catchment area, a different picture is seen, reflecting differences in rainfall and topography. In Magat, Aritao consistently shows the lowest runoff depth, with the maximum being seen at either of the other two sites depending on the spatial distribution of rainfall, and in particular the areas of the catchment affected by cyclones. The measurement period (1986-1988) includes one year (1987) when cyclones did not affect the southern half of the basin. In 1986, Santa Fe was most affected by cyclone activity. 1988 was a exceptional year in the measurement programme, with 7 cyclones affecting the catchment, and having most impact in the south, where peak flows at Baretbet reached around 3000 $m^3\ s^{-1}$. Although exceptional in itself, the previous 11 years (1977-1987 inclusive) had seen less than two cyclones per year affecting flow in the Magat catchment. The average shifts to three per year when 1988 is included, thus meaning that the 12 year average is closer to the expected frequency for the region.

The reason for the minimum value of runoff at Aritao must primarily be a lower rainfall over the catchment. There is no substantial difference in land use over the Santa Fe, Aritao and Baretbet catchments, although more of the east facing slopes in Aritao and Baretbet have been cleared. These easterly facing slopes will be the most affected by cyclones which are typically moving from east to west. Although Aritao includes the Santa Fe catchment within it, no other first-order catchments around the Magat boundary are included, thus mean elevations are at their lowest in Aritao. It has been shown that rainfall increases linearly with elevation (Blyth and White, 1990), and so the Aritao catchment can be expected to receive lower annual rainfall. The Baretbet catchment includes within its boundaries, the Matuno river basin which has some of the highest and steepest land in the whole Magat catchment. The Matuno catchment also includes an area classified as having 'extreme' erosion, the rest of the catchment to Baretbet having only 'severe' erosion problems. The area of extreme erosion will have a more rapid runoff response, and will store less of the incoming rainfall than the severely eroded areas. Thus, it is possible that Baretbet has a relatively high annual runoff, rather than Aritao having a low annual runoff. This could be considered to be a particular feature of the geography of this catchment. However, the author considers that this pattern is likely to be seen in other areas where rainfall has a dependence on elevation, and many steep, rugged sub-catchments contribute water and sediment to a flatter main river channel.

The relationship between rainfall and runoff (the runoff coefficient) can vary over time with changes in land-use. Reductions in vegetative cover reduce infiltration rates and increase the rate at which water runs off the land. They also mean that more land is subject to erosion from raindrop impact, thus increasing sediment supply. Any increase in runoff coefficient has a direct effect on erosion rates and sediment yields because:

a) increased overland flow means greater potential for both soil detachment and transport of eroded soil to the stream network
b) higher peak discharges mean greater potential transport of sediment within the river network

These two processes are not necessarily happening at the same time - the most erosive rainfall and highest rates of sediment transport to the streams, may not occur in the events that produce the largest floods.

At Dallao annual runoff varies from around 20% of rainfall in a wet year to 10% in a dry one. Of this runoff, approximately 70% occurs as direct flow during storm events. The Dallao catchments produced discharge at the catchment outlet between 16 and 44 times a year compared with rainfall on around 145 days. Storm hydrographs were normally very sharp. Direct runoff coefficients varied widely, with a tendency to increase during the wet season to a maximum of around 60%. Baseflow only exceeded 2mm over the catchment on seven occasions, with a general trend of baseflow forming a decreasing percentage of discharge as total storm runoff increased. This all points towards a rapid response system, based largely on Hortonian overland flow or minimal soil water storage capacity. A rapid runoff response was also often to be observed in the afternoons, as a result of thunderstorms in the Santa Fe catchment.

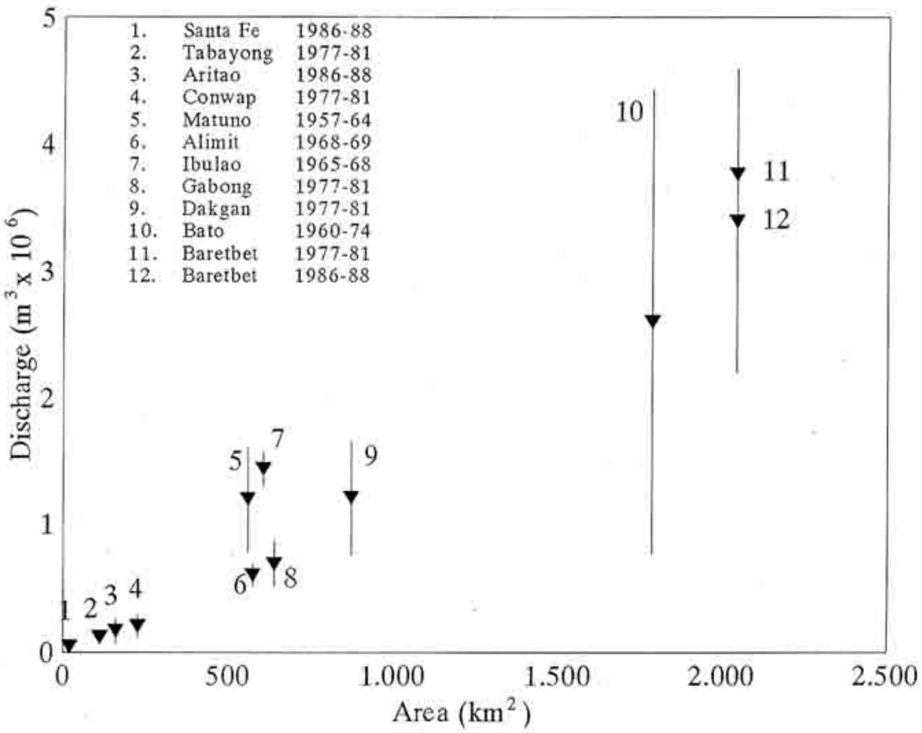

Fig. 5. Range and average of flows at sites in Magat and Casecnan
(Rango y media de caudales en distintos puntos de Magat y Casecnan)

Runoff coefficients for individual storms at the Aritao agricultural catchments are higher than the annual figures for Dallao, but individual storm runoff coefficients at Dallao also reached peak values of 65.83% and 52.20% for catchments B and C respectively during the three years of monitoring.

As part of the verification of the stage-discharge rating curve for Baretbet, runoff coefficients for cyclone-related flood events were calculated using elevation weighted rainfall. This gave runoff coefficients of between 40% and 60%. For the catchment as a whole, mean annual runoff from 1948 to 1977 was 1.632 m over the catchment. Average annual rainfall is estimated at 2200 mm, giving a long-term average runoff coefficient of 74%.

Such high runoff coefficients may be due to rainfall type and intensity, soils, land use and slope or a combination of these. Soils are very shallow, and although infiltration rates are fairly high (>6.4 cm hr^{-1} for most soils on the lower slopes) percolation rates are very slow. Thus, once soils are saturated, they stay saturated for a long while. The Magat catchment includes some very steep areas, with slopes in excess of 40%. No soils data are available for slopes over 18%, but it is probable that soils in steep areas are the most shallow and degraded. 52% of the Magat catchment is no longer under the forest cover that is the natural vegetation of this region, most of this cleared area is now grassland which is burnt annually to generate new grass growth for grazing. Such poor land cover offers little by way of rainfall interception or storage, and has comparatively low consumptive use of water. Overgrazing in many areas of the catchment is leading to further soil degradation and compaction, thus increasing still further the potential for runoff. Add to this picture the frequent passage of cyclones across or near to the catchment, and the high potential for erosion and sediment transport becomes clear.

In the Casecnan catchment, runoff coefficients were also calculated for cyclone events, and annually. The former showed a range of 47-90% for the Dakgan sub-catchment and 10-90% for Conwap. Annually the range at Dakgan was 47-86%, with runoff depths between 0.87 and 1.9m. Corresponding runoff coefficients and depths for Conwap are 30-62% and 0.44-1.17m, reflecting the lower rainfall in this part of the Casecnan catchment.

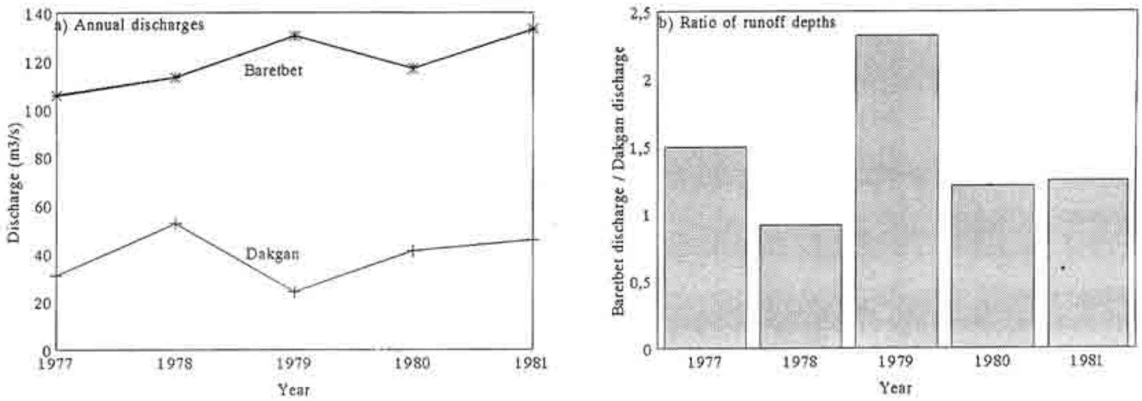

Fig. 6. Comparison of runoff at Baretbet and Dakgan
(Comparación del caudal en Baretbet y Dakgan)

Peak observed flows for the Casecnan catchment for the period 1977-1982 were 2464.1 $m^3 s^{-1}$ at Dakgan and 381.4 $m^3 s^{-1}$ for Conwap. A consideration of these values with respect to catchment area, in comparison with values from Magat is given in Table 7. Here it can be seen that the Dakgan site appears to have a higher peak discharge to area ratio than Conwap, Aritao, Baretbet or three other measurement site in the Magat catchment (Bato, Ibulao and Alimit). The only sites which exceed the ratio for Dakgan are Santa Fe, which was greatly affected by a cyclone in 1988, and the dam site, for which the extreme event of 1971 exceeds all other observed values. It must be borne in mind that the available data are for different measurement periods, and as seen at the dam site, extreme events can occur in consecutive years (1970 and 1971) after a number of years of relatively low flows. Thus, in order to draw final conclusions very long, consecutive, time series (of the order of 100 years) would be needed. In the absence of such data it can only be stated that the Dakgan catchment *appears* to have a more extreme response to extreme rainfall than most of the other sites for which data are available. This is surprising given the high percentage of forest cover above Dakgan.

Even though discharge data may be available for two sites for the same period, the peak discharge may not occur at the same time, due to the exact path followed by a particular cyclone event. Thus, peak flow at Conwap is seen in 1980, whilst that at Dakgan occurs in 1978. This is even true for 'nested' sites. Peak flow at Santa Fe and Baretbet occurs in 1988, whilst that at the intermediate site of Aritao occurs in 1986. All peaks are associated with cyclone events. Therefore, the difficulty and danger of any statistical analysis of short-term data, extrapolation or development of relationships between sites must be emphasised.

5. Sediment yield patterns - comparisons and contrasts

Sediment rating curves were derived for the three river sites in the Magat catchment. Unusually, rating curves for both wash load and suspended bed material load were valid at all sites, although some hysteresis was seen during storms for the latter. Table 8 summarises the annual sediment yields calculated from these rating curves during the Magat field programme.

Table 7. Peak discharge relative to catchment area
(Relación entre caudal máximo y superficie de cuenca)

Site	Measurement period	Year of peak	Peak discharge, Q ($m^3 s^{-1}$)	Catchment area, A (km^2)	Q/A ($m^3 s^{-1} km^{-2}$)
Santa Fe	1986-1988	1988	88	18.9	4.66
Aritao	1986-1988	1986	240	159.2	1.51
Baretbet	1986-1988	1988	3000	2041	1.47
Alimit	1967-1970	1967	911.2	573	1.59
Ibulao	1964-1970	1970	636	606	1.05
Bato	1959-1970	1960	1540	1784	0.86
Dam site*	1941-1969	1948	6795	4150	1.64
Dam site*	1941-1970	1970	9540	4150	2.30
Dam site*	1941-1971	1971	20,480	4150	4.93
Dam site*	PMF+	-	34,500	4150	8.31
Conwap	1977-1982	1980	381.4	255	1.50
Dakgan	1977-1982	1978	2464.1	873	2.82

* Magat dam
+ Probable maximum flood estimated for dam design

Table 8. Sediment yield for the Magat catchment
Aporte de sedimentos en la cuenca de Magat
(Amphlett and Dickinson, 1989; Dickinson et al, 1990)

	Annual sediment yield ($t\ ha^{-1} yr^{-1}$)
Dallao reforested sites	
B - 1985	0.3962
B - 1986	0.2411
B - 1987	0.1706
C - 1985	0.6105
C - 1986	0.3499
River sites	
Santa Fe - 1986	39.7
Santa Fe - 1987	1.5
Santa Fe - 1988	5.42
Aritao - 1986	22.0
Aritao - 1987	0.6
Aritao - 1988	3.41-6.95*
Baretbet - 1986	17.0-33.5*
Baretbet - 1987	4.0
Baretbet - 1988	20.8

* Uncertainty due to problem of choosing gradient of suspended bed material concentration rating curve

In attempting to derive similar suspended bed material rating curves for Casecnan the data were plotted on the same axes as data from Santa Fe and Aritao (Fig. 7). Few data were available for the Casecnan sites and those collected were for comparatively low flows. However, it appears that some similarity exists in data values from Santa Fe, Aritao and Conwap, whilst the Dakgan site has concentrations a factor of ten or more lower than those seen in Magat. The possible explanations for such low concentrations are many.

It is known that during floods the Magat river can scour as much as three metres, and the flow width can increase dramatically. It was estimated in 1978 (National Irrigation Administration and Engineering Consultants Inc., 1978) that in the area upstream of Bagabag (near Baretbet) for a distance of around 30 km, 4 metres of sediment had been deposited by the river over a width of 1 to 2km. This represents a sediment store of some 180 million cubic metres, meaning that sediment supply from the catchments is not required for high sediment transport rates in the rivers to occur. Such a store does not yet exist in the Casecnan catchment.

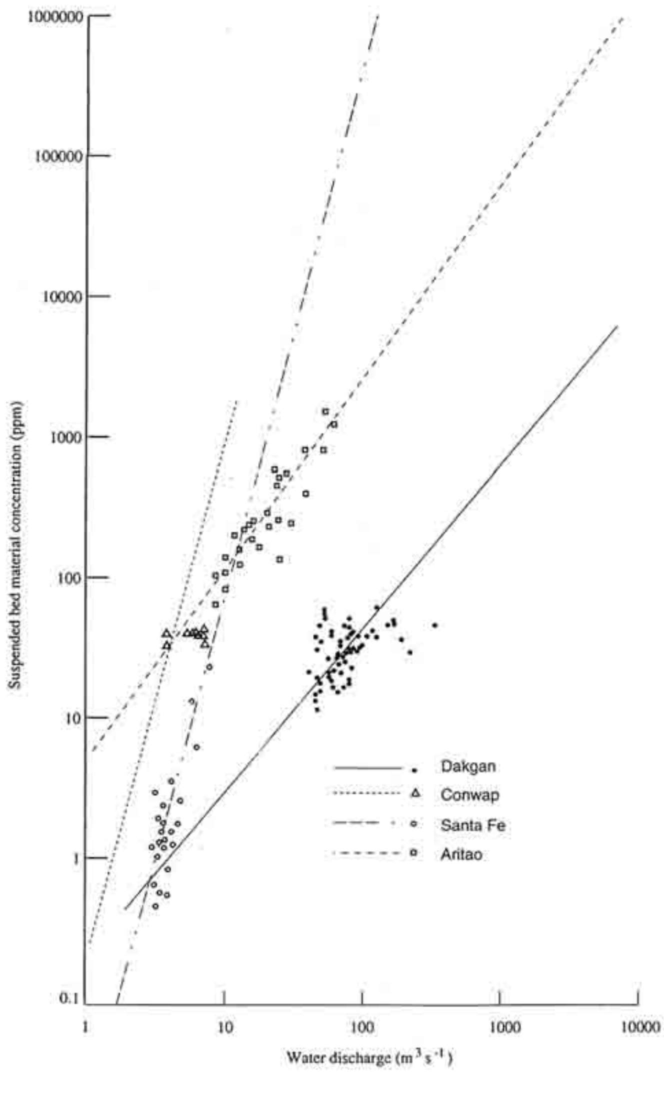

Fig. 7. Comparison of sediment rating curves in Magat and Casecnan
(Comparación de las curvas de aporte de sedimentos en Magat y Casecnan)

The geology of the lower half of the Dakgan basin is volcanic rather than the metamorphic and sedimentary rocks seen in the other three sub-catchments. However, in the Magat basin, soils developed on volcanic, metamorphic and sedimentary rocks are similar in type and erodibility. Also, where forest has been cleared in the Dakgan catchment, erosion has been high. As the current erosion status has been mapped in terms of the removal of various soil horizons, the thickness of these horizons will obviously affect the quantity of soil eroded. Thus, destruction of the 'A' horizon in one soil profile may provide more sediment than destruction of the 'A' and 'B' horizons in a different profile. Discharge in the Dakgan basin (in metres of runoff) is higher in general than that seen at Aritao, or Conwap although less than that at Santa Fe. So sediment transporting capacity is available, which rules out differences in runoff as an explanation. Vegetation differences are also a possible explanation for the observed discrepancy, with most of the Dakgan basin still under forest, and with cleared areas mainly in the upstream reaches. Furthermore, in these cleared areas which are dominantly open grassland, paddy rice is grown on areas immediately surrounding the rivers, possibly acting as a filter for any eroded soil. Although much of the Conwap catchment is also forested, the cleared areas here are at the downstream end of the catchment immediately bordering rivers. This situation is more similar to that found in Magat. It is therefore likely that the lower sediment concentrations seen at Dakgan measurement site are due to a combination of more resistant rocks and good forest cover.

Work by David (1987) showed that erosion rates in Magat were likely to be of the order of 10 to 200 times greater (depending on slope) once forest is cleared and replaced by open grassland, built-up areas or 'kaingin'. Sediment yield measurements from the reforested Dallao catchments and the small agricultural catchments also suggest that the difference between forest and agricultural land or grassland is great. Although sediment yields from the small Aritao agricultural catchments were only available for a few events, these showed a range of sediment yield from 0.4 t ha^{-1} to 6.2 t ha^{-1}. At Dallao sediment yields ranged from 0.17t ha^{-1} yr^{-1} to 0.61 t ha^{-1} yr^{-1}. In two individual storms at Aritao, the sediment loss is greater than that for any total year for the Dallao reforested catchments. The large difference in sediment yield between the reforested catchments at Dallao and the agricultural catchments at Aritao, provides an indication of the range of yields that are possible excluding mass movements; a best and worst scenario for the Magat catchment as a whole.

Thus, current low sediment concentrations at Dakgan are as a result of low erosion rates and a lack of sediment supply to the river. However, there appears to be potential for increased erosion and sediment transport at Dakgan if forest clearance occurs. Such change would suggest a shift in the Dakgan sediment concentrations on Fig. 7 upwards, thus bringing them closer to observations at other sites. However, at the same time discharge may increase, resulting in a coincident shift to the right in the points.

Table 9. Estimated sediment yield (t ha^{-1} yr^{-1}) at Conwap, Dakgan and Baretbet
Producción estimada de sedimentos (Tm ha^{-1} yr^{-1}) en Conwap, Dakgan y Baretbet

Year	Conwap	Dakgan	Baretbet
1977	0.21	1.32	4.87
1978	1.40	4.23	14.08
1979	0.19	0.27	6.90
1980	1.14	2.46	13.56
1981	1.81	2.21	9.40
1982	0.43	0.50	-

Using the derived rating curves, estimates of sediment yield for the period 1977-1982 were made for Conwap, Dakgan and Baretbet (Table 9). Here it can be seen that although the discharge response of Dakgan appears to be stronger than that of Baretbet, the estimated sediment yields are low for the reasons discussed above. Further data for Baretbet for 1983-1988 gives sediment yield figures of up to 20.8 t ha^{-1} yr^{-1} (and possibly 33.5 t ha^{-1} yr^{-1}, see Table 8), values even higher than those seen for 1977-1982. Annual sediment yields for Dakgan are consistently higher than those for Conwap, although in years with few or no cyclones (1979 and 1982) values become similar. Sediment yields at Conwap are more comparable with those seen at the reforested Dallao sites than any of the river sites, however, with Conwap more closely resembling the Magat basin, potential again exists for an increase in these yields. Peak sediment yield values are seen at all sites in the year with peak discharge.

Evidence has been gathered by Abernethy (1987) that on average sediment yields in Asian rivers show an increase of 50% per decade once clearance of the basin begins. If such an increase is applied to the annual estimates for Dakgan over a period of 50 years, the range in sediment yields increases to between 2.1 t ha^{-1} yr^{-1} and 32.1 t ha^{-1} yr^{-1}, very similar to the values seen in Magat. Applying the same technique to Conwap data gives a range of 1.4 t ha^{-1} yr^{-1} to 13.7 t ha^{-1} yr^{-1}.

Another way of investigating the potential effect of forest clearance is to look at the percentage of forest land in different slope classes in Casecnan. If this land is considered to be cleared to open grassland then an estimate of the increase in potential erosion rates can be calculated using the data of David (1987). This shows possible increase in erosion of between 20% and 130% (for secondary and primary forest conversion to grassland respectively) in Conwap, and between 20% and 136% in Dakgan. These figures suggest that a 50% increase in sediment yield per decade over 50 years would not be sustainable. However, it should be remembered that David's erosion rate figures are for sheet and rill erosion only. The relative increase in gully and landslide erosion following forest clearance is likely to be much higher.

6. Discussion and Conclusions

The combination of steep slopes, deforestation, intense rainfall and frequent high peak flows make the north of Luzon an extremely efficient sediment supply and delivery system. The nature of this area means that maintenance of good (high percentage) ground cover is necessary to prevent erosion. In fact, once access to an area is facilitated, deforestation rapidly follows, creating ideal conditions for rapid soil erosion and sediment transport downstream. The combination of deforestation and the practice of burning grasslands means that erosion over much of the area is severe to extreme. Soils in these eroded areas are very shallow, and in spite of reasonably rapid infiltration rates their low water holding and transporting capacity means that runoff response is rapid.

Frequent thunderstorms can supply large amounts of sediment to the stream network. Data from the small catchments at Aritao and Dallao show the benefits of good forest cover, and the consequence of forest clearance. 53% of the Magat catchment has now been cleared of forest, and soils in these areas are so degraded that reforestation will be very difficult if not impossible. It is therefore likely that high rates of sediment supply and rapid runoff response from these areas will continue, until soil resources are completely depleted.

In the river network, more sediment per hectare and per millimetre of runoff is carried with increasing catchment area, in contrast to the commonly held view of decreasing sediment delivery with area. The decrease in sediment yield per hectare from Santa Fe to Aritao, and the subsequent increase from Aritao to Baretbet mirrors the pattern of runoff from these catchments. For all three river sites sediment yield in tonnes increases exponentially with increasing runoff, because the high runoff years are those with extreme cyclone-related floods and high sediment transporting capacity. Therefore, further clearance of the catchment is likely to result in even higher runoff and sediment yield figures.

If catchment management were successfully introduced, annual and peak runoff figures may be reduced. However, for the reforested Dallao catchments, runoff coefficients peak at around 66%; similar to the annual runoff coefficient of 74% for Magat as a whole and the 40% to 60% runoff coefficients for large floods estimated for Baretbet. Annual runoff coefficients for Dallao are around 10% to 19%, much lower than those seen in the Magat catchment as a whole, but it seems that this reduction is achieved through reduction in the number and size of smaller runoff events rather than the large cyclone-related floods. This is confirmed by the similar runoff rates at Dakgan (in metres over the catchment). This may mean that the sediment supply to the river network by small storms becomes less efficient under forest cover, although the occasional cyclone-related floods will transport large amounts of previously detached sediment to the rivers. In Magat there is a large sediment store already in the river valleys, so that the supply of sediment to the rivers is of less importance than it would be in other less degraded catchments, such as Casecnan. It appears that the capacity to transport this stored material, in cyclone-related floods over the medium to long term, would not be greatly reduced by catchment management.

The potential increase in erosion and sediment supply to rivers in Casecnan should be borne in mind during the future development of the area. It is inevitable that more people will move in and more land will be cleared after construction of the dam. If this development is not well managed, the result in terms of sediment yield to the reservoir could be catastrophic.

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