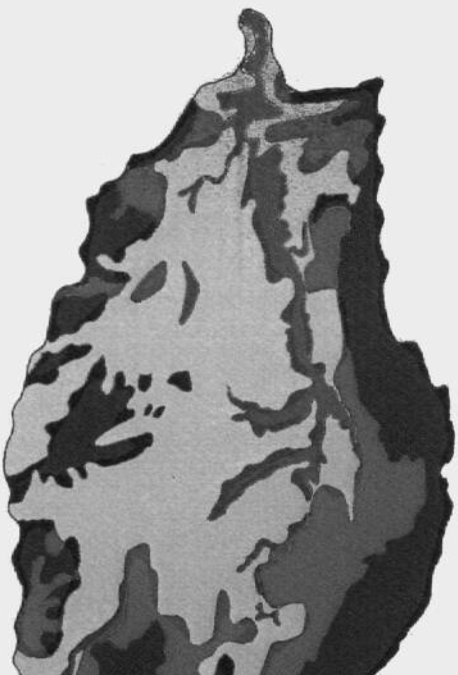
THE EFFECT OF DEFORESTATION ON THE EXTENT OF FLOODS IN THE CAGAYAN VALLEY, PHILIPPINES



THE EFFECT OF DEFORESTATION ON THE EXTENT OF FLOODS IN THE CAGAYAN VALLEY, PHILIPPINES

A model approach

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SUMMARY

The Centre of Environmental Science (CML) of Leiden University, the Netherlands, and the College of Forestry and Environmental Management of Isabela State University, the Philippines, are engaged in a collaborative environmental research programme in the Cagayan Valley in Northern Luzon, the Philippines. The research is based on a Problem in Context approach, in which the environmental problem is taken as the starting point and the criterium of relevance for the lines of multidisciplinary research that describe the most important actors, their motives and problem-causing activities on the one hand, and the environmental consequences and limits on the other hand.

Over the last two decades the 27,000 km^2 Cagayan Valley has experienced a rapid rate of deforestation. Commercial logging has converted most of the primary forest to secondary forest, which in its turn is gradually being converted to brush and grassland by the activity of slash-and-burn farmers, extensive grazing and random burning. Over the period 1965 - 1987 the area covered by forest (primary or secondary) decreased from 45 to 30%. Land use in the Valley is relatively extensive; it consists of commercial logging and slash-and-burn agriculture in the uplands, and rainfed agriculture, irrigated rice production and extensive grazing in the lowlands. Large tracts of grass-covered land are left idle. The Valley is a high rainfall area (2000 - 3000 mm/year), with an 8-month wet season and a 4-month dry season. Typhoons during the wet season cause frequent and extensive floods which hamper the economic use of the zones adjacent to the river system.

In the CML programme, deforestation was identified as the main environmental problem in the Valley, and the lowland hydrological effects of deforestation were identified as an important line of research. Inhabitants of the area generally hold the opinion that the extent of floods and droughts have increased due to deforestation; an opinion which is shared by many in the West on the basis of "common sense". The scientific evidence on the matter however is far from conclusive.

The research has been carried out along two lines. First the hydrological data of the Cagayan watershed that span the period of deforestation were analysed for changes in riverbed level, peakflows and dry season flow. However, the quality of the hydrological data was insufficient to give firm evidence for changes in these parameters. The main shortcomings in the data were: lack of upland rainfall stations, low frequency of stage readings, unreliability of stage-discharge relations and relocation of hydrological stations.
The research was continued by a model approach. As flooding was considered to be a more critical problem than drought, the choice was made to limit the model exercise to the effect of deforestation on floods.
Based on the information in a consultancy report on water resources development in the Cagayan watershed, a hydrological model was constructed that simulates the extent of floods along the downstream reach of the Cagayan river. The model consists of a module with an empirical description of the flood hydrographs emanating from the subbbasins due to peak rainfalls, and a deterministic one-dimensional hydraulic module (DUFLOW) describing the flood propagation in the downstream river reach.
The model was used to simulate changes in downstream flooded area due to deforestation-induced changes in the subbasin flood hydrographs and changes in riverbed siltation rate. Horizontal migration of the river channel (riverbank erosion, shifts in river course) and the associated changes in the extent of floods were not taken into account.

Model simulations show that a change in upland stormflow (i.e. volume of discharge during storm event) is more relevant for downstream flooding - in the absence of dikes, as is the case in the Cagayan river - than a change in peakflow (maximum instantaneous discharge) or time-to-peak. Based on literature reports of paired-basin experiments, stormflow has been assumed to increase by 25% after 100% forest removal.
Based on a sediment budget, the present siltation rate of the main river channel is estimated at 0.5 - 1.4 cm/year, increasing to 1.3 - 3.6 cm/year after complete deforestation of the Cagayan watershed.
At these values, model results show that both the increase in upland stormflow and the increase in siltation rate contribute approximately equally to the increase in yearly flooded area in the medium term (15 - 40 years from present); in the long term the increase in the siltation rate, driven by upland erosion, is the more important mechanism.
With use of the information in the consultancy report, deforestation-induced flood damage, at the present intensity of floodplain land use, is estimated at 5 - 10 US$ (at 1985 value) per year per hectare of deforested land.
The main uncertainties, in descending order, are the level and spatial differentiation of damage per area of flooded land, the rate and location of siltation in the river system, and the chosen value for stormflow increase.

Comparison of the costs and benefits of deforestation and other forms of upland land use in the Cagayan Valley leads to the recommendation to optimize upland land use in terms of upland benefits and costs, and to include downstream effects only as a second step. This recommendation is dependent on the low intensity of land use along the river. In watersheds with a similar climate as the Cagayan Valley, but with large urban centres, the economic benefits of upland deforestation may quickly be outweighed by an increase in lowland flood costs.

1. Introduction

The Centre of Environmental Science (CML) of Leiden University, the Netherlands, and the College of Forestry and Environmental Management of Isabela State University, the Philippines, are engaged in a collaborative environmental research programme in the Cagayan Valley in Northern Luzon, the Philippines. The research is based on a Problem in Context approach, in which the environmental problem is taken as the starting point and the criterium of relevance for the lines of multidisciplinary research that describe the most important actors, their motives and problem-causing activities on the one hand, and the environmental consequences and limits on the other hand ([De Groot 1992]).
In the CML programme, deforestation was identified as the main environmental problem in the Valley, and the lowland hydrological effects of deforestation were identified as an important line of research ([Maus & Schieferli 1989]).

In this report an attempt is made to qualify and quantify the lowland hydrological effects of deforestation in the Cagayan Valley.
Following a description of the area (chapter 2), the scientific consensus and local opinion on the hydrological effects of deforestation are described in chapter 3.
In chapter 4 the hydrological data of the Cagayan watershed that span the period of deforestation are analysed for changes in riverbed level, peakflows and dry season flow.
In chapter 5 the question is tackled with a model approach. As floods are considered to be a more critical problem in the Cagayan Valley than drought, the model is limited to the extent of deforestation-induced floods. From the model results an estimate is made of the flood damage induced by deforestation.
In chapter 6 the estimate of deforestation-induced flood damage is compared with the other costs and benefits of upland landuse in the Cagayan Valley.
Recommendations for further research are made in chapter 7.

Many people have contributed to this report by lending their ear and giving their comments. I would like to thank in person Wouter de Groot (CML), Sampurno Bruynzeel (Free University, Amsterdam) and Gerhard van den Top (CML) for their stimulating supervision and valuable comments on the draft version of this report; Ahdore Yacinto (Department of Public Works and Highways, Manila) for her kind assistance in gathering the hydrological data; Marino Romero (Isabela State University, Cabagan) for his introduction to the uplands of the Cagayan Valley; and Mirjam Stoffer for her support during the modelling work.
This report would not have been possible without the existence of the "Final report for the master plan study on the Cagayan river basin water resources development", by the Japan International Cooperation Agency and the Philippine Ministry of Public Works and Highways, 1987 ([JICA 1987]). Unfortunately, this report is in the "grey" circuit.

2. The Cagayan Valley and river

The Cagayan Valley is an elongated watershed of approximately 27,000 km^2, bordered by the Cordillera to the West and the Sierra Madre to the East. The main features of the topography are given in figure 1.

Over the last two decades the watershed has experienced a rapid rate of deforestation. Commercial logging has converted most of the primary forest to secondary forest, which in its turn is gradually being converted to brush and grassland by slash-and-burn agriculture, extensive grazing and random burning.
The approximate extent of forest cover around 1965 is shown in figure 3; the survey method is not documented. The extent of forest cover in 1987, taken from satellite images, is shown in figure 4. It is apparent from these figures that deforestation in the period 1965-1987 was concentrated in the South and East of the Cagayan watershed; the foothills of the Cordillera were largely deforested before 1965. The change in forest cover is summarized in table 1.

Table 1 Deforestation in the Cagayan watershed
Source 1965: [BR_USDI 1996]. Source 1987: NAMRIA + Swedish Space Corps 1987

	primary forest	secondary forest	total forest	other	total
1965	35 %	10 %	45 %	55 %	27000 km^2
1987	11 %	19%	30 %	70 %	

Land use in the Valley consists of commercial logging and slash-and-burn ("kaingin") agriculture in the uplands, and rainfed agriculture, irrigated rice production and extensive grazing in the lowlands. The agricultural production is mainly for subsistence, and low in comparison to the rest of the Philippines. Considerable tracts of grass-covered land are left idle. Economic use of the zones adjacent to the river system is seriously hampered by floods ([Maus & Schieferli 1989]).

The climate in the Cagayan Valley is influenced by the tropical monsoon. The annual isohyets (figure 2) show a strong gradient in rainfall perpendicular to the Sierra Madre. Figure 5 shows the seasonal distribution of (area averaged) rainfall and evaporation (as measured with evaporation pans). The wet season, defined as the period where rainfall exceeds evaporation is from April to December; during this season on average 2 to 5 typhoons cross the Valley each year. As a reference, rainfall and evapo-transpiration in the Netherlands have been included in the figure, indicating the extremely high rainfall in the Cagayan watershed, and the considerably higher, and fairly constant evapo-transpiration.

The seasonal distribution of the Cagayan river discharge is given in figure 6. As a reference, the discharge distribution of the European Meuse and Rhine rivers have been included. The Cagayan discharge is strongly seasonal, reflecting the strong seasonality in rainfall.

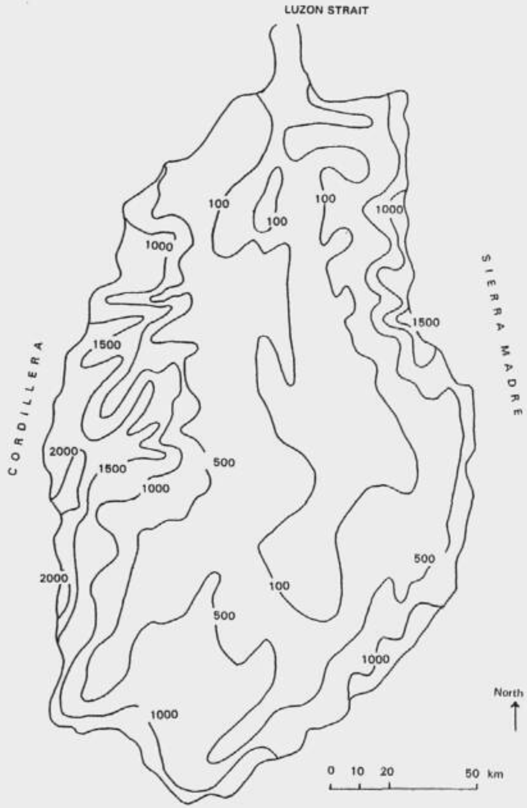

Figure 1 Topography of the Cagayan Valley
(m above mean sea level)

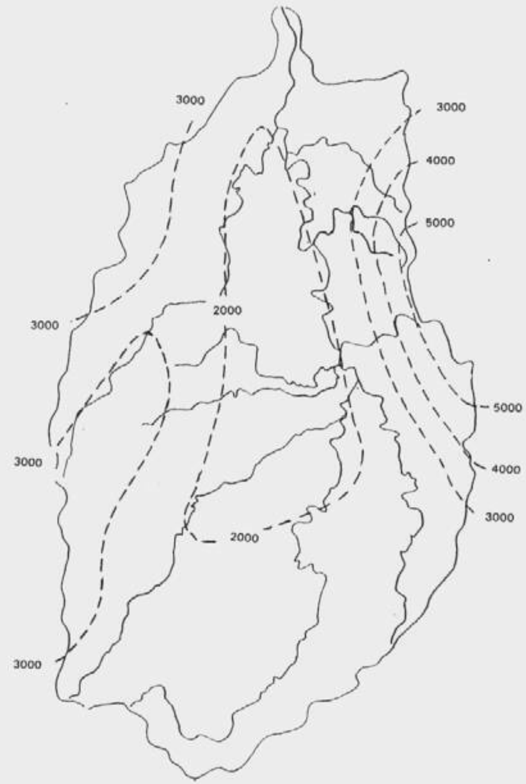

Figure 2 Yearly rainfall (mm). Source: JICA fig HY-2.2

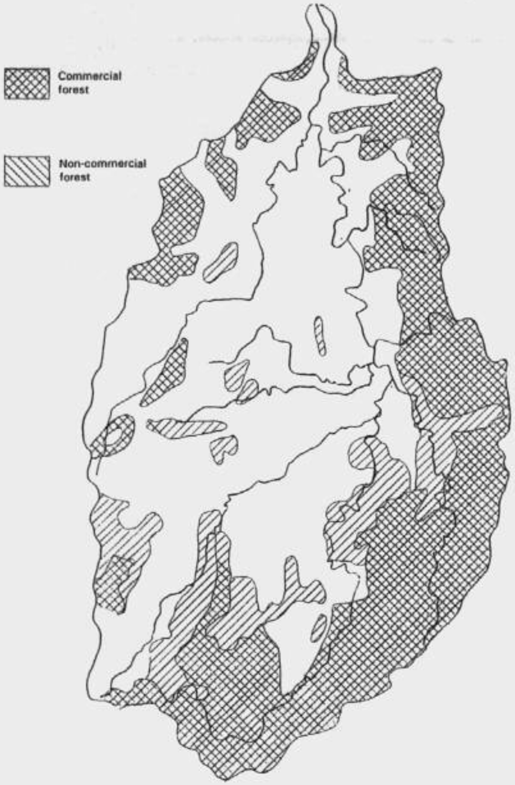

Figure 3 Forest cover around 1965.
Source: BR_USDI 1966

Figure 4 Forest cover in 1985
Source: NAMRIA + Swedish Space Corps 1987

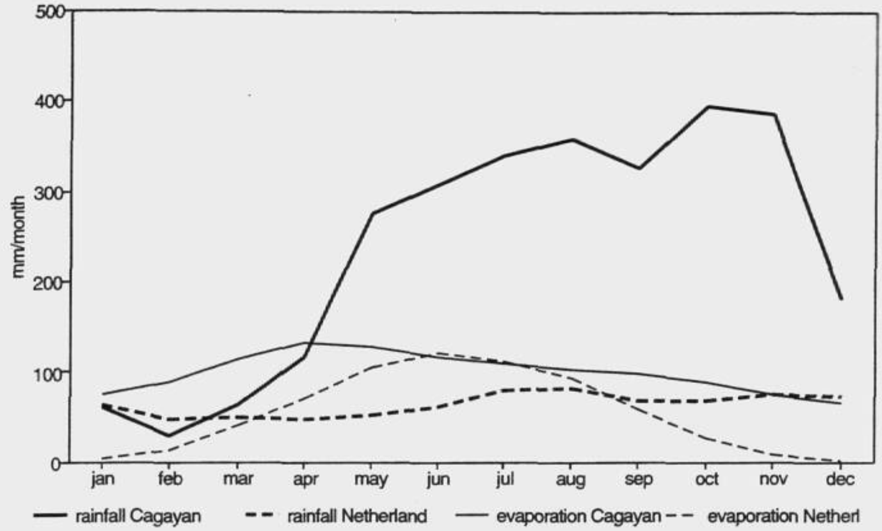

Figure 5 Average seasonal pattern of rainfall and evapotranspiration in the Cagayan Valley and the Netherlands.

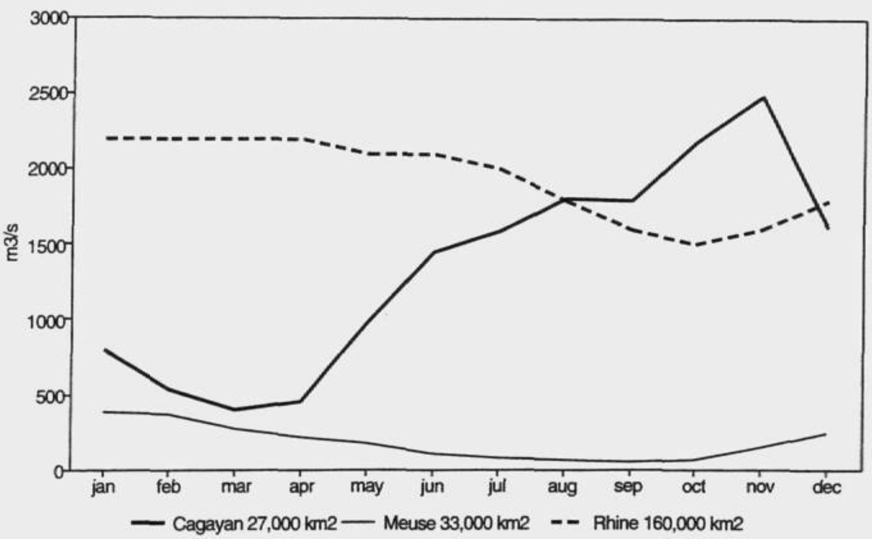

Figure 6 Average seasonal pattern of the discharge of the Cagayan River, the Meuse and the Rhine.

Although the area of the Cagayan watershed is only 20% of the Rhine watershed, the Cagayan river discharge during the wet season is of comparable magnitude as the winter and spring discharge of the Rhine. The maximum discharge of the Cagayan river in the past two decades is approximately 14,500 m3/s (model simulations of the 1973 and 1980 floods in [JICA, annex FC page 8]); the maximum recorded discharge of the Rhine in the period 1976-1991 is approximately 10,000 m^3/s.

The zones adjacent to the Cagayan river system are prone to frequent and extensive floods (figure 7). The main river and tributaries are largely unconfined and unregulated. Small stretches along the tributaries are protected by earth dikes. Along various stretches revetments aim to reduce river bank erosion ([JICA, annex FC, page 10 - 11]). At present, the Magat dam in the Magat tributary is the only major dam. The main purpose of the reservoir is the provision of irrigation water; in addition, the reservoir provides flood control space that reduces the peak discharges of this tributary. Various plans for additional dams and large-scale diking schemes have been made (the JICA report is the most recent and most comprehensive of these plans), but have not been executed so far.

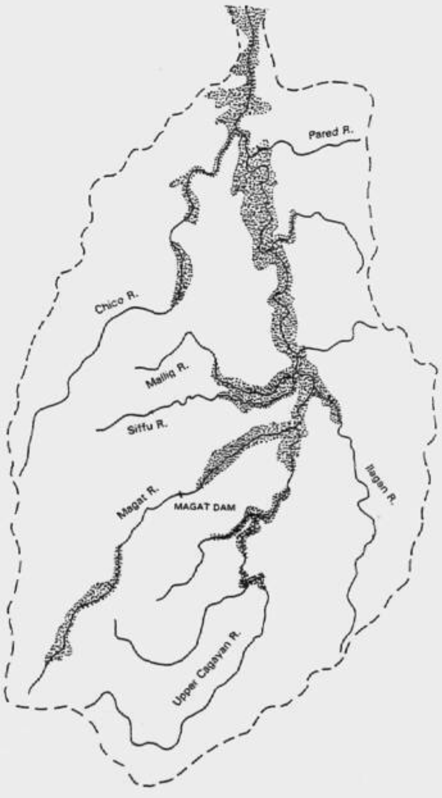

Figure 7 Extent of the 1973 and 1980 floods. Source: JICA figure M-2.

3. The effects of deforestation on river hydrology

3.1 The scientific consensus

Deforestation is defined as the removal of forest and the subsequent prevention of forest regrowth. Figure 8 gives a conceptual model of the river hydrological effects of deforestation.

A. No effect on rainfall

It is generally assumed that small- and medium scale deforestation has no influence on rainfall. Scientific reports demonstrating an effect of deforestation on rainfall on the scale of the Cagayan Valley have not been found.

B. Increased evapo-transpiration

Due to a higher absorption of sun energy and a greater rooting depth, transpiration by a forest vegetation is higher than the transpiration by shrub or grassland. In addition, the high forest leaf area stores more rainwater during rainfall; this intercepted rainfall is readily evaporated. The decrease in evapo-transpiration leads to a higher water table. These effects have been demonstrated, as summarized in [Bruynzeel 1990].

With an unaffected rainfall, a decrease in evapo-transpiration leads to an increase in baseflow and stormflows from deforested watersheds. The many paired-basin field experiments that have been conducted worldwide (summarized in [Bosch & Hewlett 1982] and [Bruynzeel 1990]) consistently support the increase in baseflow after deforestation. This increase occurs immediately after forest removal, and is reversible: reforestation decreases baseflow, due to an increase in evapo-transpiration.

Paired-basin references on changes in stormflow are scarce, as they require dense and high-quality hydrological and meteorological measurements, but point at an increase in stormflow (see paragraph ...), or are indecisive. From the increase in stormflow, an increase in the frequency and extent of flooding events is expected. As the evapo-transpiration effect does not increase with rainfall, a more prominent effect is expected on small flooding events (1* per 1-2 years) than on large flooding events (1* per 10-100 years).

C. Soil degradation.

Deforestation has the following soil effects:

- soil compaction during forest removal (heavy machinery, logging roads) and subsequent habitation (roads, villages).
- a decrease in soil organic matter content, due to a decrease in production and destruction by fire.
- an decrease in soil depth due to erosion.

These effects are well documented, and have been summarized, among others, in example [Morgan 1980] and [Bruynzeel 1990]). The combined effects tend to decrease the infiltration capacity and water storage capacity of the soil. Debate on the relative importance of infiltration capacity versus water storage capacity exists ([Bruynzeel 1990]), but both mechanisms are expected to increase stormflows. The severity of these changes in soil hydrological properties depends on the type and intensity of land use after forest removal. If the deforested area is not utilised, changes tend to be small. If soil degradation is severe, the recharge of groundwater may be hampered; a mechanism that may explain the frequent field reports of baseflow decrease following deforestation [Bruynzeel 1989].

Soil degradation is a slow process; effects will become apparent gradually, and reversibility may depend on (very) slow processes as rock weathering.

D. River siltation

The increased erosion in the watershed leads to an increased sediment input in the river system. This sediment accumulates in various zones, with possible economic consequences. A heavy river sediment load increases the rate of riverbank erosion [Morisawa 1985]). Siltation in the river channel leads to an increase in the severity of floods, irrespective of any change in the water discharge regime. The history of the Yellow River in China is a well-known example.

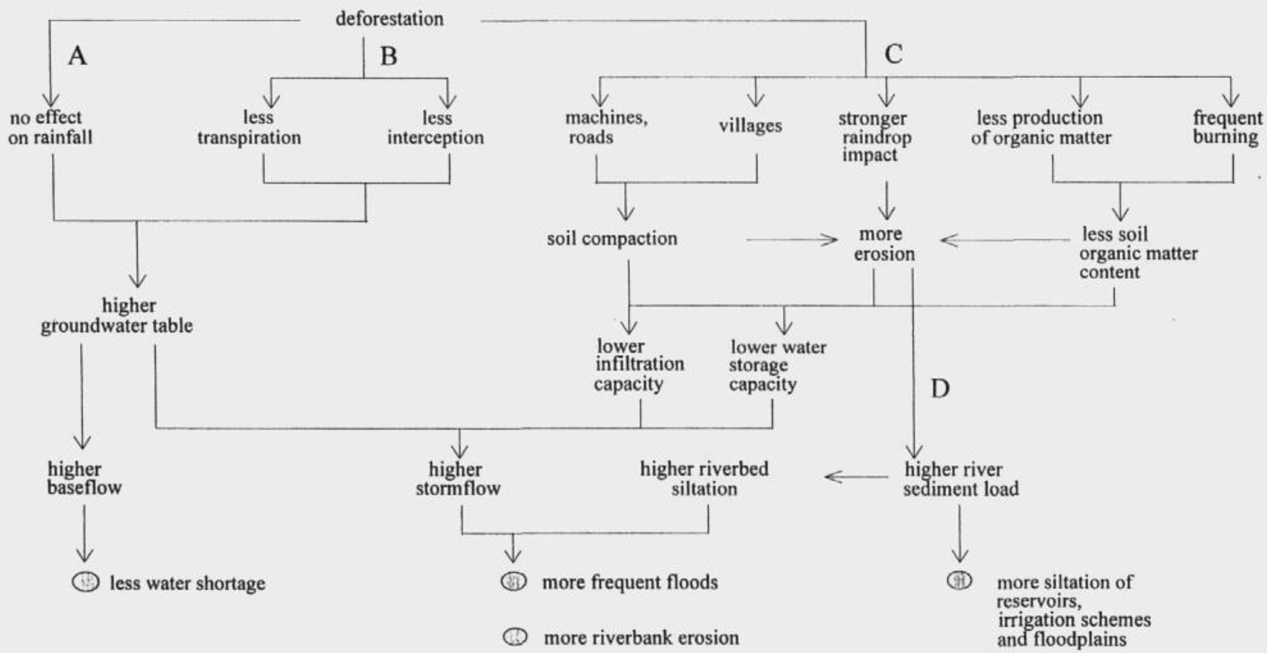

Figure 8 Conceptual model of the hydrological an morphological effects of deforestation.
Adapted from [Hamilton and King 1983].

3.2 Local observations

Inhabitants of the area generally hold the opinion that the extent of floods and droughts have increased due to deforestation; an opinion which is shared by many in the West on the basis of "common sense". Based on informal interviews with inhabitants in the watersheds of Tuguegarao, Tumauini and Massipi (figure 9) the observations of local inhabitants can be summarized as follows.

River morphology

- Tumauini: river is becoming shallower and wider, and the river bed is shifting more rapidly.
- Massipi: the amount of rocks in the river bed has increased. The riverbed has risen, and has become wider.

These observations point at the increase in erosion and siltation due to deforestation.

Dry season flow

- Tuguegarao: river running in front of house used to be 1 m deep; now it is only 30 cm deep. Creek feeding Tuguegarao river is becoming extinct.
- Tumauini: confluence of Tumauini and Cagayan river used to be so deep that the bottom could not be seen; now the confluence is shallow and full of rocks.
- Massipi: a 2 m deep swimming site in the river has disappeared after the logging operation.

These observations could be caused by one or more of the following processes: a high deposition in previously deeper river reaches, a decrease in dry-season flow, or an increase in the part of the dry-season flow that is not visible due to the buildup of coarse material on the riverbed. The extinction of the creek could be caused by the considerable increase in built-up area in the creek watershed, reducing groundwater recharge.

Floods

- Tuguegarao: floods occur more frequently, and are quicker to follow rainfall events. Yard in front of house was flooded recently; it never flooded before.
- Massipi: flash floods have increased, and are more dangerous due to floating logs.
- Tumauini: floods are more dangerous; they carry more mud, logs and branches of trees.

These observations could be caused by soil degradation and river siltation. The obstruction and damage to dyking systems by floating logs and branches is an additional mechanism of flood increase in the downstream vicinity of areas where logging is taking place.

Although these local perceptions are anecdotal and unvalidated, they do consistently point towards a tangible change in river hydrology and morphology in the downstream vicinity of deforested areas in the Cagayan Valley.

Figure 9 Location of the Tuguegarao, Massipi and Tumauini watersheds.

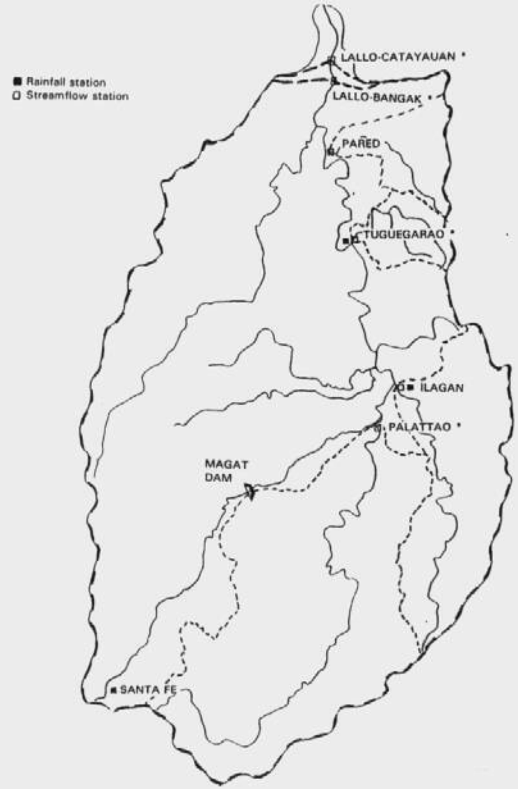

Figure 10 Stations with long hydrological and meteorological timeseries. Selected stations are marked with *.

4. Analysis of hydrological timeseries

In this chapter an attempt is made to find changes in the discharge regime and the morphology of the Cagayan river system during the recent process of deforestation, on the basis of the available hydrological timeseries as collected in the routine monitoring programme in the Valley. Watersheds in the Cagayan Valley that experience different levels of deforestation can be considered as uncontrolled paired-basin experiments. The uncontrolled nature leads to methodological problems with regards data quality that are generally avoided in true paired-basin experiments. On the other hand, the approach has the advantage that results are directly relevant for the specific meteorological, geological and vegetation and land use conditions of the Cagayan Valley; conditions which must be taken into account when extrapolations are attempted from true paired-basin experiments that have been conducted outside the region.

4.1 Method

Within the Cagayan basin, watersheds have been identified that comply with the following criteria:

- long timeseries of rainfall and river discharge
- considerable deforestation in the period spanned by the hydrological timeseries

The analysis attempts to compare, peak discharges, baseflow and the riverbed level before and after deforestation.

Changes in peak discharges and baseflow are analysed by comparison of the exceedence frequencies in earlier and later periods.

The riverbed level is estimated by using the measurements of the wet cross section, river width and river stage that are available from the stage-discharge measurements, according to the following formulas:

riverbed level = river stage - average water depth
average water depth = wet cross section / river width

At high discharges the average water depth decreases as the floodplains are included in the wet cross section. Therefore the above calculation has been made on the stage-discharge measurements that have been performed during episodes with a low discharge.

4.2 Selection of watersheds

Rainfall data are available at the Meteorological Institute PAGASA, Manila. Stations in the Cagayan Valley encompassing the period 1965-1985 are:

- Tuguegarao (1950 - 1990)
- Ilagan (1957 - 1990)
- Sta Fe (1966 - 1985)
- Baguio (1950 - 1990)
- Nayon (1968 - 1981)

Locations are indicated in figure 10.

Discharge data are available at the Department of Public Works and Highways (DPWH), Manila. In 1955 a large number of hydrological stations went into operation in the Cagayan Valley. Around 1970 nearly all these stations were discontinued. From 1983 the following

stations were reopened:
- Pared river
- Tuguegarao river
- Ilagan river
- Upper Cagayan river (Palattao)
- Cagayan river (Lal-lo)

The data of Tuguegarao, Palattao and Lal-lo were selected for further analysis. The Pared station is influenced by backflow from the Cagayan river, which confounds the influence of land cover changes in the watershed. The recent Ilagan data appear to be less reliable.

The extent of deforestation in the three selected watersheds over the period 1965 - 1987 is shown in table 2.

Table 2 Deforestation in the watersheds of the Tuguegarao river, Upper Cagayan river (Palattao station) and Cagayan river (Lal-lo station). Source 1965: [BR-USDI 1966]. Source 1987: NAMRIA + Swedish Space Corps satellite images.

		primary forest	secondary forest	total forest	other
Tuguegarao river at Tuguegarao bridge Watershed = 655 km^2	1965	70 %	5 %	75 %	25 %
	1987	20 %	30 %	50 %	50 %
Upper Cagayan river at Palattao Watershed = 6600 km^2	1965	56 %	15 %	71 %	29 %
	1987	6 %	27 %	33 %	67 %
Cagayan river at Lal-lo Wateshed = 27000 km^2	1965	35 %	10 %	45 %	55 %
	1987	11 %	19 %	30 %	70 %

4.3 Data quality

Rainfall

Most of the rainfall stations in the Cagayan Valley are located in the lowlands. The timeseries of the upland stations that do exist are short and fragmented. Although the exact values for upland rainfall are hypothetical, there is no doubt that upland rainfall is considerably higher than lowland rainfall (see figure 2). From waterbudgets and reasonable assumptions on evapotranspiration, JICA [annex Hydrology, page HY-13] estimates that the rainfall for the Cagayan Valley as a whole is a factor 1.5 higher than the average of the rainfall measured at the stations within the Valley. This factor is 1.35 for the watershed of the Upper Cagayan and a high 2.2 for the Tuguegarao watershed. Whereas these factors may be used to correct for year total rainfall, there is no method to correct for dry-season rainfall, and much less for the extreme rainfall events that cause peak discharges. Therefore the baseflow and peak discharges must be analysed without a correction for rainfall.

Discharge
Discharge in the DPWH stations is determined from daily measured water stages by means of stage-discharge relations (SDR). The quality of the discharge timeseries then depends on the quality of the stage measurements and the quality of the SDR's.

Stage is measured 3 times per day; the SDR is applied to the (daily) average of these measurements. This procedure leads to an underestimate of peakflows due to the exponential form of the SDR's, and a decrease in resolution. [Boerboom 1992] analysed hydrological timeseries of a number of tributaries of the Cagayan river for changes in the unit hydrograph following deforestation of the respective watersheds. This approach failed due to the fact that the frequency of waterlevel observations was too low.

In 1983 new gauges were installed at most stations that have not always been defined accurately relative to the old gauges; this problem is evident at station Tuguegarao.

In order to establish SDR's, stage-discharge measurements are performed with a frequency of 5-10 times per year. Width, water depth and stream velocity of the river are measured, and from these the discharge (m^3/s) is calculated. The SDR's are quite unreliable in the relevant trajectories: measurements of extreme discharges events are absent, as they occur during extreme weather conditions. Measurements of dry season discharges at comparable (low) stages are highly divergent, which may reflect sudden random changes in the riverbed level during the preceding wet season. It is standard practice at DPWH to make adjustments to the low trajectory of an SDR if a number of dry-season discharge measurements deviates from the original SDR; in the procedure the mid- and high trajectory of the SDR is unchanged. Thus the SDR's may change from year to year in the low trajectories. It may have been preferrable to exclude the translation by SDR's and analyse the stage timeseries directly. This is only possible for station Lal-lo; for the other stations the stage data before 1972 are no longer available.

4.4 Results and discussion

4.4.1 Tuguegarao

SDR
Although the pre-1973 and post-1983 gauges are on the same location, the (relative) 0-level on these gauges is different. From the information at DPWH the 0-level of the post-1983 gauge seems to be 18.0 meter below the 0-level of the pre-1973 gauge. In that case, however, the SDR's for both periods are highly divergent (figure 11 and 12). A better fit is obtained by assuming that the 0-level of the post-1983 gauge is 17.35 m below that of the pre-1973 gauge. The scatter in the measurements at the lower end of the SDR is large (figure 13).

Riverbed
Estimates of the riverbed level have been made from the stage-discharge measurements at a discharge smaller than 10 m^3/s. These are plotted against time in figure 14. Depending on the assumption on the 0-level of the present gauge, the riverbed seems to be at a constant level, or to decrease in time.

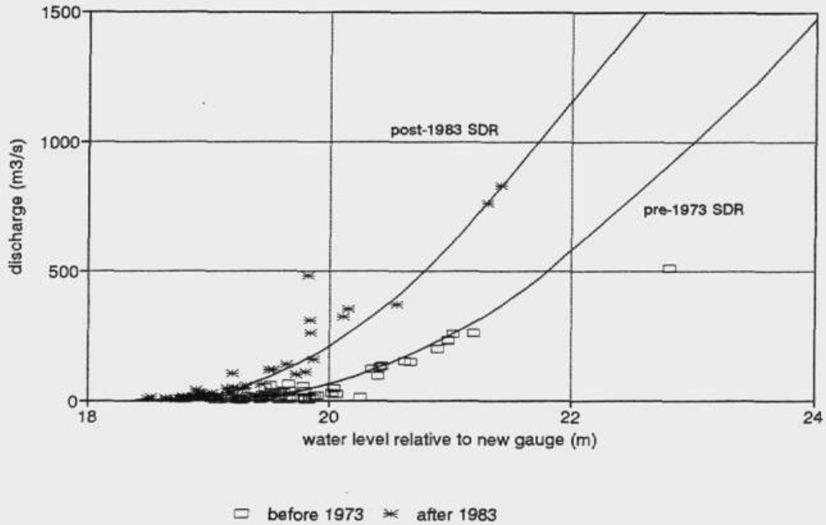

Figure 11 Stage-discharge measurements and stage-discharge relations at Tuguegarao station. The 0-level of the post-1983 gauge is set at 18.0 m below the 0-level of the pre-1973 gauge.

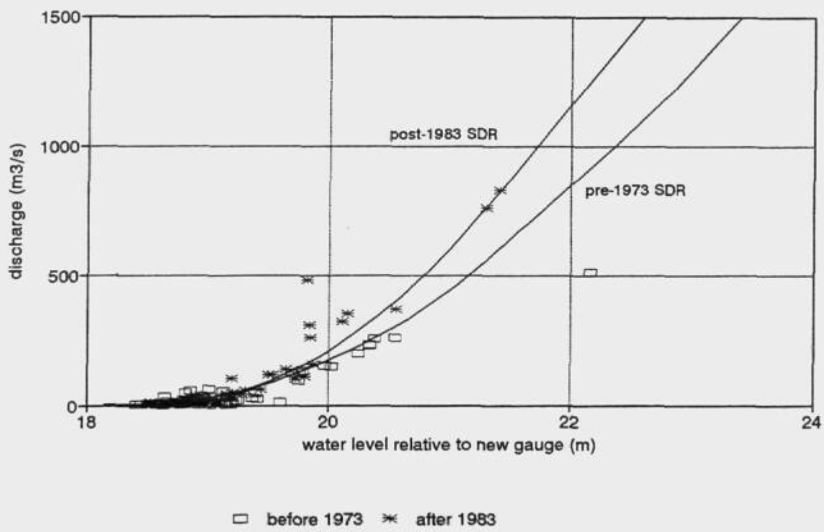

Figure 12 Stage-discharge measurements and stage-discharge relations at Tuguegarao station. The 0-level of the post-1983 gauge is set at 17.35 m below the 0-level of the pre-1973 gauge.

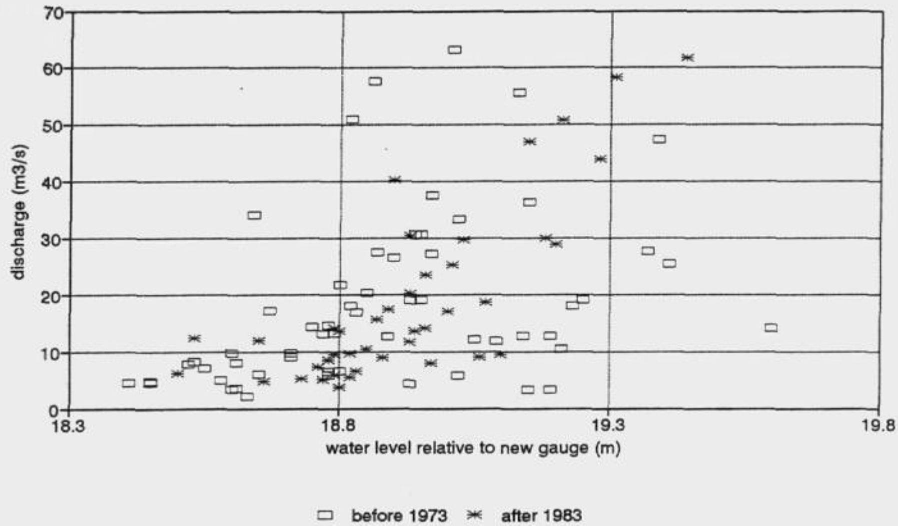

Figure 13 Stage-discharge measurements at Tuguegarao station with discharges smaller than 70 m^3/s.

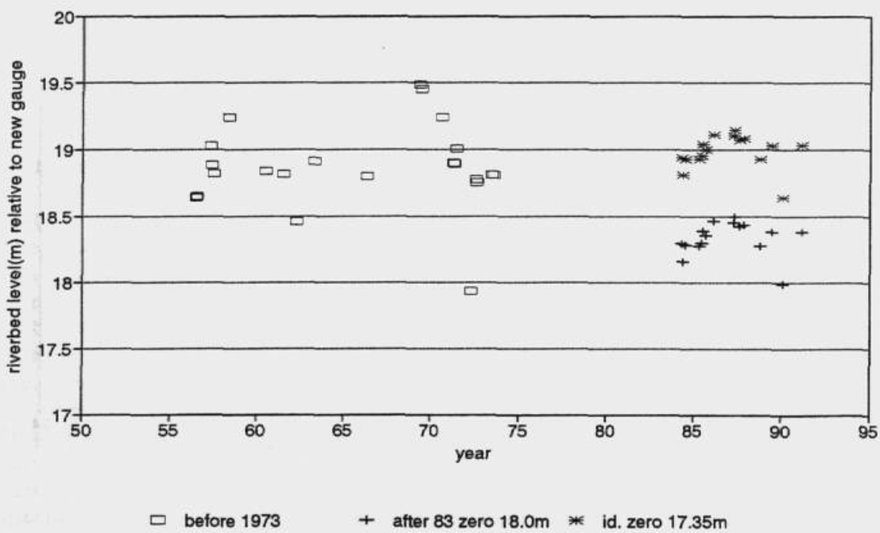

Figure 14 Trend in riverbed level at Tuguegarao station, under the two assumptions of the 0-level of the post-1983 gauge relative to the pre-1973 gauge.

Peak discharges

The frequency and magnitude of peak discharges seems to have increased after 1983 (figure 15). As discharges higher than 800 m^3/s have never been actually measured, a high uncertainty in the upper reaches of the SDR's must be taken into consideration. An indication of this uncertainty can be obtained by assuming that the pre-1973 and the post-1983 SDR are approximations of the same, unchanged SDR. The post-1983 discharges have been recalculated from the post-1983 stages and the pre-1973 SDR. Due to the uncertainty in the 0-level of the present gauge relative to the pre-1973 gauge two transformations have been applied to the post-1983 stages prior to the application of the pre-1973 SDR:

high correction: pre-1973 SDR on post-1983 stage - 18.0 m
low correction: pre-1973 SDR on post-1983 stage - 17.35 m

The exceedence frequency of the pre-1973 peak discharges and the original and corrected post-1983 peak discharges are given in figure 16. With the correction for the uncertainty in the SDR's the change in the frequency and magnitude of peak discharges is small, or absent. Evidence that peakflows in the Tuguegarao watershed have increased is therefore weak. In addition, any increase could well be caused by the occurrence of heavier rainstorms in the post-1983 period, a factor that cannot be taken into consideration as the rainfall measurements at Tuguegarao city are not representative for the watershed as a whole.

Baseflow

Baseflow seems to have decreased after 1983 (see figure 17). Over the 90 driest days of the year, the baseflow has decreased with a remarkably constant value of 3.4 m^3/s. In the early '80s the irrigation scheme at Penablanca came into operation, with a water intake slightly upstream of the hydrological station at Tuguegarao bridge. The intake can be estimated from the water demand of irrigated rice (approximately 20 mm/day, if losses due to transport and drainage are included) and the extent of the scheme (550 ha) at 1.2 m^3/s; the maximum intake capacity of the inlet is 3.3 m^3/s (personal communication of irrigation officer). Taking these figures at face value, there still is a weak indication of a decrease in post-1983 baseflow, contrary to the expected increase following deforestation.

4.4.2 Palattao

The DPWH data on the area of the Palattao watershed give the impression that the station has been relocated after 1973. The coordinates of the old and new station point at a slight relocation. Discharge timeseries at Palattao have been digitized for the period 1964 - 1972; the period 1984 - 1989 has not been digitized. An analysis of changes in peakflow and dry season flow has not been made.

SDR

The discharge measurements at Palattao are shown in figure 18. As in Tuguegarao there are no discharge measurements in the high trajectory. The maximum measured discharge (1500 m^3/s) is well below the maximum recorded (via SDR) value of 6000 - 9000 m^3/s. As in Tuguegarao the scatter in the lower trajectory of the SDR is large.

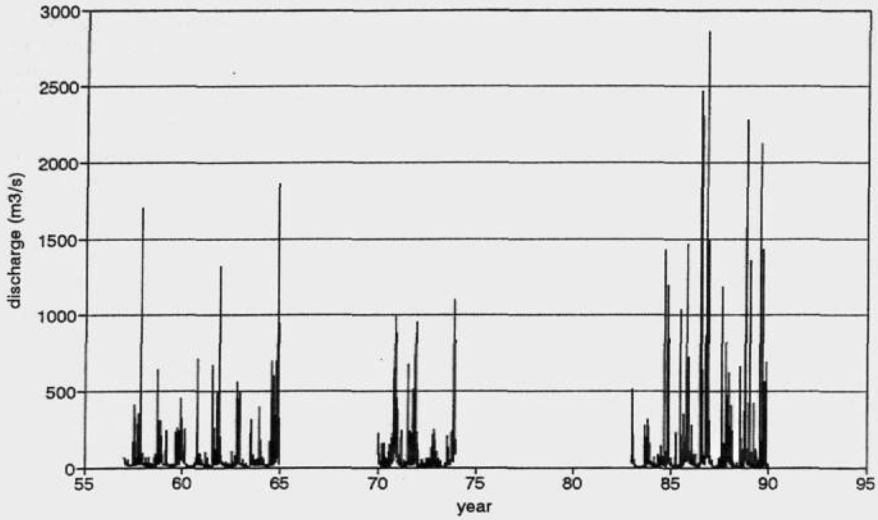

Figure 15 Timeseries of the Tuguegarao river discharge

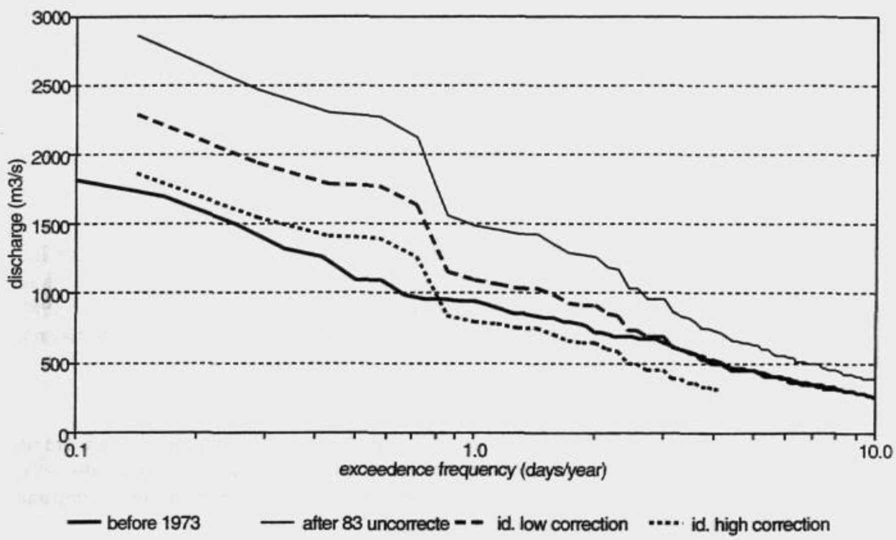

Figure 16 Pre-1973 and post-1983 peakflow exceedence frequencies of the Tuguegarao river. The various forms of the post-1983 exceedence frequency reflect the uncertainty in the SDR's and the 0-level of the post-1983 gauge relative to the pre-1973 gauge.

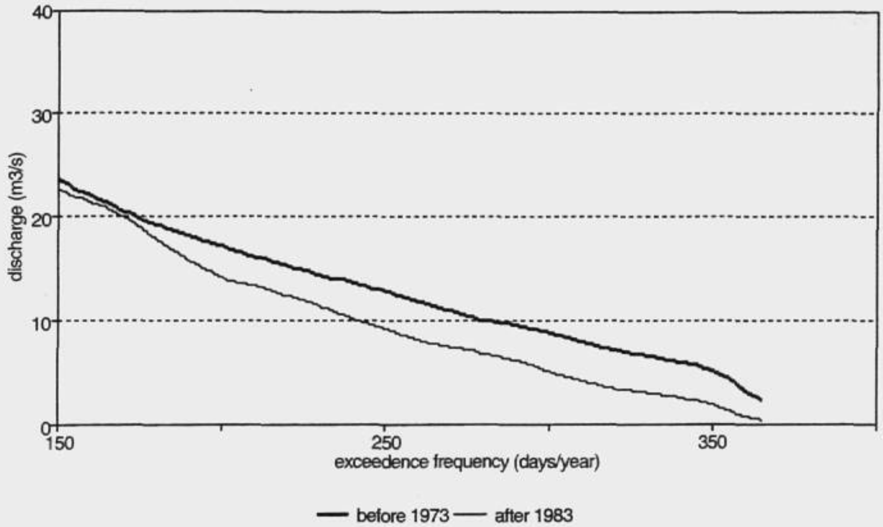

Figure 17 Pre-1973 and post-1983 baseflow exceedence frequencies of the Tuguegarao river.

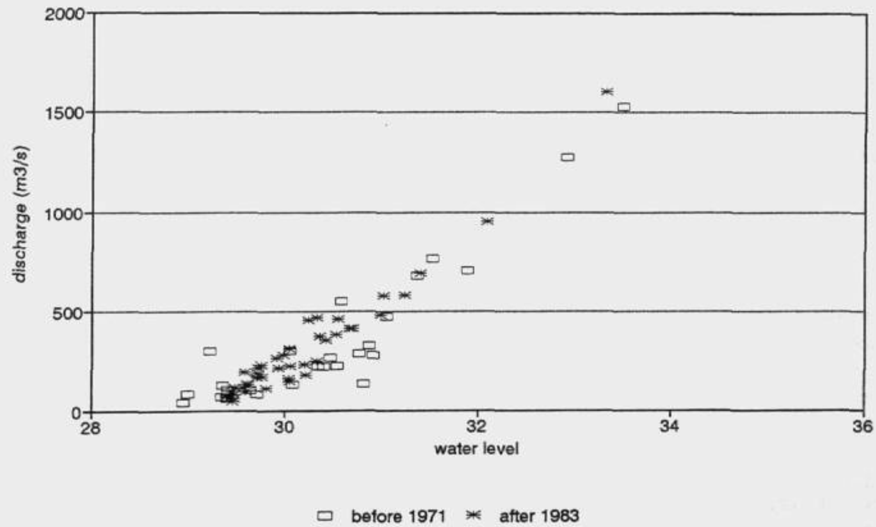

Figure 18 Stage-discharge measurements at Palattao station.

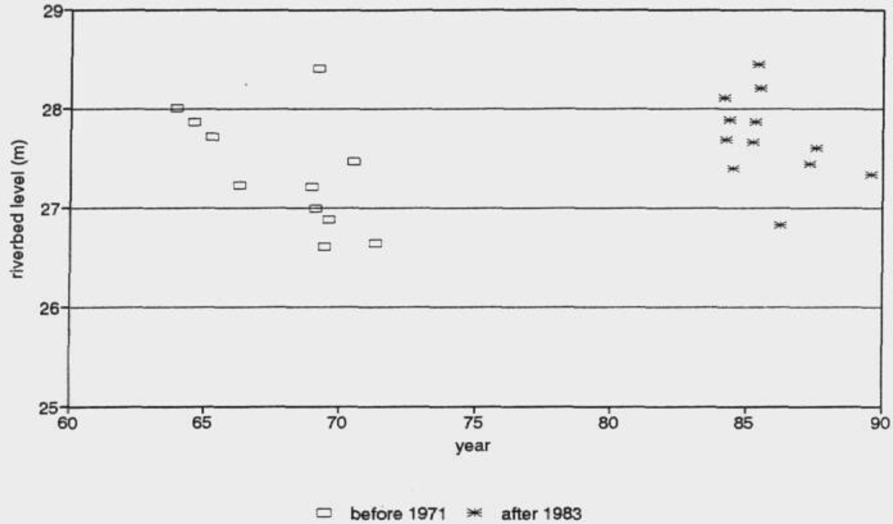

Figure 19   Trend in riverbed level at Palattao station.

Riverbed level
Estimates of the riverbed level have been made from the stage-discharge measurements with a discharge smaller than 150 m^3/s. Riverbed level fluctuations are in the order of 1 meter (see figure 19), possibly due riverbed dynamics or measurement inaccuracies. No trend is apparent.

4.4.3 Lal-lo

Before 1972 the hydrological station was located at Catayauan (km 24 from sea); in 1984 the station has been reopened at Bangak (km 30 from sea). Before 1972 no stage-discharge measurements were made at Lal-lo. Therefore, trends in riverbed level cannot be analysed. The analysis focuses on changes in peak levels and dry season levels.

Peak levels
Post-1983 peak levels at Bangak are higher than pre-1972 peak levels at Catayauan (figure 20). However, a correction has to be made for the relocation of the hydrological station. For this river reach [JICA p FC-9] gives a value of 1/3450 for the water surface slope during the 1980 flood. On average, Bangak station should then measure 1.5 m higher peak levels than Catayauan station. After this correction, peak levels appear to have decreased rather than increased (figure 21), which may well be due to the uncertainty in the correction factor.

Dry season levels
Post-1983 dry season levels at Bangak are higher than pre-1972 dry season levels at Catayauan (figure 20). [JICA p FC-9] gives a value of 1/8680 for the slope in waterbed in this reach. Bangak station should then measure 0.7 m higher dry season levels than Catayauan station. After this correction, dry season levels seem to have decreased rather than increased (figure 22). Again, this may well be due to the uncertainty in the correction factor.

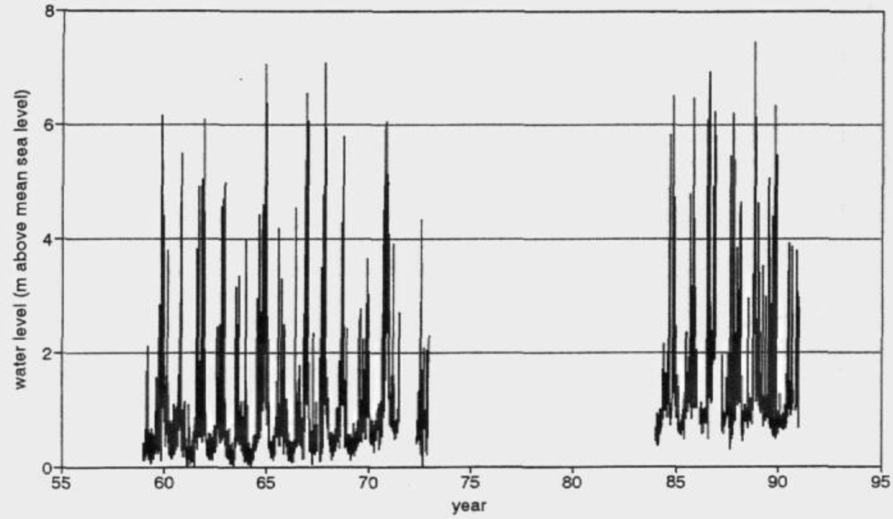

Figure 20 Timeseries of the waterlevel of the Cagayan river at Lal-lo station.

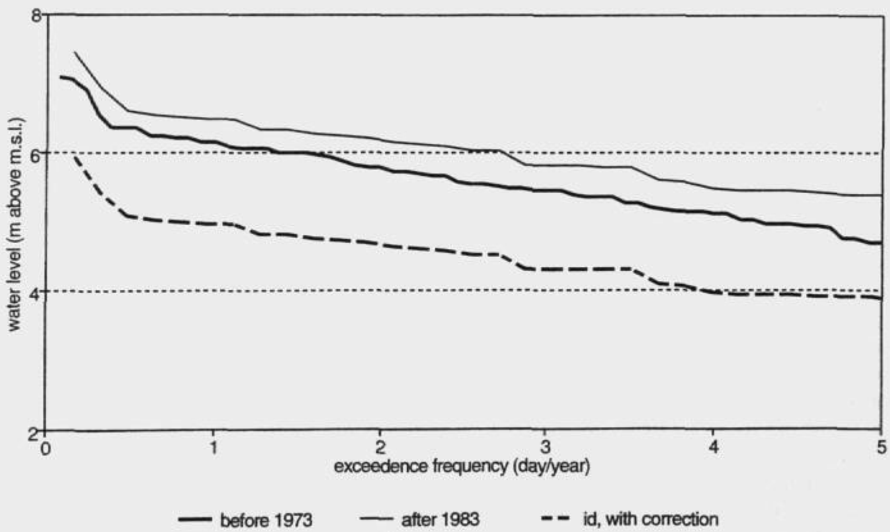

Figure 21 Pre-1973 and post-1983 peak level exceedence frequencies of the Cagayan river at Lal-lo station. The post-1983 exceedence frequency has been corrected for the upstream relocation of the hydrological station.

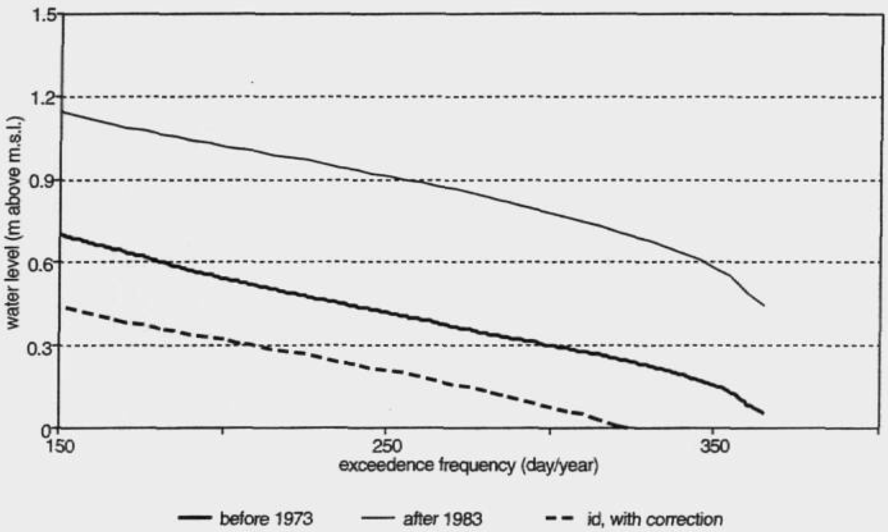

Figure 22 Pre-1973 and post-1983 dry season level exceedence frequencies of the Cagayan river at Lal-lo station. The post-1983 exceedence frequency has been corrected for the upstream relocation of the hydrological station.

4.5 Conclusions

The hydrological timeseries of the selected watersheds in the Cagayan Valley do not provide firm evidence for changes that correlate with the deforestation in the period 1965 - 1989. There is some evidence for an increase in peakflows from the 655 km^2 Tuguegarao watershed; however this apparent change has not been corrected for the variation in rainfall.
There is some evidence that the baseflow from the Tuguegarao watershed may have decreased, contrary to the expected increase after deforestation. No changes were found in the peak levels and dry-season levels of the Cagayan river.

An attempt to find hydrological changes on the basis of the data of a routine monitoring programme is only viable if the quality of the data is high, and the rate of deforestation is considerable. Whereas the extent of deforestation in the Cagayan Valley over the investigated period is high (25% - 50%), the approach was confronted with severe methodological problems due to the quality of the data. The most serious shortcomings were:
- lack of upland rainfall stations
- low frequency of stage readings
- unreliability of stage-discharge relations in the high and low trajectories
- relocation of hydrological stations.

In order to establish changes in peak discharges, all the above shortcomings are critical. Whereas some of the shortcomings can be improved in a routine monitoring programme, the high spatial and temporal variation of rainfall is very difficult to monitor routinely. Therefore the approach is less promising for establishing changes in peak discharges. As baseflow is less dependent on the spatial and temporal variation in rainfall, and reliable and frequent baseflow measurements are easier to perform than peak discharge measurements, the approach is more promising for establishing changes in baseflow. Hydrological stations that are placed in locations where changes in river morphology are small (rock outcrops) are most promising.

The Palattao data, representative of the Upper Cagayan river, have not been fully analysed. Based on the results for Tuguegarao and Lal-lo it is not likely that firm evidence can be drawn from the Palattao data. On the other hand, this station may be interesting:

- the scale of the watershed is intermediary between the Tuguegarao watershed and the Cagayan basin as a whole
- deforestation has been quite severe (see table 2)
- there are 2 rainfall stations in this watershed
- the rainfall gradient with altitude is relatively slight

Before proceeding in the analysis of these data, it is advisable to investigate to what extent the hydrological station has been shifted.

5. Approximation of deforestation-induced floods with a hydrological model

Based on the information in the annexes Hydrology (HY) and Flood Control (FC) of the JICA report ([JICA 1987]) a hydrological model has been constructed that simulates the frequency and extent of floods in the downstream Cagayan basin. The following effects of deforestation have been analysed for their contribution to downstream floods:
- an increase in the stormflow from deforested watersheds
- an increase in the riverbed siltation rate.

Horizontal migration of the river channel (riverbank erosion, meander cutoff, shift in river course) and the associated changes in the extent of floods have not been taken into account.

Model construction is described in chapter 5.1.
The choice of the value for deforestation-induced increases in stormflow and siltation rate are motivated in chapters 5.2 and 5.3 respectively.
The model results are given in chapter 5.4.
Deforestation induced flood damage has been estimated in chapter 5.5.
The main uncertainties in the estimates are discussed in chapter 5.6.
In the following paragraphs reference is made to the text, figures and tables of the JICA report, by means of the following abbreviations:

DA	annex Dams
FC	annex Flood Control
HY	annex Hydrology
M	Main report

Relevant tables have been included in annex 1.

5.1 Model construction

In [JICA-HY] and [JICA-FC] a hydrological model of the Cagayan river and major tributaries is presented that simulates the course of stormflows caused by different rainfall intensities (see figure 23). This model, consisting of the modules Subbasins and River Channels has been replicated (paragraph 5.1.1).
Because the JICA model does not generate water levels or flooded areas, the Cagayan river downstream of the Magat river confluence has been schematized in the 1-dimensional hydraulic model DUFLOW (paragraph 5.1.2). The replicated JICA model is used to generate the necessary input for the DUFLOW model. The output from the DUFLOW model has been compared with the relevant information in the JICA report (paragraph 5.1.4).

5.1.1 Replication of the JICA model

Module Subbasins
This module calculates a timeseries of the stormflow emanating from the subbasins (varying in size from 100 - 1000 km^2) due to peak rainfalls that have a return period of 2, 5, 10, 25, 50 and 100 years. A subbasin is represented by 2 storages that generate discharge due to rainfall. When rainfall starts, storage S1 is filled, of which a fraction f is discharged. After the cumulative rainfall reaches threshold Rs, storage S2 is filled; this rainfall is discharged entirely. In addition, there is a time lag Tl before the discharge emanates from the watershed.

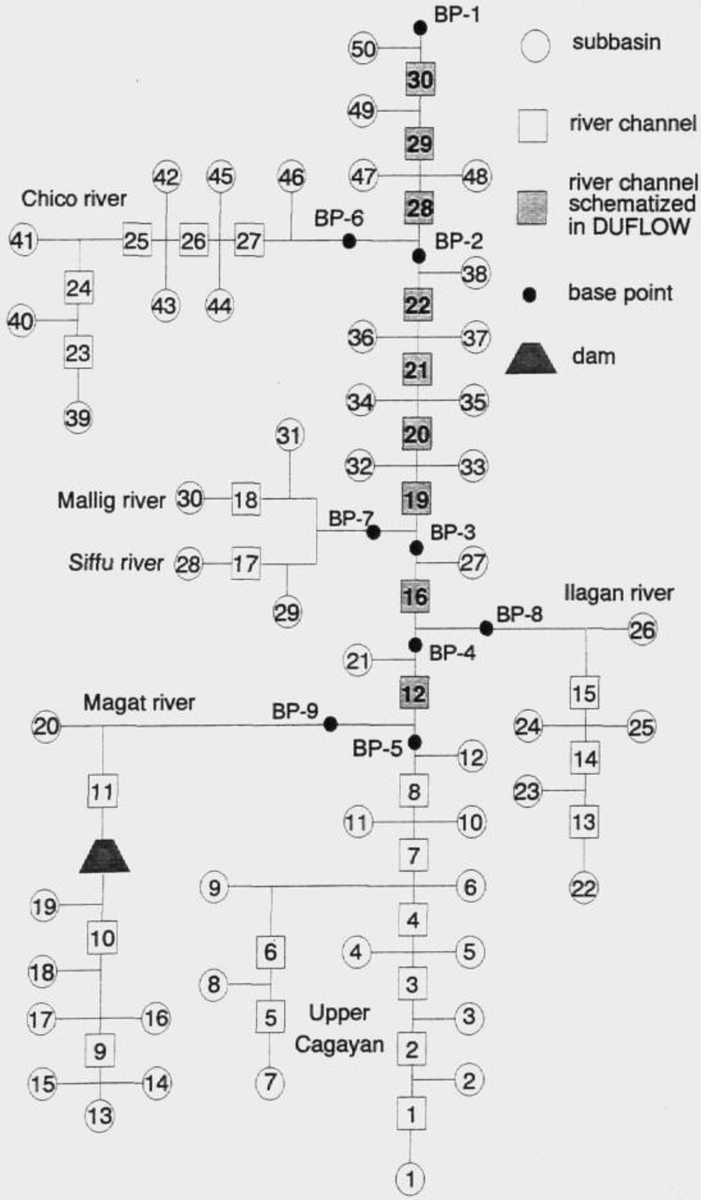

Figure 23 Hydrological model of the Cagayan river system developed by JICA. The figure shows the section of the Cagayan river that was modelled with DUFLOW.

The module consists of the following formulas (p HY-24 to 26):

Qout(t)	= Q(t+Tl)
Q(t)	= 0.2778* (f*q1 + q2 +qbase)* A
q1	= (1/K* S1)^(1/P)
q2	= (1/K* S2)^(1/P)
dS1/dt	= r1 - q1
dS2/dt	= r2 - q2
r1	= r, if Sum(r) < Rs
	= 0, if Sum(r) >= Rs
r2	= 0, if Sum(r) < Rs
	= r, if Sum(r) >= Rs

Qout(t)	discharge from subbasin on hour t (m^3/s)
Q(t)	discharge with no time lag on hour t (m^3/s)
Tl	time lag in discharge (hours)
f	primary runoff coefficient (-)
q1, q2	discharge from subbasin storage S1 and S2 (mm/hour)
qbase	baseflow (mm/hour)
A	area of subbasin (km^2)
K,P	coefficients (-)
S1, S2	storages in subbasin (mm)
r, r1, r2	rainfall on subbasin (mm/hour)
Rs	cumulative rainfall at which storage S1 is saturated (mm)

Rainfall intensities, as a function of return period, are given in table HY-4.5 (see annex 1). In this table consideration is given to the spatial heterogeneity in rainfall intensity over the Cagayan basin. For the prediction of stormflows in the downstream Cagayan river JICA uses the rainfall pattern "Intensive rainfall on Upper Cagayan Basin". The distribution of peak rainfalls in time is given in figure HY-4.10 (see annex 1). The JICA study assumes that this rainfall distribution occurs simultaneously over the whole basin. Values for the parameters in the subbasin module (A, K, P and Tl) are given in table HY-4.7 (see annex 1). Values for f (0.5), Rs (150 mm) and qbase (0.04 $m^3/s,km^2$) are the values used by JICA.

Module River Channels

This module routes the stormflow through the channel network, with the following empirical formulas:

Qout(t)	= Q(t + Tl)
Q(t)	= 1/K * S(t) ^(1/P)
dS(t)/dt	= I(t) - Q(t)

Qout(t):	discharge from channel reach on hour t (m^3/s)
Q(t):	discharge with no time lag on hour t (m^3/s)
Tl:	timelag (hours)
S(t):	storage in channel reach on hour t (m^3)
I(t):	inflow in channel reach on hour t (m^3/s)
K, P:	coefficients

The module has been copied unchanged. Values for the coefficients K, P and the timelag Tl are are given per channel reach in table HY-4.9 (see annex 1).

Test of the replica

The replica of the JICA model can be tested by comparison of the 1/100 year stormflows shown in figure 24. The locations (BP1 - BP3) can be found in figure 23.
The replica gives slightly higher maximum discharges, and these maxima occur slightly earlier than with the original model. The other points (BP4 - BP9) compare equally. As a whole the replicated values compare well with the original values.

5.1.2 DUFLOW model of the downstream Cagayan river

DUFLOW ([DUFLOW 1992]) is a 1-dimensional dynamic hydraulic model. The model solves a simplified form of the Navier-Stokes equation with an implicit numerical scheme. In order to do so, the cross sections of the river channel and floodplain must be schematised in nodes and sections. The Cagayan river downstream of the confluence with the Magat river has been schematised in 10 sections and 11 nodes (see figure 23 and Annex 2). All sections correspond with channels in the JICA hydrological model, with the expection of channel 21, which is disproportionately long (76 km) and has been split in 2 sections.

The schematisation of the cross sections of the **river channel** is based on table FC-2.1 and figure M-5.2. At each node, the minimum bank level in figure M-5.2 has been taken as the bank level of the schematization. The river channel width has been taken from table FC-2.1.

Two options for the riverbed level have been elaborated (see figure 25). In the option "shallow" the riverbed level has been calculated by substracting the river channel depth given in table FC-2.1 from the (minimum) bank level in figure M-5.2. The resulting riverbed levels are much higher (up to 10 m) than the "lowest bed of existing channel" in figure M-5.2. This may point at a highly undulating riverbed at all cross sections, or some inconsistency in the JICA datasets. In order to investigate the sensitivity of the model to the riverbed level, a second "deep" schematisation has been constructed in which the riverbed level is set at an arbitrary value of 4 meter above the "lowest bed of existing channel" in figure M-5.2. On average the riverbed level in the shallow schematization is 5 m above the riverbed level in the deep schematization. The shallow and deep schematizations only differ in the riverbed level; the channel width, bank level and schematization of the floodplains are identical in both cases.

The schematization of the cross section of the **floodplains** adjacent to the river is based on figure 7, which shows the flooded area during the 1973 and 1980 floods; the water levels during these floods are reported in table FC-2.3. The flooded area in figure 7 has been measured per section; division by the length of the section gives the flooded width corresponding to the level reported in table FC-2.3. A constant slope has been assumed for this reach of the floodplain. The floodplains further removed from the river have been schematized roughly on the basis of 1:250,000 maps of the Cagayan basin, by measuring the width between the lowest contourlines bordering the river.

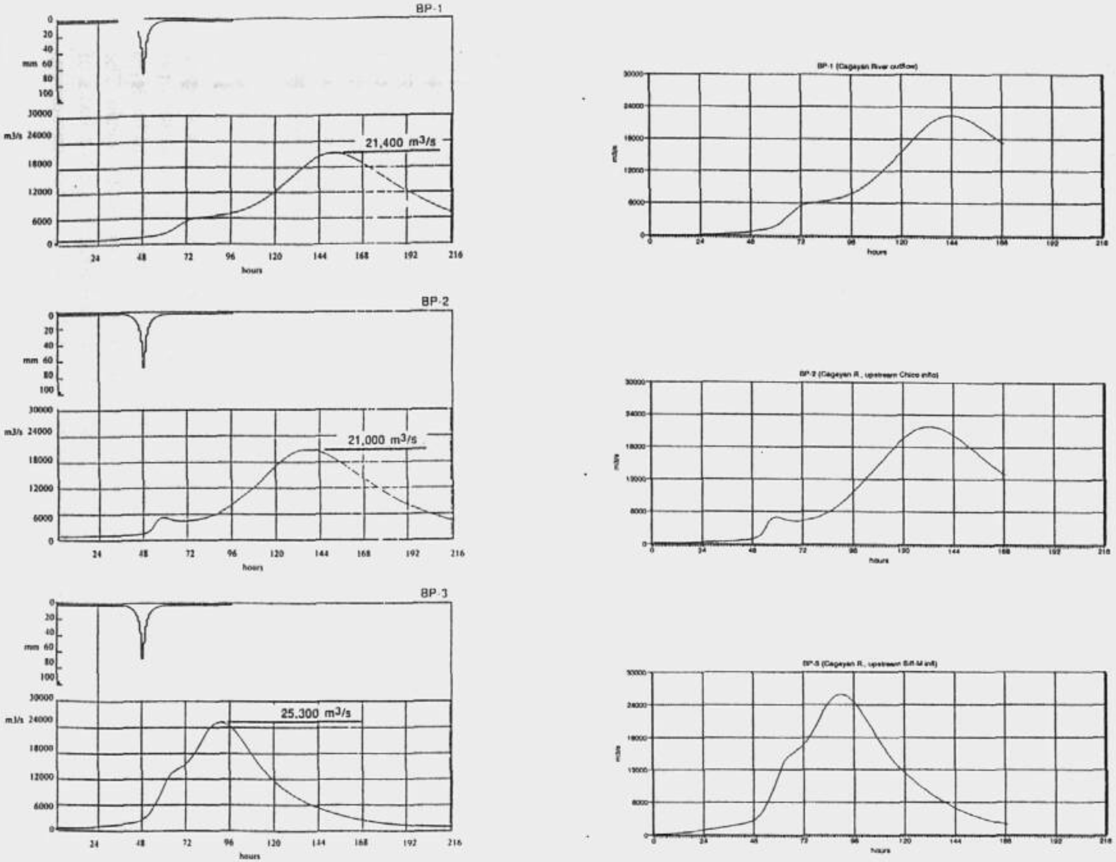

Figure 24 Comparison of the output of the replica (right) and the JICA hydrological model (left). 1 in 100 year stormflow.

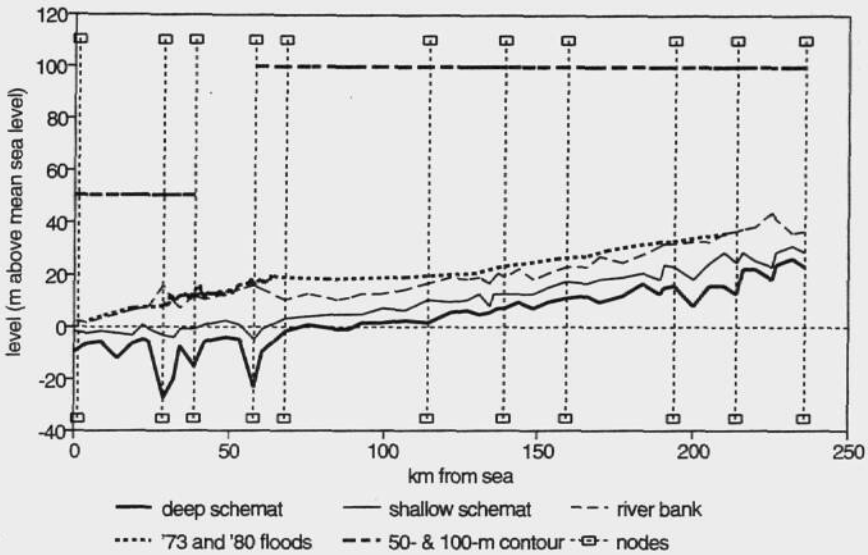

Figure 25 Schematization of the level of the Cagayan riverbed and floodplains.

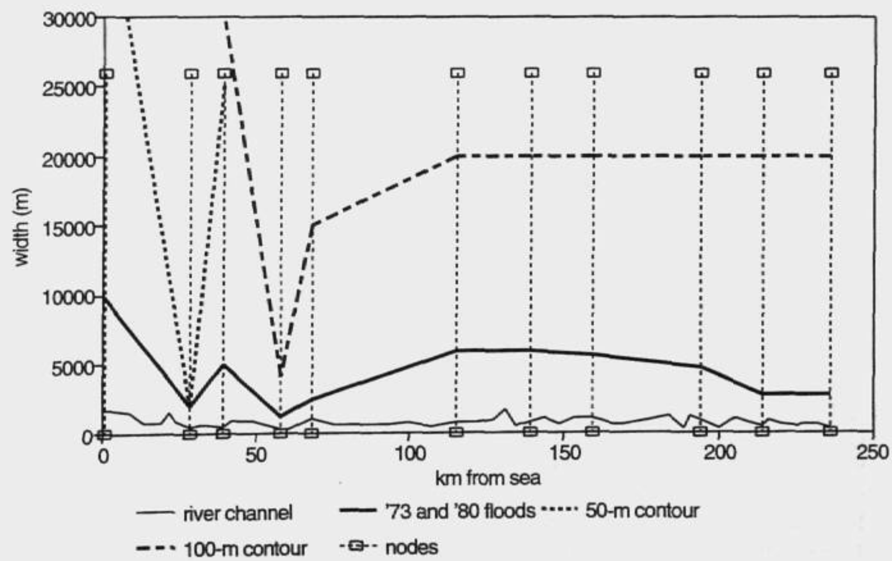

Figure 26 Schematization of the width of the Cagayan river channel and floodplains.

These are 100-m contour lines, with the exception of the reach downstream of the confluence with the Chico river, where the maps give 50-m contour lines. Also for this reach a constant slope has been assumed. The schematization of the cross section is shown in figure 26.

The Duflow model has the option of assigning the floodplains as contributing to water flow, or only acting as water storage. The model does not have the option of restricted flow on the floodplains (i.e. a higher resistance to waterflow on the floodplains than in the river channel). The choice has been made to set the flowing width at half the storing width for water levels above the bank level. The consequence is that water flows over approximately half the width of the flooded floodplain adjacent to the river, and does not flow over the further removed half of the flooded floodplain.

The bottom shear stress - the only parameter in the model - is set at a Chezy value of 35, a common value in river flow simulations.
Boundary conditions for the model are the discharges emanating from the tributaries (Upper-Cagayan, Magat, Ilagan, Siffu, Mallig and Chico) and the subbasins that discharge directly into the schematized part of the Cagayan river. These discharges are generated by the replica of the JICA model. The level at the outflow to sea has been held constant at average sea level.
Initial values for levels and discharges were obtained by a simulation with a constant discharge from all subbasins of 0.16 m^3/km^2,s.

5.1.3 Flooded area as a function of the rainfall event

Figure 27 shows the flooded area caused by rainfall with a return period of 2, 10 and 100 years, as simulated with the shallow schematization.
It is apparent that the flooded area increases considerably from a 2- to a 10-year rainfall, but hardly increases from a 10- to a 100-year rainfall. Although the increase in rainfall levels off with increasing return period, the main reason is the concave topography of the floodplain (see figure 28). In the area that was flooded in 1973 and 1980 the slope of the floodplain is only 1-2 m/km; further away from the river the slope is much steeper.

5.1.4 Verification of the model

The most appropriate method for model verification is a comparison of predicted and actual flooded area as a function of return period. Unfortunately, these data are not included in the JICA report.

The flooded area in figure 7 can be a point of verification, if the return period of floods with this extent is known. On page FC-8 it is stated that the 1973 flood was the largest flood since 1906, and the 1980 flood was the largest since 1973. This indicates that the return period of the 1973 and 1980 floods is in the order of 25 years. Figure 29 shows that the shallow schematization replicates the 1973 and 1980 flood levels reasonably well when simulating a once per 10-year rainfall. The deep schematization gives a reasonable replication of these flood levels when simulating a once per 25-year rainfall.

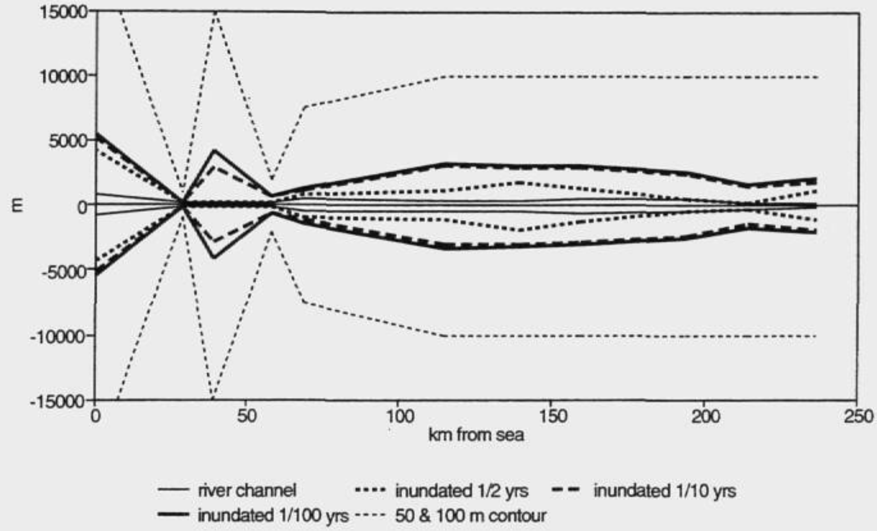

Figure 27 Frequency and extent of the flooded area along the downstream Cagayan river as predicted by the model with the shallow schematization.

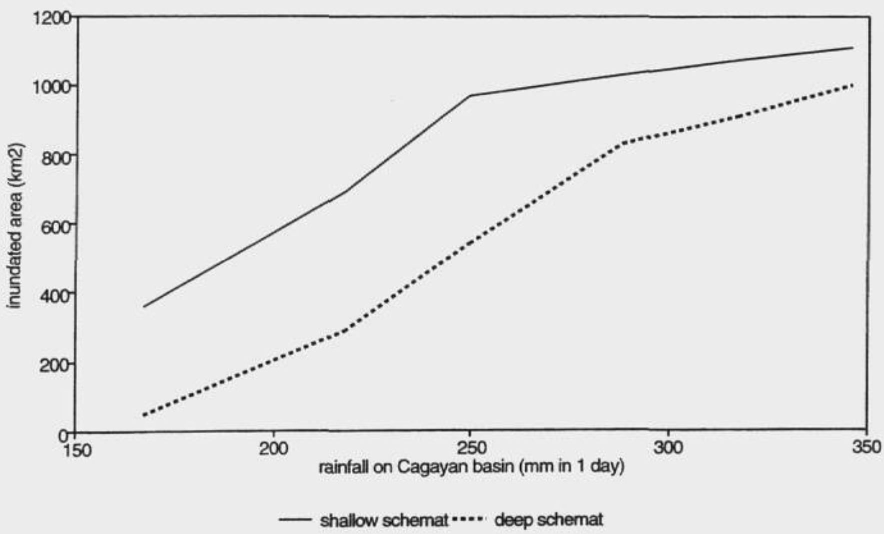

Figure 28 Extent of the flooded area along the downstream Cagayan river as a function of the rainfall event.

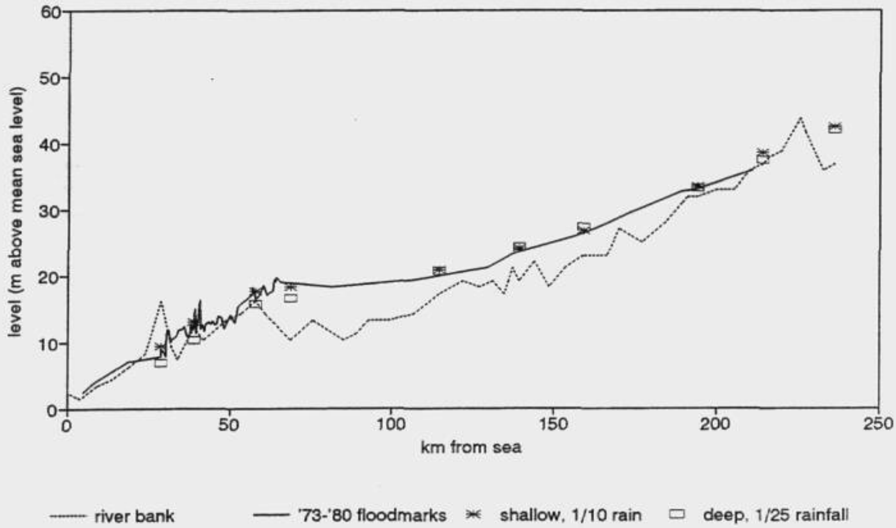

Figure 29 Comparison of the modelled maximum levels with recorded floodmarks.

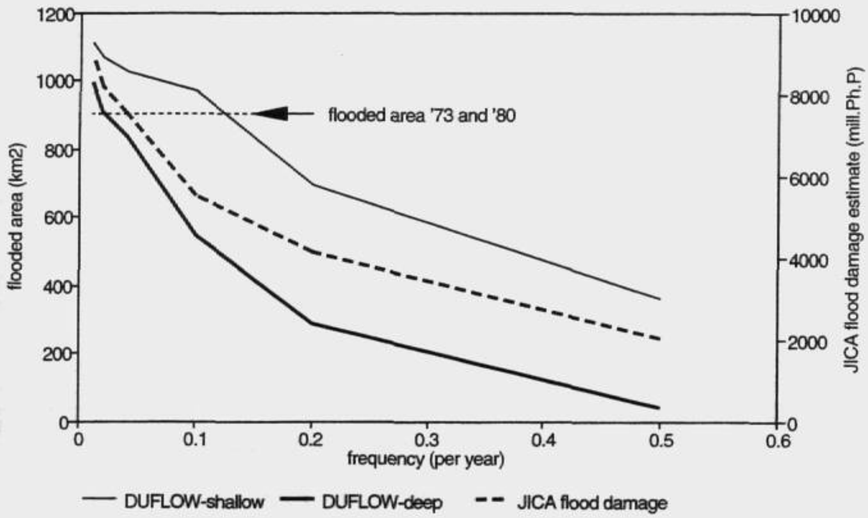

Figure 30 Comparison the modelled flooded area frequency distribution with the JICA estimate of the flood damage frequency distribution.

Table FC-5.5 gives the return period for flood **damage** along different reaches of the Cagayan river, with no mention of the corresponding flooded area. Figure 30 compares the flood damage frequency distribution with the model predictions of the flooded area frequency distributions with both the deep and shallow schematizations; these forms correspond well.

5.1.5 Influence of rainstorm trajectory on the extent of floods

As extreme rainstorm events like typhoons tend to travel across a watershed, different areas of the watershed experience their maximum rainfall at different points in time. Rainstorms of equal magnitude, but differing in trajectory across the watershed can cause marked differences in flooded area, especially in larger watersheds [Bruynzeel 1990].
The effect of storm trajectory has been simulated by shifting the outflow from the tributaries in time. A storm trajectory from south to north has been simulated by advancing the outflow from the Upper Cagayan and Magat river with 1 day, and retarding the outflow from the Chico with 1 day. A storm trajectory from north to south has been simulated by retarding the outflow from the Upper Cagayan and Magat river with 1 day, and advancing the outflow from the Chico river with 1 day. Simulations were made with the shallow schematization and a rainfall with a return period of 2 years. Results (figure 31) show that rainstorms that move downstream (in the case of the Cagayan Valley from South to North) lead to a larger flooded area than rainstorms of equal magnitude that move upstream, or occur simultaneously over the entire area.

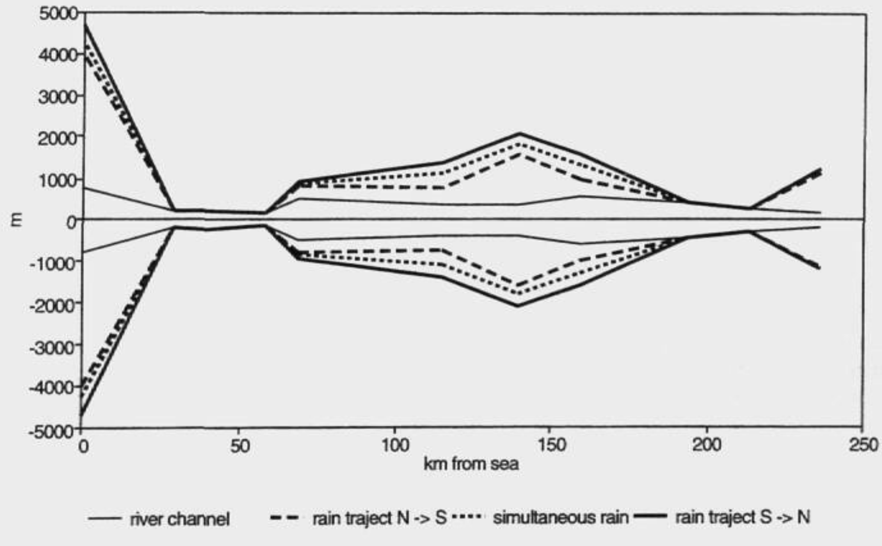

Figure 31 Dependence of the extent of the flooded area on the rainstorm trajectory. Rainfall event once per 2 years; shallow schematization.

5.2 Deforestation-induced increase in stormflow

As the analysis of local hydrological timeseries in Chapter 5. did not lead to firm evidence on any hydrological changes correlating with the deforestation process, the choice of an upstream increase in stormflow has been made on the basis of literature references of paired-basin experiments.

5.2.1 Peakflow or stormflow? Identifying the relevant variable.

In the literature frequent references are found to considerable increases in peakflow (the maximum value of the storm discharge) in small-scale (0.1 - 10 km^2) paired-basin deforestation experiments. References to changes in peakflow in watersheds larger than 10 km^2 are virtually absent.

Peakflows are strongly attenuated while progressing downstream, due to storage in the river channel and floodplains. Therefore data on increases in peakflow from paired-basin experiments cannot be applied directly to the scale of subbasins in the model (approx. 500 km^2).

[Hewlett & Helvey 1970] state that the relevant variable when considering changes in downstream flooded area is the stormflow (total of discharge during storm episode), rather than the peakflow.

In order to test this statement, the model has been used to simulate changes in downstream flooded area with the following transformations of subbasin discharge (see figure 32):

- P1: peakflow increased with 50%; time-to-peak decreased with 50%; stormflow volume unchanged
- S1: stormflow volume increased with 20%, equally distributed over rising and falling limb
- S2: stormflow volume increased with 20%, increase distributed over falling limb
- S3: stormflow volume increased with 20%, increase distributed over second half of the falling limb

The effect of these transformations on the extent of the flooded area are shown in figure 33. Simulations were performed with the shallow schematization and a rainfall return period of 2 years, as well as with the deep schematization and rainfall return periods of 2 and 5 years.

The changes in peakflow and time-to-peak (P1) on the scale of the subbasins have no influence on the extent of the flooded area on the scale of the Cagayan watershed - as long as the stormflow volume remains unaffected. The extent of the flooded area is strongly affected by changes in stormflow volume (S1), but is insensitive to the distribution in time of the stormflow volume (S2 and S3).

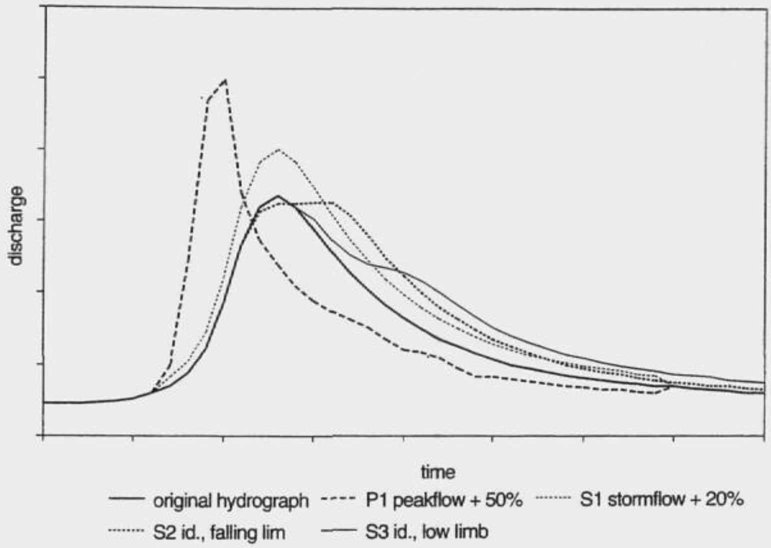

Figure 32 Transformations of the subbasin storm hydrographs.

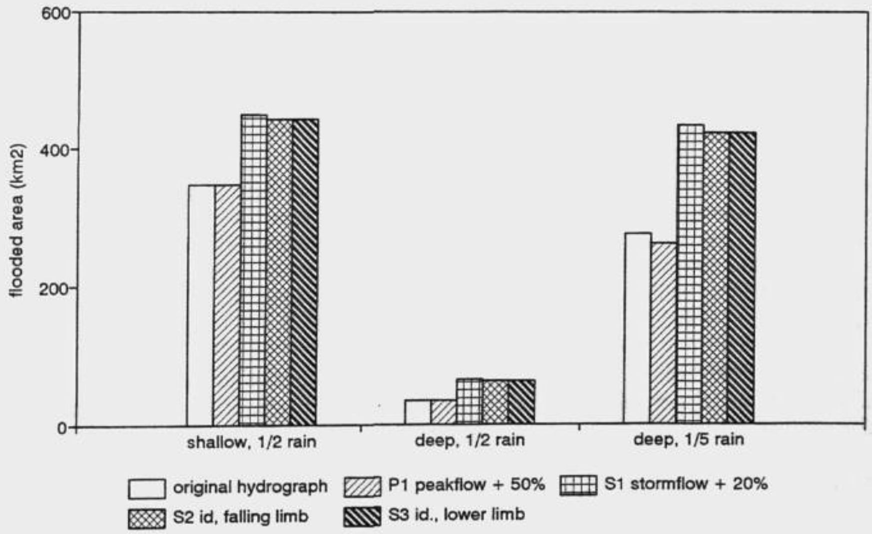

Figure 33 Modelled extent of the flooded area in the downstream Cagayan river, as a function of transformations of the subbasin storm hydrographs. For a description of the transformations, see text and figure 32.

From the results it is apparent that only paired-basin experiments which report the effect of land-use change on stormflow are relevant. In addition, the insensitivity of the downstream flooded area to the distribution in time of the upstream stormflow volume indicates that the question of scale is less important when considering stormflow; experimental results from small paired-basins can be applied to the scale of the subbasins used in the model.

The fact that the Cagayan river is not confined by dikes is highly relevant in this respect. If the downstream river were confined by dikes, subbasin peakflows would be more apparent downstream, and the associated peak levels would be the determining factor as any overtopping of the dikes would trigger floods by dike erosion.

5.2.2 Deforestation and stormflow in literature

A literature search has been made for experiments and field studies that quantify the effect of changes in landuse on stormflow (also referred to as "quickflow"). Search criteria were:

1. the change in landuse is a well-described transformation between the extremes of primary forest and intensively grazed and burned grassland
2. rainfall events are in the order of 100 - 500 mm
3. changes in stormflow are reported, with specification of the magnitude of the corresponding rainfall events

The number of relevant references found (table 3) is limited. Due to the second criterium all references of paired-basin experiments in low rainfall areas had to be excluded. The third criterium proved to be very restrictive. References to paired-basin experiments always report changes in total yearly discharges (water yield) and regularly report changes in peakflow and time-to-peak, but seldom report changes in stormflow. This is unfortunate, as the setup of most of the experiments seems to be sufficient to calculate changes in stormflow. If changes in stormflow are reported, generally no distinction is made in the magnitude of the rainfall event (i.e. large and small rainfall events are lumped).

The 25% increase reported by [Hewlett & Helvey 1970] occurred during a rainfall event of 275 mm, which corresponds with a reported return period of 100 years. This matches well with the situation in the Cagayan Valley, where rainfall events with a return period of 100 years are in the order of 200 - 500 mm. The calibration period in the experiment - already 18 years! - could still be too short to calibrate the basins for such extreme events. The change in landuse is atypical in that trees and foliage were not removed or burned.

[Pearce et al. 1980] report increases in stormflow with a distinction in the magnitude of the rainfall events (small, medium, large), but do not report the actual size of the rainfall events. The value given in table 3 has been deduced from the text.

The reference in [Bonnell et al 1991] is indirect; the original report was not readily available.

Table 3 References to changes in stormflow after deforestation at high rainfall events

	Hewlett & Helvey 1970	Bonell et al 1991	Pearce et al 1980	Qian Wangcheng 1983
Location	Coweeta, Appalachians, United States	Babinda, Queensland, Australia	South Island, New Zealand	Hainan, China
Area	40 ha	?	5 ha	70 - 500 km^2
Before/ control	primary forest	primary forest	primary forest	approx. 50% forest
After/ experimental	complete deforestation with minimum soil disturbance; stems, branches and foliage not removed	70% ungrazed grassland becoming regrowth	complete deforestation and burning	approx. 20% forest
Rainfall event	275 mm	185 mm (2602 mm in 14 days)	Not indicated; estimated at 80-100 mm	approx. 170 mm
Effect on stormflow	+25%	+11%	+ 20%	not significant

It is well to point out that the relevant search criterium is quite extreme. In order to draw a statistically relevant conclusion on a deforestation-induced change in stormflow, caused by a rainfall event with a return period of X years, it is necessary to continue measurements for approximately N*2*X years, with N the number of replications necessary for obtaining statistical significance, and the factor 2 taking account of the calibration and experimental period. If N is set at a value of 3, and the interest is in rainfall episodes with a return period of 10 years, the experiment should last 60 years! In addition, rainfall and discharge measurements must be of high quality throughout this period. Only the best paired-basin experiments, continued over many decades, can yield the desired results. Taking the rate and irreversibility of deforestation in the humid tropics into account, one may wonder whether conclusive scientific evidence on changes in stormflow, and the associated floods, will be obtained in time to influence decisionmaking on this controversial issue.

5.2.3 Choice of increase in stormflow

The 25% increase in stormflow reported in [Hewlett & Helvey 1970] has been chosen as the basis for the simulations of deforestation-induced floods in the Cagayan Valley. It has been assumed that primary and secondary forest do not differ in hydrological properties. Furthermore, it has been assumed that the proportional increase in stormflow after deforestation is independent of the rainfall return period. This assumption is probably incorrect as the scientific evidence suggests that the proportional increase of small stormflow events is larger than the proportional increase of large stormflow events. However, no quantitative information was found that could be used to differentiate the stormflow increase by events.

Complete deforestation of a completely forested watershed (either primary or secondary forest) then leads to a 25% increase in stormflow at any rainfall return period.

Based on table 1, at present 30% of the Cagayan watershed is forested. No attempt has been made to distinguish in forest cover (and consequently stormflow increase after deforestation) per subbasin. Thus complete deforestation of the Cagayan Valley leads to an increase in stormflow from all subbasins of 7.5% (i.e. 30% of 25%).

5.3 Deforestation-induced increase in riverbed siltation

No data on the riverbed siltation rates in the Cagayan river system are available. Accurate measurements of the river channels of the Cagayan river system have been performed by JICA in the years 1983- 1985. It is unknown whether accurate measurements have been made in a previous period; in any case the JICA measurements can serve as a benchmark. The analysis in chapter 5 does not indicate changes in riverbed level of the Tuguegarao river and the Cagayan river at Palattao; however, the margin of error in this analysis is large.

The riverbed siltation rate is estimated on the basis of a sediment budget of the Cagayan river system (see figure 34). Soil material, consisting of silt (< 63 mu) and sand (> 63 mu) enters the river system. It is assumed that all silt is transported to sea. Part of the sand input, determined by the sediment transport capacity (STC) of the river is transported to sea; the remainder is deposited in the channel or on the floodplains of the downstream tributaries or the main river. Floodplain siltation will only occur during flooding events. For the model simulations only the siltation rate in the main river (downstream of the Magat confluence) is relevant.

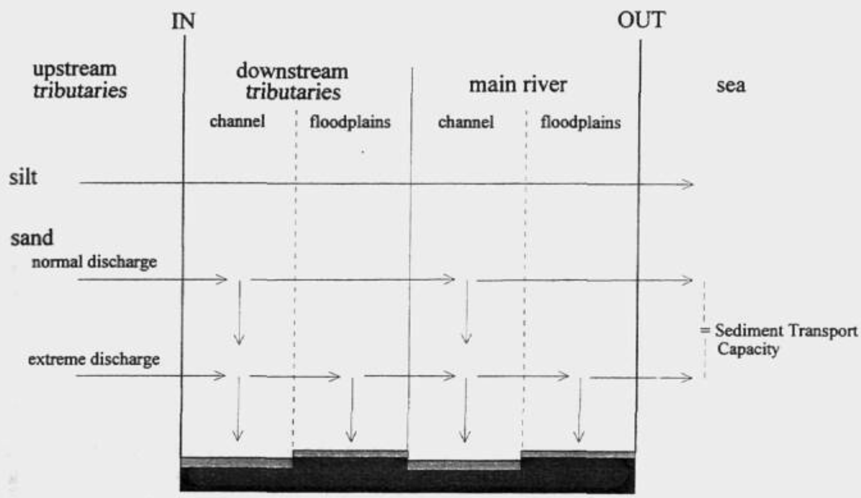

Figure 34 Conceptual sediment budget of the Cagayan river system.

5.3.1 Sediment input

Sediment yield

Sediment yield measurements in the Cagayan Valley (figure 35) range from 16 to 38 ton/ha,year. The area of the monitored watersheds ranges from 1780 to 4100 km^2. At the Magat-dam site, an increase is apparent from 23 to 38 ton/ha,year over the period 1972-1984. No data are available of the sediment yield from the Sierra Madre watersheds or the lowlands.

The sediment yield of 33 ton/ha,y at Baretbet, situated in the largely deforested Magat watershed has been taken as the estimate of upland sediment yield from deforested areas. Estimates of erosion under primary and secondary forest in the Magat watershed, based on the Universal Soil Loss Equation, vary from 1 to 6 ton/ha,year [David & Collado 1987]. A value of 3 ton/ha,year has been used as the upland sediment yield from forested areas. These values are considered to be representative for the area above the 200-meter contour line (= 17400 km^2). It is assumed that all sediment from the Magat Dam watershed accumulates in the Magat reservoir and does not contribute to siltation of the downstream reaches. Sediment yield from the central unforested but planer area of the Valley (= 9600 km^2) has been set arbitrarily at 10 ton/ha,year. As the size of the monitored watersheds is large, a sediment delivery ratio has not been taken into account. A response-time between land use change and change in sediment yield has been disregarded.

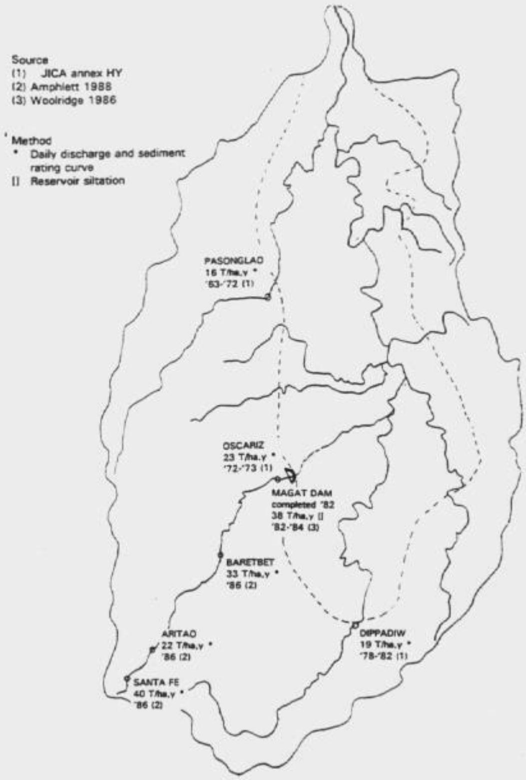

Figure 35 Reported data of sediment yield in the Cagayan Valley. The 200-meter contour line is shown with a dashed line.

Sediment composition

In the sediment yield measurements at Santa Fe, Aritao and Baretbet bedload (sand >63 mu) and washload (silt < 63 mu) have been measured separately (see table 4). In the larger watersheds Aritao and Baretbet, 63% of the sediment yield consists of sand. This figure has been used in the calculations.

Table 4 Sediment yield in 3 sub-basins of the Magat reservoir watershed. From [Amphlett 1988]

Site	area (km^2)	bedload (sand) ton/ha, year	washload (silt+clay) ton/ha, year	washload as % of total load
Santa Fe	19	32.3	3.2	10
Aritao	160	13.6	8.3	38
Baretbet	2041	21.2	12.2	36

Sediment yield and discharge

A considerable part of the sediment yield may occur during brief stormflow events.
Based on data reported in [Amphlett 1988] a rough estimate of the distribution of the sand yield over normal discharge events and stormflow events has been made. From figure 36 a strong correlation between discharge and sand flux at Aritao station is evident. For this station [Amphlett 1988] developed the following rating curves for the sand and silt concentrations:

[sand (g/l)] = 0.00430 * discharge (m^3/s) ^ 1.55
[silt (g/l)] = 0.00067 * discharge (m^3/s) ^ 1.87

From the discharge timeseries in figure 35 an approximate discharge frequency distribution was derived; from the combination of this frequency distribution and the above sand- and silt rating curves an approximate frequency distribution of the sand and silt fluxes was obtained (table 5). The table indicates that approximately 50% of the yearly sand yield may occur during the 1-2 days with maximum discharge.

Table 5 Approximation of the frequency distribution of the sand and silt fluxes at Aritao station in 1986. Based on data in [Amphlett 1988].

Discharge frequency distribution (from figure 35)		Sand flux (ton/ha, year)	Silt flux (ton/ha, year)
Frequency (days/year)	Discharge (m^3/s)		
1	140	6.8	5.2
10	40	2.8	1.4
172	15	3.9	1.5
172	3	1.0	0.2
Total (= 365 days)		14.5	8.3

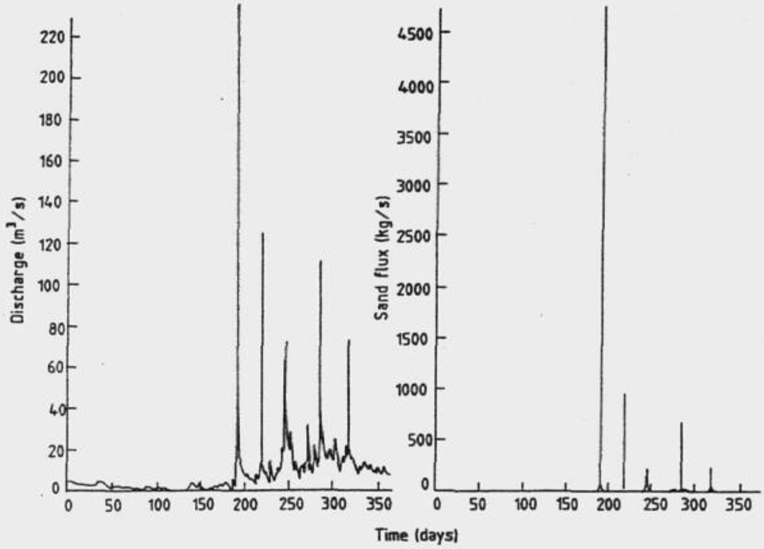

Figure 36 Timeseries of discharge and sand flux at Aritao station in 1986. From [Amphlett 1988].

5.3.2 *Sediment output*

It is generally assumed ([Morisawa 1985], [Graf 1984]) that the entire washload (i.e. silt fraction) of a river is transported to sea. The average riverbed grain size of 400 mu (page HY-40), indicates that this assumption applies to the Cagayan river.
In the JICA report (pages HY-36 to 40) the sediment transport capacity (STC) of the different reaches of the river system is calculated with the formula of Einstein-Brown. This is a modification of the Einstein bedload formula (see f.e. [Graf 1984]), and applies to the transport of sand. The results of the JICA calculations are given in figure HY-5.2. The sediment (i.e. sand) transport capacity in the downstream reach near sea (km 1.0) is approximately 5 million m^3 per year. On a long time-scale an increase in sand input will lead to an increase in river gradient, and therefore an increase in STC. As this process is slow, it has been assumed that the STC remains constant after deforestation.

5.3.3 Location of siltation

The sand yield that is not transported to sea, is deposited somewhere in the river system. Siltation may occur in the river channel of the downstream major tributaries (TC), the floodplains along these downstream tributaries (TF), the river channel of the Cagayan river (CC), and the floodplains along the Cagayan river (CF). The Cagayan river upstream from the confluence with the Magat river is regarded as a major tributary.
No data are available data to determine the distribution of siltation over the above units of the river system. JICA p M-22 states that siltation is likely to be restricted to the tributaries, as no

extreme increases in the Cagayan riverbed level have been reported. However, the report does not substantiate this statement.

Conceptually, it is plausible that during "normal" discharge events (i.e. excluding the maximum discharges that occur 1-2 days per year), a large proportion of the sand deposition occurs in the downstream tributary channels. During extreme discharges the proportion reaching the main river increases; during these events deposition on both tributary floodplains and main river floodplains occurs. This conceptual approach is expressed in the following formulas:

Sn = a*(SY*b - STC)
Se = (1-a)*(SY*b - STC)

normal discharge:

c * Sn	->TCn
(1-c) * Sn	->CCn

extreme discharge

d*e*Se	->TCm
d*(1-e)*Se	->TF
(1-d)*e*Se	->CCm
(1-d)*(1-e)*Sm	->CF

Siltation rate in the downstream tributaries = (TCn + TCm)/ At
Siltation rate in the Cagayan river = (CCn + CCm)/ Ac

SY: Sediment yield (sand + silt) (m^3/y)
STC: Sediment (=sand) transport capacity (m^3/y)
Sn: Amount of sand that is deposited in the river system during normal events (m^3/y)
Se: Amount of sand that is deposited in the river system during extreme events (m^3/y)
a: Proportion of sediment yield during normal events
b: Proportion of sand in sediment yield
c: Proportion of siltation in downstream tributaries during normal discharge
d: Proportion of siltation in downstream tributaries during extreme discharge
e: Proportion of siltation in channel during extreme discharge
At: River channel surface area of the downstream tributaries.
Ac: River channel surface area of the downstream Cagayan river

Based on table 4, "a" has been set at 50%. Based on table 5, "b" has been set at 63%. The values for c,d and e have been varied in 2 scenarios:

A. *High siltation in the downstream tributaries and high floodplain siltation*, leading to a low siltation in the downstream river channel: c = 100%, d = 50%, e = 70%.
B. Lower siltation in the downstream tributaries and no floodplain siltation, leading to a high siltation in the downstream river channel: c = 80%, d = 30%, e = 100%.

Values for At and Ac have been calculated from table FC-2.1. The downstream Cagayan river has been defined as the stretch downstream of the Magat confluence (see figure 23). The upward boundary of the downstream tributaries has been set at the 200-m contour line (see figure 35).

Table 6. Estimation of the riverbed siltation rate in the Cagayan river system

BASIC DATA

Cagayan area (km^2)	27000
Upland area above 200-m contour (km^2)	17400
Watershed of Magat reservoir (km^2)	4100
Total forest cover (km^2)	8100
Lowland area below 200-m contour (km^2)	9600
Sediment yield	
upland forest (ton/ha,y)	3
upland no-forest (ton/ha,y)	33
lowland, no forest (ton/ha,y)	10
Density (ton/m^3)	1.8
Silt fraction	0.37
River channel surface area	
downstream Cagayan (km^2)	180
downstream tributaries (km^2)	160
Sediment transport capacity (million m^3/year)	5

SEDIMENT BUDGET (million m^3/year)

Present	IN	OUT	SILTATION
Total	16.2	11.0	5.2
Sand	10.2	5.0	5.2
Silt	6.0	6.0	0

After complete deforestation	IN	OUT	SILTATION
Total	29.7	16.0	13.7
Sand	18.7	5.0	13.7
Silt	11.0	11.0	0

SCENARIOS

	A	B
Sediment yield distribution over discharge events		
- normal events/ (normal+ extreme events)	50%	50%
Partitioning of sediment within river system		
• Normal events, no siltation on floodplains		
- tributary/ (tributary+ main)	100%	80%
• Extreme events		
- tributary/ (tributary + main)	50%	30%
- channel/ (channel + floodplain)	70%	100%

RIVERBED SILTATION RATE (cm/year)

Scenario A.	Present situation	After deforestation	Increase
Downstream Cagayan	0.5	1.3	0.8
Downstream tributaries	2.2	5.8	3.6

Scenario B.	Present situation	After deforestation	Increase
Downstream Cagayan	1.4	3.6	2.2
Downstream tributaries	1.9	4.9	3.0

5.3.4 Estimate of increase in siltation rate

Table 6 summarises the basic data, gives sediment budgets in the present situation and after complete deforestation, as well as the estimates of the siltation rate in the downstream tributaries and the main river in the present situation and after complete deforestation. The present siltation rate in the main river is estimated at 0.5 - 1.4 cm/year, increasing to 1.3 - 3.6 cm/year after complete deforestation of the Cagayan Valley. The extremes of these estimates have been used in the model simulations.

The estimates clearly have the status of guesstimates and need confirmation by field measurements. Siltation may be concentrated in certain locations, for example the confluence of tributaries and the main river, or the relatively flat gradients in the main river. These mechanisms have not been taken into consideration.

5.4 Model predictions of deforestation-induced floods

The following scenario's have been run:

Scenario	Stormflow increase (%, from all subbasins)	Riverbed siltation (m)
0	0	0
1	7.5	0
2 (*)	15.0	0
3	0	1.5
4	0	3.0
5	7.5	3.0

(*) Scenario 2. has been used for a sensitivity analysis of stormflow increase.

These scenario's have been run with both the deep and the shallow schematization, for rainfall return periods of 2, 5, 10, 25, 50 and 100 years.
From the maximum water levels predicted by the model the flooded areas per model section were calculated and summated. From the flooded areas and the corresponding return period a yearly flooded area was calculated. For the purpose of the flood damage estimates described in section 5.5, 3 zones on the floodplains were distinguished. The results are given in tables 7a and 7b. Based on the siltation rate estimates in table 6, the period of time has been estimated between the present situation, and the situation in scenario's 3,4 and 5. Trends in the yearly flooded area after complete deforestation are shown in figures 37 to 40 for the shallow and the deep schematizations and the extremes of the estimates of the increases in siltation rate.

Even if no further deforestation takes place, there is a gradual increase in yearly flooded area due to siltation. The deforestation-induced increase in subbasin stormflow leads to an increase in flooded area which is constant in time. The deforestation-induced increase in siltation rate leads to an increase in flooded area which increases in time. Depending on the siltation rate estimates, the effect of additional stormflow is surpassed by the effect of additional siltation after approximately 15 - 40 years. In the medium term, the mechanisms of stormflow increase and riverbed siltation contribute approximately equally to the increase in yearly flooded area; in the long term, riverbed siltation is the more important mechanism.

Table 7 Model simulations of flooded area along the Cagayan river downstream of the Magat confluence under different scenario's of deforestation-induced increases in subbasin stormflow and riverbed siltation rate. Three flood zones are distinguished for the purpose of flood damage estimation (see paragraph 5.5.2).

A: model simulations with the shallow schematization

YEARLY FLOODED AREA (km2)

	Scenario 0	1	2	3	4	5
total area	428	457	483	554	676	700
zone1	250	261	275	296	337	337
zone2	159	174	182	225	285	303
zone3	19	22	25	33	54	59

FLOODED AREA (km2) AS A FUNCTION OF THE RAINFALL RETURN PERIOD

		Return period (years) 1	2	5	10	25	50	100
Scenario 0	total area	0	359	691	967	1028	1068	1110
	zone1	0	277	361	456	456	456	456
	zone2	0	82	301	453	456	456	456
	zone3	0	0	29	58	116	155	197
Scenario 1	total area	0	403	743	980	1042	1085	1125
	zone1	0	297	382	456	456	456	456
	zone2	0	106	328	455	456	456	456
	zone3	0	0	32	69	129	172	212
Scenario 2	total area	0	433	802	991	1056	1068	1143
	zone1	0	315	415	456	456	456	456
	zone2	0	115	350	455	456	456	456
	zone3	0	4	36	79	143	155	230
Scenario 3	total area	0	530	955	1004	1063	1104	1143
	zone1	0	346	456	456	456	456	456
	zone2	0	172	450	454	456	456	456
	zone3	0	12	48	94	150	191	230
Scenario 4	total area	0	803	992	1042	1102	1143	1181
	zone1	0	450	456	456	456	456	456
	zone2	0	321	451	455	456	456	456
	zone3	0	32	85	131	189	230	268
Scenario 5	total area	0	853	1001	1053	1116	1159	1198
	zone1	0	450	456	456	456	456	456
	zone2	0	365	451	456	456	456	456
	zone3	0	37	93	141	203	246	285

Table 7 continued

B: model simulations with the deep schematization

YEARLY FLOODED AREA (km2)

	Scenario 0	1	2	3	4	5
total area	176	196	218	261	378	412
zone1	126	135	145	171	236	256
zone2	44	55	65	82	128	140
zone3	5	6	8	8	14	17

FLOODED AREA (km2) AS A FUNCTION OF THE RAINFALL RETURN PERIOD

		Return period (years) 1	2	5	10	25	50	100
Scenario 0	total area	0	45	287	544	834	910	997
	zone1	0	45	270	337	413	419	456
	zone2	0	0	17	196	373	411	432
	zone3	0	0	0	10	47	79	109
Scenario 1	total area	0	52	342	591	863	929	1040
	zone1	0	52	296	339	416	419	456
	zone2	0	0	46	237	390	418	456
	zone3	0	0	0	15	58	91	127
Scenario 2	total area	0	65	398	641	892	975	1063
	zone1	0	65	313	353	419	451	456
	zone2	0	0	84	268	403	419	456
	zone3	0	0	0	21	70	104	150
Scenario 3	total area	0	112	476	741	904	1003	1062
	zone1	0	109	336	407	419	456	456
	zone2	0	4	139	311	414	446	456
	zone3	0	0	1	23	70	100	149
Scenario 4	total area	0	281	652	852	1007	1057	1097
	zone1	0	251	364	413	456	456	456
	zone2	0	30	277	393	455	456	456
	zone3	0	0	12	46	96	145	184
Scenario 5	total area	0	326	714	882	1027	1074	1115
	zone1	0	281	396	427	456	456	456
	zone2	0	45	302	400	456	456	456
	zone3	0	0	16	55	114	161	202

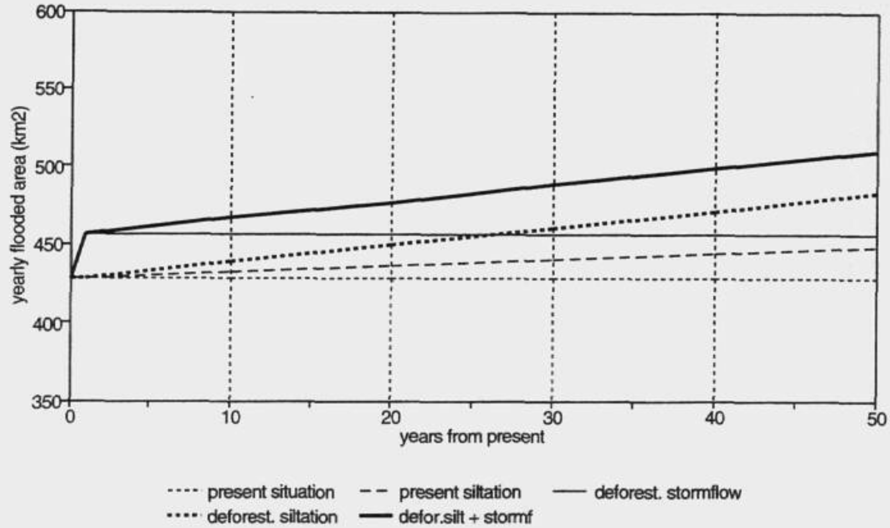

Figure 37 Model prediction of the trend in flooded area along the downstream Cagayan. Shallow schematization, low siltation rate estimate.

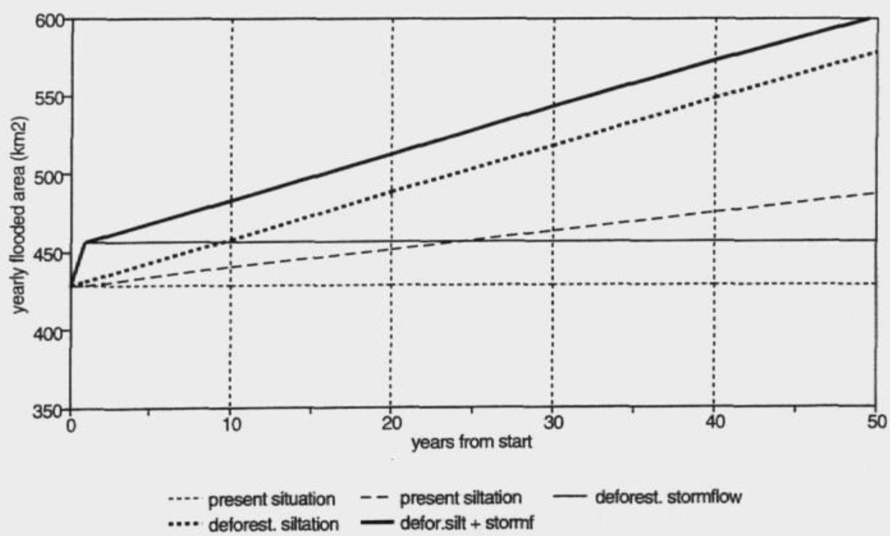

Figure 38 Model prediction of the trend in flooded area along the downstream Cagayan. Shallow schematization, high siltation rate estimate.

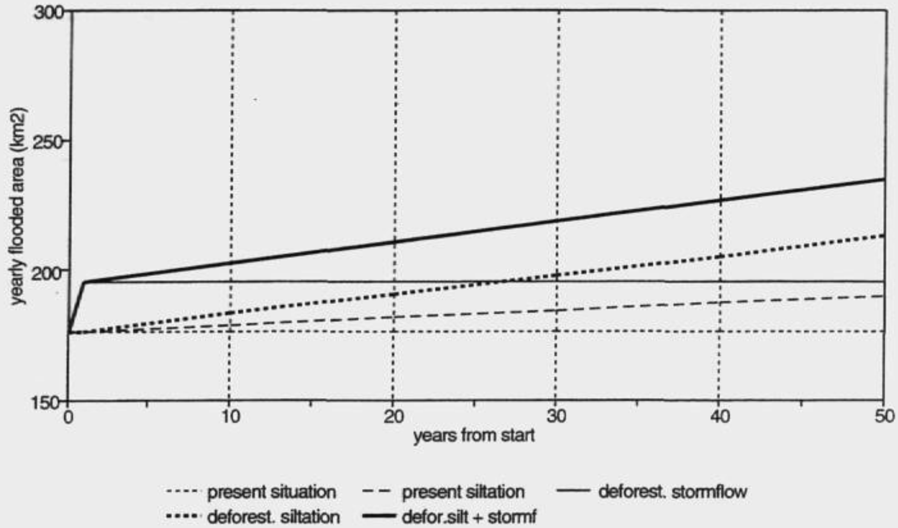

Figure 39 Model prediction of the trend in flooded area along the downstream Cagayan. Deep schematization, low siltation rate estimate.

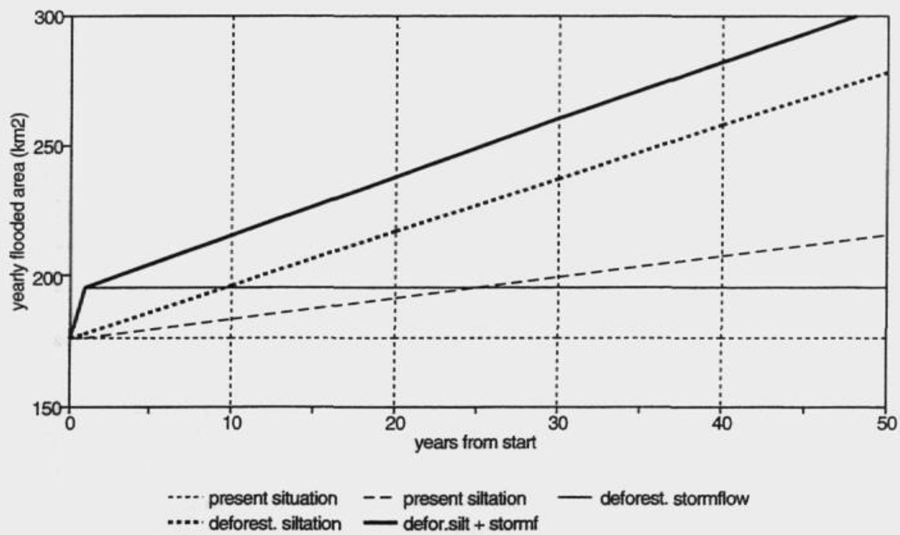

Figure 40 Model prediction of the trend in flooded area along the downstream Cagayan. Deep schematization, high siltation rate estimate.

5.5 Flood damage

It is to be expected that landuse on the floodplains adjusts itself to the risk of flooding. Infrastructure and housing will be located in areas that do not flood frequently. Therefore the damage per unit of flooded area is expected to increase with distance from the river channel. From the information in the JICA report an attempt has been made to estimate unit flood damages (US$/km^2 flooded area) that take this spatial differentiation into account.
With these values for unit flood damage, estimates have been made of the flood damage due to deforestation.

5.5.1 Available information on flood damage

In the JICA report three independent estimates of flood damage can be found:

1. OCD & DSWD
   Table 8 gives an overview of the flood damage in Region 2 during the period 1970-1993. Region 2 coincides, and is slightly larger than the Cagayan watershed. The 1970-1985 data are from the Office of Civil Defence (OCD), and are reported in JICA table FC-2.2. The 1986-1993 data are from the Department of Social Welfare and Development (DSWD). The method used to compile these data is unknown. As it is unlikely that those suffering flood damage are compensated, it is probable that not all damage is reported, and these data underestimate the actual damage. In addition, many casualties occur during floods, losses which are difficult to express in money.

2. JICA
   The JICA report gives estimates of the flood damage as a function of the flood return period in table FC-5.5 (see annex 1). The damage consists of a number of items that are specified in table FC-5.4. The most important items are damage to buildings and infrastructure, which can be assumed to be located in areas that do not flood frequently. It is therefore remarkable that the table indicates considerable damage to these items with the frequent floods (return period 2 and 5 years). The item "intangible damages" includes loss of lives and injury.

3. DAMS
   In Annex DAMS (DA) cost-benefit analyses of the proposed dams are presented. For dams that have a function in flood prevention a constant value of 75,000 US$ damage per km^2 of flooded area is used (p DA-10; US$ indexed to 1985). The annex assumes this value to be constant: the flooding of 1 km^2 adjacent to the river causes the same amount of damage as the flooding of 1 km^2 further away from the river. The value is taken from the report "Nationwide flood control plan and river dredging program" which not available.

The return periods of the flood damage estimates ad 1. and ad 2. are compared in figure 41. The JICA estimates of flood damage are a factor 5 higher than the OCD & DSWD estimates.

Table 8 Flood damage in the Cagayan Valley.
The damage during the 1973 flood has been set to the damage during the 1980 flood.
Monetary values in Philippine Pesos have been indexed to 1985, and converted to US$ of 1985 (1 US$ of 1985 = 19 Ph.Peso of 1985).

Year	Index factor	Storm date	DAMAGE Ph.P (million)	Ph.P of 1985 (million)	US$ of 1985 (million)
1970	10.0	12-Oct-70	0.4	4	0.2
1971	8.3	24-Jul-71	0	0	0.0
1972	7.7	24-Jun-72	0	0	0.0
1973	6.3	24-Nov-73	0	1475	77.6
1974	4.8	29-Oct-74	44.3	211	11.1
1975	4.5		2.7	12	0.6
1976	4.0		4.5	18	0.9
1977	3.7		7.6	28	1.5
1978	3.4	26-Oct-78	26.7	92	4.8
1979	2.9	01-Aug-79	4.5	13	0.7
1980	2.5	03-Nov-80	590.0	1475	77.6
1981	2.2	17-Sep-81	74.1	165	8.7
1982	2.04	13-Oct-82	62.0	127	6.7
1983	1.85	05-Sep-83	8.6	16	0.8
1984	1.23	28-Aug-84	62.5	77	4.1
1985	1.00	22-Jun-85	29.1	29	1.5
1986	0.91		222.0	202	10.7
1987	0.84		555.0	469	24.7
1988	0.81		1029.0	838	44.1
1989	0.77		1135.0	877	46.2
1990	0.67		537.0	360	18.9
1991	0.59		825.0	488	25.7
1992	0.50		791.0	396	20.9
1993	0.46		4250.0	1938	102.0

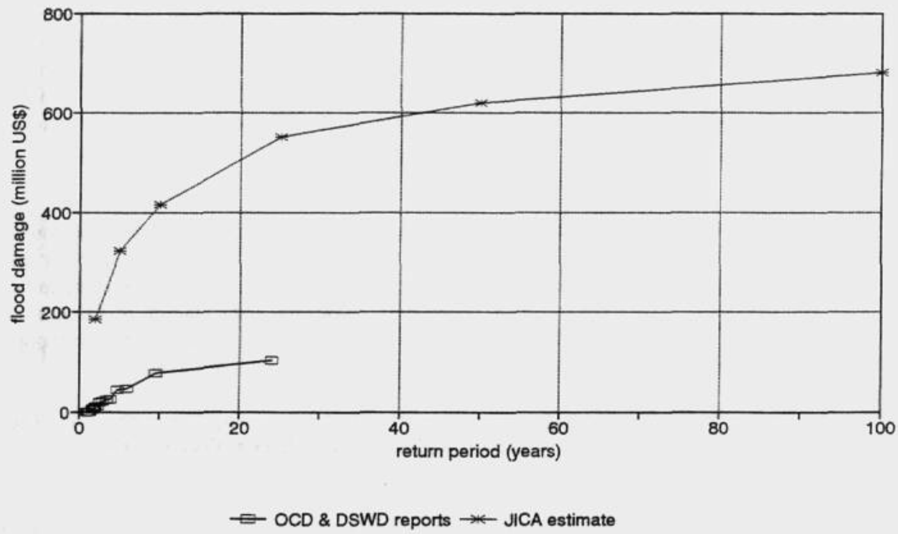

Figure 41 Return periods of the flood damage in the entire Cagayan Valley as estimated by JICA and calculated from the flood damage reports compiled by OCD & DSWD.

5.5.2 Estimates of unit flood damage

Values for unit flood damage have been estimated by fitting the return period of flood damage from OCD and JICA on the return period of flooded area simulated in the 0-scenario.

The OCD and JICA flood damage estimates, which cover the whole Cagayan valley, were adjusted to take into account that the model simulations only cover the Cagayan river downstream of the Magat confluence. The JICA estimate for the reach downstream of the Magat confluence is specified in table FC-5.5. The OCD estimate is adjusted with a factor of 0.67, which is the ratio of the damage along the reach downstream of the Magat confluence and the damage in the whole Valley in table FC-5.5.

In order to add some spatial differentiation, the floodplain was divided into 3 zones parallel to the river:

- zone 1 is closest to the river, is flooded more frequently than zone 2, but experiences less damage per unit of flooded area. The width of this zone has been set arbitrarily at half the flooded width in the 1973 and 1980 floods.
- zone 2 is adjacent to zone 1; the upward boundary is formed by the flooded width in the 1973 and 1980 floods
- zone 3 is adjacent to zone 2

The choice for 3 zones, and the boundaries between the zones are arbitrary.

The flooded area frequency distribution per zone is given in tables 7a and 7b under scenario 0. Under the assumption that the unit flood damage (US$/km^2) does not vary per zone, the flooded area frequency distribution has been fitted to the flood damage frequency distribution with the following formula:

Flood damage = a* (flooded area zone 1) + b* (flooded area zone 2) +
c* (flooded area zone 3)

a,b,c: unit flood damage in zones 1, 2 and 3 (US$/km^2)

The flooded area distribution estimates of both the deep and the shallow schematization were fitted to both the OCD and JICA flood damage distribution estimates. Values for a, b and c were varied until optimal fits between the flood damage and flooded area frequency distributions were obtained. The distinction between zones 2 and 3 proved to be too detailed; therefore zones 2 and 3 were lumped.

Figures 42 and 43 show the optimal fits for the shallow and deep schematizations respectively. The optimized values for unit flood damage in the two zones are given in table 9.
The fit of the flooded area distribution with the deep schematization on the JICA flood damage distribution is unsatisfactory: in zone 1 the unit flood damage is much higher than in zone 2. Therefore no further calculations have been made with this combination. The other values for unit flood damage could be realistic.

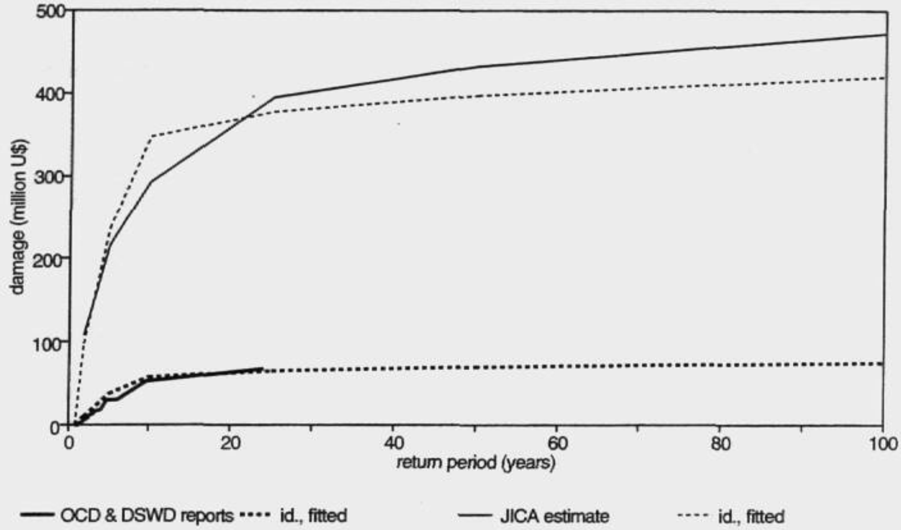

Figure 42 Optimal fits of the flood damage and flooded area frequency distributions along the downstream Cagayan. Flooded area frequency distribution as modelled with the shallow schematization.

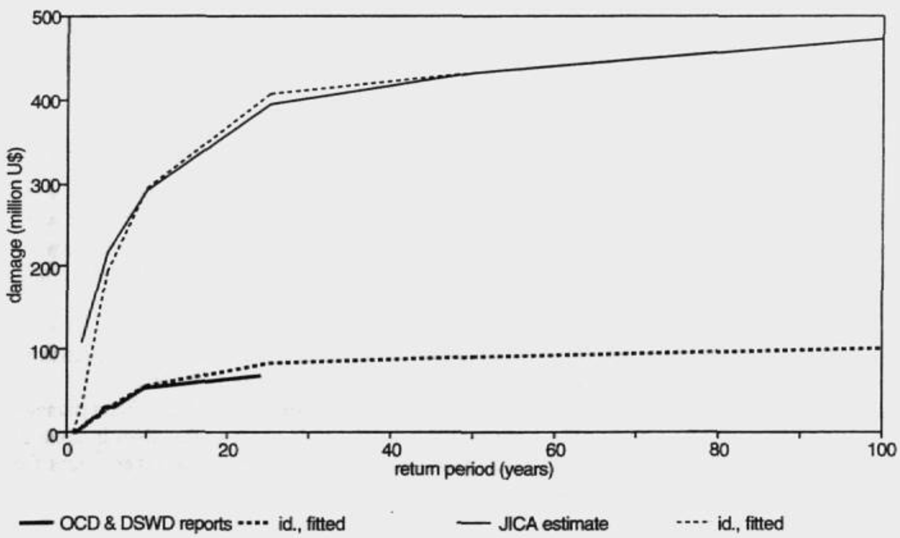

Figure 43 Optimal fits of the flood damage and flooded area frequency distributions along the downstream Cagayan. Flooded area frequency distribution as modelled with the deep schematization.

Table 9 Estimates of unit flood damage. All values in US$ indexed to 1985

	Flooded area simulated with *shallow schematization* (US$/km^2)		Flooded area simulated with *deep schematization* (US$/km^2)	
	Zone 1	Zone 2	Zone 1	Zone2
1.OCD	5,000	110,000	100,000	100,000
2.JICA	200,000	500,000	700,000	280,000
3.DAMS	75,000	75,000	75,000	75,000

5.5.3 Estimates of flood damage due to deforestation

The flood damage due to complete deforestation of the Cagayan Valley has been calculated by combining the results in tables 7a, 7b and 9. As the model results in table 7 only apply to the Cagayan river reach downstream of the Magat confluence, estimates for the entire Cagayan Valley were obtained by increasing the flood damage values with 49% (= 100/67). A distinction has been made between the contribution of the increase in stormflow, the increase in siltation rate, and the combination of both.

The contribution of an increase in stormflow alone can be considered to be constant as long as the increase in stormflow persists and unit damage values do not change, and can therefore be expressed as a constant cost. The contribution of siltation increases with time, and cannot be expressed as a constant cost. In cost-benefit analyses this problem is circumvented by discounting. This has not been attempted on the argument that the resulting value (for example: net present value) lacks direct appeal. Here, two costs have been calculated: the average cost over a period of 25 years from present, and the cost in year 25 from present.

The increases in flood damage after deforestation have been expressed per unit of deforested area (8100 km^2), in order to obtain an impression of the value of forest in terms of decreased flood damage. Results are given in table 10.

The estimates of deforestation-induced damage based on the OCD and DAMS damage functions compare well under both schematizations, and are in the order of 5 - 10 US$ per ha of deforested area per year. The high values of the JICA damage function are reflected in estimates which are a factor 5 higher than the estimates based on the OCD and DAMS damage functions. As indicated in chapter 5.5.1, the JICA estimate of infrastructure damage caused by frequent floods (return period 2 to 5 years) is very high; therefore the estimates based on OCD and DAMS are considered to be more realistic for the "present" situation (i.e. the period 1970-1985).

The moment of writing of this report is a decade removed from the dataset on which the above estimates are based. Constant factors as an increasing population and the pressure for land, combined with more variable factors as the recent economic growth in the Philippines and the world market for food grains all point in the direction of an increasing trend in the unit flood damage in the Cagayan Valley.

Table 10 Flood damage estimates in the present situation, and after complete deforestation of the Cagayan Valley. All values in US$ indexed to 1985.

Schematisation	Damage function	Damage (million US$ per year)						Damage per unit of deforested area (US$/ha, year)	
		Present situation			Increase after complete deforestation				
		No siltation	With siltation		Stormflow increase	Siltation increase		Stormflow + siltation increase	
			low siltation (*)	high siltation (*)		low siltation (*)	high siltation (*)	low siltation (*)	high siltation (*)
Shallow	1.OCD& DSWD	31	32 - 33	33 - 34	3.0	1.0 - 2.0	2.6 - 4.9	4.9 - 6.2	6.7 - 9.8
	2.JICA	207	210 - 213	216 - 224	16.7	5.7 - 11.0	14 - 27	27 - 33	36 - 52
	3.DAMS	48	48 - 49	50 - 51	3.2	1.1 - 2.1	2.7 - 5.2	5.2 - 6.4	6.8 - 10
Deep	1.OCD& DSWD	27	28 - 29	29 - 31	3.1	1.0 - 2.0	2.5 - 4.9	5.1 - 6.4	6.9 - 10
	3.DAMS	21	21 - 22	22 - 23	2.3	1.0 - 1.5	1.9 - 3.7	3.8 - 4.8	5.2 - 6.4

(*): average over 25 year period from present (low value), and value in 25 years from present (high value)

5.6 Uncertainties

In order to arrive at the model simulations and damage calculations presented above, a large number of assumptions have been made. The results are therefore subject to many uncertainties. Table 11 lists the main uncertainties together with a subjective estimate of the quality of the approximations, the magnitude of the influence on the results, as well as the possibility of decreasing the uncertainties.

Because the effect of deforestation on flooded area is deduced from the difference between model simulations, the asumptions that are equal in both simulations are less critical.
The most critical uncertainties are then: the influence of deforestation on subbasin stormflow, the influence of deforestation on the riverbed siltation rate, and the unit flood damage estimates.

The uncertainty in the unit flood damage estimates is a factor 5, which translates directly in the estimate of the flood damage due to deforestation.

Simulations show that the increases in flooded area double with a doubling of the increase in subbasin stormflow or siltation rate. The chosen value for the proportional stormflow increase (+ 25%) is the highest value found in literature. It is highly improbable that the actual stormflow increase is a factor 5 higher than the value used in the model simulations, therefore the uncertainty in the stormflow increase is considered to be less critical than the uncertainty in the unit flood damage estimates.

Siltation may be concentrated in certain locations, for example the confluences of the tributaries and the main river, or the relatively flat gradients downstream of in the main river. If the zones with heavy siltation coincide with the zones of relatively high economic activity and infrastructure density, deforestation-induced flood damage may be considerably higher than the estimates presented above. In addition, the effect of siltation on floods increases over the years. For these reasons, the uncertainty in the riverbed siltation rate is considered to be more critical than the uncertainty in stormflow increase.

Table 11 Uncertainties in the estimates of the increases in flooded area and flood damage due to deforestation

	quality	easily improved	method	critical for effect of deforestation
rainfall return periods	good	no long-term measurements are required		
spatial distribution of rainfall in Cagayan Valley	poor	average	calculation of covariances between rainfall timeseries	
module for sub-basins	fair	no good data for calibration are not available		
influence of deforestation on stormflow	poor	no measurements in the Cagayan Valley are not feasible	literature search can reveal additional information;	X
schematisation of river channel	fair	yes	refine schematisation (more sections) with data in JICA report; contact JICA for additional data/ interpretation; collect field data on frequency distribution of flooded area	
schematisation of floodplains	poor	yes	schematise with 1:25000 maps; collect field data on frequency distribution of flooded area	
siltation estimates	fair, but not validated by measurements	yes	inventarise riverbed siltation rates; renewed measurement of river channels	XX
unit damage estimates; zonation of damage	poor	yes	contact DSWD and JICA for basis of flood damage estimates	XXX

6. Comparison of deforestation-induced flood damage with other costs and benefits of upland landuse

In order to assess the relevance of deforestation-induced floods in the Cagayan Valley, the associated flood damage estimate is compared with the net benefits and environmental costs of upland landuse in the Cagayan Valley. The procedure of discounting has been avoided on the argument that the resulting values (for example: net present value) lack direct appeal. Costs and benefits have been expressed as constant yearly values as much as possible. Thus the benefit of commercial logging has been calculated as the yearly interest on the one-time revenue of the logging operation.

The resulting matrix (table 12) contains a number of important as yet unquantified cells.
In the uplands the main blank cells are:

- the benefit of sustainable upland agriculture (more specific: agriculture with maximum soil cover and sufficiently long fallow periods)
- the on-site cost of erosion in terms of decreased productivity, induced by unsustainable agriculture (kaingin plots with short fallow periods, cattle grazing on frequently burned grasslands)

The quantification of the benefits of the present forms of upland agriculture (which are here considered to be unsustainable) needs improvement. The potential benefit of eco-tourism could be important in selected areas.
In the lowlands the main blank cell is:

- the effects of deforestation on the dry season water availability for economic purposes such as agriculture

Other lowland costs that have not been quantified, are:

- riverbank erosion
- loss in productivity of floodplain agriculture due to siltation (deposition of sand)
- siltation of irrigation schemes

The matrix shows the large economic benefits of commercial logging of primary forest. Evidently, primary forest represents a considerable amount of capital. Utilization of (part of) this capital for the economic development of the region or the country, is an attractive option.

Despite the large margins of uncertainty, the lowland costs of deforestation that have been quantified are lower than the benefits of the various forms of upland land use. Therefore it seems to be a rational approach to optimize upland land use in terms of upland benefits and costs as the first priority, and to include the downstream effects only as a second step.

It should be kept in mind that the boundary between "upland" and "lowland" has not been made explicit in the matrix. Progressing up into the mountains, the benefits of land use per unit of area will decrease, and the costs will increase due to increased erosion. Therefore, at a certain boundary upland benefits will no longer outweigh lowland costs.

The balance may also shift if the downstream damage increases, due to the destruction or the restraint of economic activity along the river system. In the Cagayan Valley, it is unlikely that these factors will tip the balance in the near future. However, deforestation in watersheds with large urban centres and a similar climate to the Cagayan Valley is an unattractive option, as the damage per unit of flooded urban area is drastically higher. In these watersheds the economic benefits of deforestation may quickly be outweighed by lowland flood costs.

Table 12 Approximation of yearly net benefits and environmental costs of upland land use in Cagayan Valley, Philippines (US$/ha,year). US$ indexed to 1985. [Notes] are given on the next page.

PHILIPPINES, CAGAYAN VALLEY		Forest destruction, followed by unsustainable agriculture		Forest destruction, followed by sustainable agriculture		Sustainable forestry		Forest reserve	
		Net benefits	Environ costs	Net benefits	Environ costs	Net benefits	Environ costs	Net benefits	Environ costs
Natural values, upland indigenous people		0		0		PM		PM	
Ecotourism		0		0		0		?	
Forest production • First cut • sustainable yield (rattan, cutting cycle, forest plantation)	UP LAND	 250 [1] 0		 250 [1] 0		 125 [2] 170 [3]		 0 50 [4]	
Upland agriculture		50- 120 [5]		?		0		0	
Erosion • on site (productivity)			?		0		0		0
• siltation . reservoirs . irrigation schemes . sand deposition on floodplains	LOW LAND		 8 [6] ? ?		 2 [7] ? ?		 0 0 0		 0 0 0
Floods • flood damage • riverbank erosion	LOW LAND		5 - 10 [8] (25 - 50) [8] ?		2 - 5 [9]		1		0
Water shortage in the dry season			?		?		?		0

Notes to table 12.:

1.: From [NRAP 1991], [MPFD 1991]

Standing volume of wood:	240 m^3/ha
Cut:	200 m^3/ha
Loss (branches, crowns):	50 %
Price:	150 US$/ m^3
Profit margin:	35%
Interest rate on inflation-free currency:	5% per year

NB. - The one-time net benefit of wages for forest labourers has not been included.
- It is assumed that all logging equipment is imported; therefore the purchase of equipment does not contribute to the local or national economy.

2.: Assume profit of careful and selective 1st logging is 50% of destructive 1st logging

3.:

Sustainable yield of second-growth forest:	3.5 m^3/ha,y [NRAP 1991]
Loss (branches, crowns):	70%
Price:	100 US$/$m^3$
Equipment costs:	30%

NB. - Wages are included in net benefits, as wages represent income for forest labourers.
- It is assumed that all logging equipment is imported; therefore the purchase of equipment does not contribute to the local or national economy.

4.: Rattan production from [Aquino et.al. 1992].

5.: [Romero 1992]: *1100 PH-P(1990)/ha,year* on kaingin plots in Tumauini watershed, Isabela, PH.
[Reyes 1983]: 600 PH-P(1977)/ha,year on kaingin plots in Pantabangan watershed, Nueva Ecija, PH.
Estimates appear to be approximate. It is unclear whether fallow periods have been included in yearly benefits per surface area.

6.: The Magat dam traps 16*10^6 m^3 sediment per year [World Bank 1989, Annex 2]. Construction cost of dam: 0.2 US$/$m^3$ storage capacity [JICA table FC 4.1 and 4.4]. Sediment is assumed to originate from the deforestation of an area of 4100 km^2 (= catchment area of Magat dam).

7.: Erosion with sustainable agriculture is assumed to be 25% of erosion with unsustainable agriculture.

8.: Estimate in paragraph 5.5.3 of this report.

9.: Erosion and stormflow increase with sustainable agriculture is assumed to be 25% of erosion and stormflow increase with unsustainable agriculture.

7. Recommendations for further research

1. Effect of deforestation on flood damage

a. Establish the reliability of the OCD & DSWD, and JICA damage functions.

In chapter 5.5 the JICA damage function is considered less reliable due to the high prediction of infrastructure damage with frequent floods. However, if the JICA damage function proves to be correct, the lowland flood costs due to deforestation would be considerable with respect to the upland benefits.

b. Quantify changes in riverbank erosion

The JICA report contains detailed data of riverbank erosion in the period 1964-1979. From aerial photo's the recent rate of riverbank erosion can be quantified and investigated for a trend that correllates with the extent of deforestation.

c. Inventarise riverbed siltation rates and indentify locations with concentrated siltation

If no accurate measurements before 1983 are available of the river channel of the Cagayan and tributaries, the JICA measurements should serve as a benchmark. If estimates of riverbed siltation rates in chapter 5.3.4 are approximately accurate, the present riverbed level should be on average 15-30 cm higher than in 1983, an increase that could be detected by renewed measurements of the river channels. In addition, these measurements could identify the river reaches where heavy siltation is taking place. It is worthwhile to inventarise local experience with regards riverbed siltation.

d. Inventarise the order of magnitude of damage due to siltation of irrigation schemes and sand deposition on floodplains

An estimate of the damage due to siltation of irrigation schemes can be made from the sediment budgets in chapter 5.3 and an inventarisation of dredging costs in the irrigation schemes in the Cagayan watershed.
Changes in the composition of floodplain deposits can be established by an analysis of soil cores. The associated damage can be calculated from literature values of average crop yields on both the original soil as the newly-formed soil.

e. Systematic literature search for deforestation-induced changes in stormflow

The amount of references on paired-basin experiments is huge. The literature search reported in chapter 5.2.2 has only encompassed part of these references. A systematic literature search, including the "grey" literature may provide additional evidence.
Due to the high instrumental requirements and the long time-period involved, field experiments in the Cagayan Valley on the effect of deforestation on stormflow are not recommended. If the value of a 25% increase in stormflow after complete deforestation is approximately correct, it is highly improbable that a further analysis of historical hydrological data will reveal changes that are statistically significant.

2. Effect of deforestation on dry season flows

The effect of deforestation on dry season flows is an interesting point of controversy between science and common opinion (see chapter 3). If deforestation increases water shortage, the associated damage may be considerable. A preliminary phase is recommended, in which the extent of water shortage in the Cagayan watershed is ascertained, and evidence of changes in dry-season flow following deforestation is gathered.

a. Quantify the extent of water shortage in the Cagayan watershed

The annexes Irrigation and Waterbalance of the JICA report contain detailed analyses of water demand and supply in the Cagayan watershed. Analysis of these annexes can reveal the zonation, timing, extent and costs of water shortage in the Cagayan watershed.

b. Inventarise and test local observations on changes in water availability during the dry season

Inventarisation of local observations should ascertain the component of the hydrological cycle (frequency and intensity of dry-season rainfall, streamflow, groundwater level) that seems to be changing after deforestation, as well as the zonation of these changes.
Dry-season extinction of upland creeks following deforestation is frequently reported by local people. A black-box statistical test of the occurrence of this phenomenon in forested and deforested areas could verify this claim. After statistical verification of the phenomenon, hypotheses of the probable mechanisms should be formulated and tested in a next phase.

c. Analyse historical data

In comparison with stormflow, dry-season flow is less dynamic and less influenced by rainfall, therefore an analysis of historical data is confronted with less methodological problems (see chapter 4.5).
The main problem is the large scatter in de stage-discharge rating curves (SDR's) at low stages (refer to figure 13). This problem could be circumvented if the stage data before 1972 could be traced; trends in stage rather than discharge could then be analysed. If the pre-'72 stage data cannot be traced, the scatter in SDR's could be lessened by an analysis of the reliability of the individual discharge measurements.

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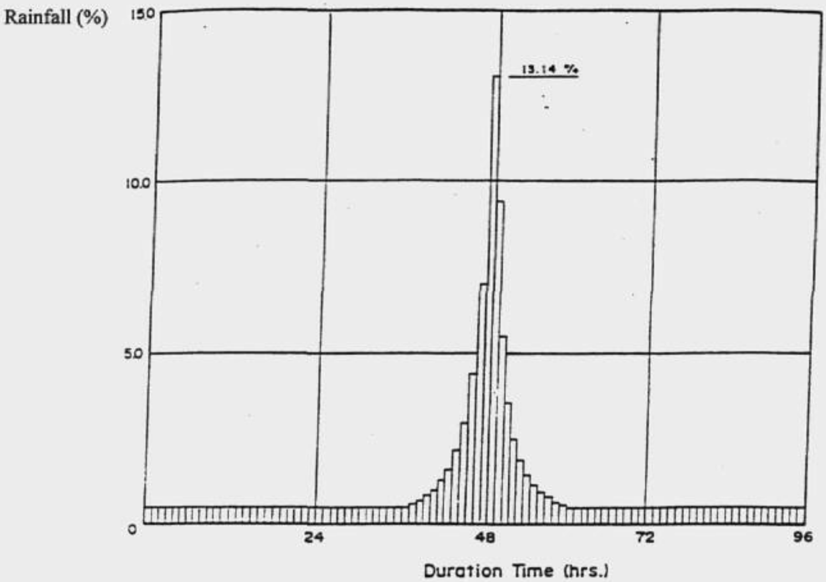
ANNEX 1. Relevant tables from the JICA report

Table HY-4.5 Areal rainfall distribution

(*) U: Upper Cagayan Basin M: Magat Basin I: Ilagan Basin
S: Siffu Basin C: Chico Basin
(**) BP-4 means the area upsteram of BP-4 except U
(***) BP-3 means the area between BP-3 and BP-4

	Area		Return period (years) 2	5	10	25	50	100
Intensive rainfall	U	(*)	204	285	340	409	462	515
on Upper Cagayan Basin	BP-4	(**)	168	231	273	326	366	405
	BP-3	(***)	142	183	209	244	263	287
	BP-2		150	192	215	243	266	284
	BP-1		161	173	178	179	180	181
Intensive rainfall	M	(*)	177	241	283	336	376	416
on Magat Basin	BP-4		196	276	330	399	451	503
	BP-3		142	183	209	244	263	287
	BP-2		150	192	215	243	266	284
	BP-1		161	173	178	179	180	181
Intensive rainfall	I	(*)	191	264	313	375	421	468
on Ilagan Basin	BP-3		175	239	282	336	376	417
	BP-2		150	192	215	243	266	284
	BP-1		161	173	178	179	180	181
Intensive rainfall	S	(*)	165	220	256	301	335	367
on Siffu Basin	BP-2		171	230	268	316	353	388
	BP-1		161	173	178	179	180	181
Intensive rainfall	C	(*)	169	233	276	330	371	412
on Chico Basin	BP-1		168	214	242	277	303	327



t (hr)	Rainfall (%)	t (hr)	Rainfall (%)	t (hr)	Rainfall (%)	t (hr)	Rainfall (%)
1	0.48	25	0.48	49	9.38	73	0.48
2	0.48	26	0.48	50	5.47	74	0.48
3	0.48	27	0.49	51	3.58	75	0.48
4	0.48	28	0.49	52	2.52	76	0.48
5	0.48	29	0.49	53	1.88	77	0.48
6	0.48	30	0.49	54	1.45	78	0.48
7	0.48	31	0.49	55	1.15	79	0.48
8	0.48	32	0.49	56	0.94	80	0.48
9	0.48	33	0.49	57	0.78	81	0.48
10	0.48	34	0.49	58	0.66	82	0.48
11	0.48	35	0.49	59	0.56	83	0.48
12	0.48	36	0.49	60	0.49	84	0.48
13	0.48	37	0.52	61	0.49	85	0.48
14	0.48	38	0.61	62	0.49	86	0.48
15	0.48	39	0.71	63	0.49	87	0.48
16	0.48	40	0.85	64	0.49	88	0.48
17	0.48	41	1.04	65	0.49	89	0.48
18	0.48	42	1.29	66	0.49	90	0.48
19	0.48	43	1.64	67	0.49	91	0.48
20	0.48	44	2.17	68	0.49	92	0.48
21	0.48	45	2.99	69	0.49	93	0.48
22	0.48	46	4.38	70	0.49	94	0.48
23	0.48	47	7.04	71	0.48	95	0.48
24	0.48	48	13.14	72	0.48	96	0.48

Figure HY-4.10 Hourly rainfall distribution

Table HY-4.7 Storage function of subbasins

Basin no.	Area (km2)	Length (km)	Slope	K	P	T1 (hr)
1	1150	92.1	40	27.5	0.416	3.8
2	481	25	90	21.6	0.504	0.6
3	733	37.5	50	25.7	0.439	1.2
4	298	35	260	15.7	0.646	1.1
5	351	62.5	330	14.6	0.684	2.4
6	142	30	740	11.5	0.827	0.9
7	477	42.5	200	17	0.608	1.4
8	387	56	40	27.5	0.416	2.1
9	193	22.5	560	12.5	0.774	0.5
10	264	45	1730	8.9	1.009	1.6
11	1106	65	1040	10.4	0.895	2.5
12	1051	55	1000	10.5	0.887	2
13	620	26	190	17.2	0.601	0.7
14	292	44	80	22.3	0.49	1.5
15	550	41	90	21.6	0.504	1.4
16	1228	45	390	13.9	0.711	1.6
17	628	53	80	22.3	0.49	1.9
18	559	57	240	16.1	0.634	2.1
19	266	42.5	480	13.1	0.747	1.4
20	970	112	560	12.5	0.774	4.7
21	247	30	390	13.9	0.711	0.9
22	876	82	190	17.2	0.601	3.3
23	474	50	220	16.5	0.622	1.8
24	215	38	680	11.8	0.81	1.2
25	652	48	120	19.8	0.539	1.7
26	915	63	120	19.8	0.539	2.4
27	209	35	150	18.5	0.568	1.1
28	656	48	150	18.5	0.568	1.7
29	408	88	1910	8.6	1.033	3.6
30	362	51	150	18.5	0.568	1.8
31	589	82	1390	9.5	0.959	3.3
32	964	55	220	16.5	0.622	2
33	327	39	120	19.8	0.539	1.3
34	92	19	3940	6.9	1.225	0.3
35	657	74	70	23.3	0.475	3
36	1042	76.5	5000	6.5	1.295	3
37	969	70	140	18.9	0.559	2.7
38	73	13.5	5000	6.5	1.295	0.1
39	386	26	70	23.3	0.475	0.7
40	334	42.5	90	21.6	0.504	1.4
41	157	25	30	30	0.389	0.6
42	533	36	40	27.5	0.416	1.1
43	372	44	70	23.3	0.475	1.5
44	612	53.5	230	16.3	0.628	2
45	856	58	60	24.4	0.458	2.2
46	1301	70	120	19.8	0.539	2.7
47	169	30	240	16.1	0.634	0.9
48	417	19	350	14.4	0.693	0.3
49	393	69	480	13.1	0.747	2.7
50	278	29.5	5670	6.2	1.334	0.8

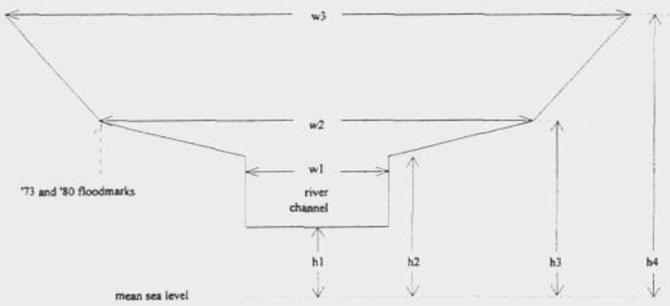
Table HY-4.9 Storage function of Channel
(Present river condition)

Channel No.	Length (km)	Slope	K	P	Timelag (hour)
1	25.0	1/330	68.9	0.593	3.3
2	31.0	1/560	69.2	0.595	4.1
3	19.3	1/790	65.8	0.629	2.6
4	17.2	1/980	68.4	0.610	2.3
5	56.0	1/40	50.9	0.648	4.4
6	22.5	1/590	3.6	0.894	3
7	45.0	1/1730	22.6	0.824	6
8	58.0	1/2900	82.7	0.774	7.7
9	45.0	1/390	66.6	0.623	6
10	42.5	1/480	145.4	0.557	5.6
11	63.5	1/870	15.7	0.948	8.4
12	20.5	1/6410	28.3	0.810	2.7
13	14.0	1/260	59.4	0.502	1.9
14	38.0	1/680	178.1	0.492	5
15	40.0	1/2470	27.5	0.780	5.3
16	18.5	1/3850	5.0	0.946	2.4
17	88.0	1/1910	0.6	1.499	11.6
18	82.0	1/1390	0.1	1.685	10.8
19	35.5	1/3940	16.3	0.944	4.7
20	19.0	1/19000	12.9	0.930	2.5
21	76.5	1/5000	33.1	0.938	10.1
22	13.5	1/5000	47.3	0.701	1.8
23	20.0	1/110	22.9	0.631	1.9
24	20.0	1/120	11.4	0.683	1.9
25	25.5	1/120	25.8	0.629	2.4
26	53.5	1/230	16.3	0.834	7.1
27	61.0	1/1030	73.2	0.787	8.1
28	10.0	1/50000	17.8	0.809	1.3
29	11.5	1/19170	24.8	0.775	1.5
30	29.5	1/5670	250.0	0.626	3.9

Table FC-5.5 Annual flood damages

Stretch	Return period of no-damage (years)	Damage (million Ph.P of 1985) 2-year	5-year	10-year	25-year	50-year	100-year	Annual average damage (mill.Ph.P/yr)
Main Cagayan river								
Mouth-Chico	2.56	-	340	479	734	916	1174	137
Chico-Tuguegarao	1.06	1298	2164	2970	4172	4521	4761	1409
Tuguegarao-Siffu	1.05	689	1500	1935	2378	2524	2681	859
Siffu-Ilagan	1.05	16	33	46	70	84	102	21
Ilagan-Magat	1.10	28	80	100	153	169	238	44
Magat-Upstream	1.35	119	291	390	720	1018	1257	172
Tributaries								
Siffu	0.82	34	63	82	117	138	158	37
Mallig	1.75	41	53	73	94	107	111	30
Ilagan	1.04	33	116	145	201	222	312	60
Lower Magat	1.03	364	547	664	771	923	900	352
Upper Magat	1.03	873	945	1003	1080	1176	1218	372
Mouth-Magat		2031	4117	5530	7507	8214	8956	
Total		3495	6132	7887	10490	11798	12912	3793

ANNEX 2. Schematization of the downstream Cagayan river



Section	Length	Node	h1 shallow	h1 deep	h2	h3	h4	w1	w2	w3
	(m)		(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)
		1	28.4	27.0	36.8	39.0	100	350	2691	20000
12	22000									
		2	25.2	17.2	35.2	38.0	100	516	2750	20000
16	20000									
		3	23.2	20.2	31.9	33.0	100	854	4643	20000
19	35000									
		4	17.5	15.3	23.0	26.4	100	1108	5609	20000
20	19700									
		5	12.5	11.3	19.1	23.5	100	754	5816	20000
21a	24500									
		6	10.4	5.4	17.1	19.9	100	733	5940	20000
21b	46300									
		7	3.2	2.5	10.3	18.9	100	1025	2435	15000
22	10500									
		8	-4.8	-19.1	16.2	16.7	100	299	1173	4000
28	19000									
		9	-0.3	0.5	11.5	12.9	50	455	5600	30000
29	10000									
		10	-3.3	-17.0	16.2	16.3	50	410	410	2000
30	29000									
		11	-5.4	-5.4	0.0	1.6	50	1588	10000	40000