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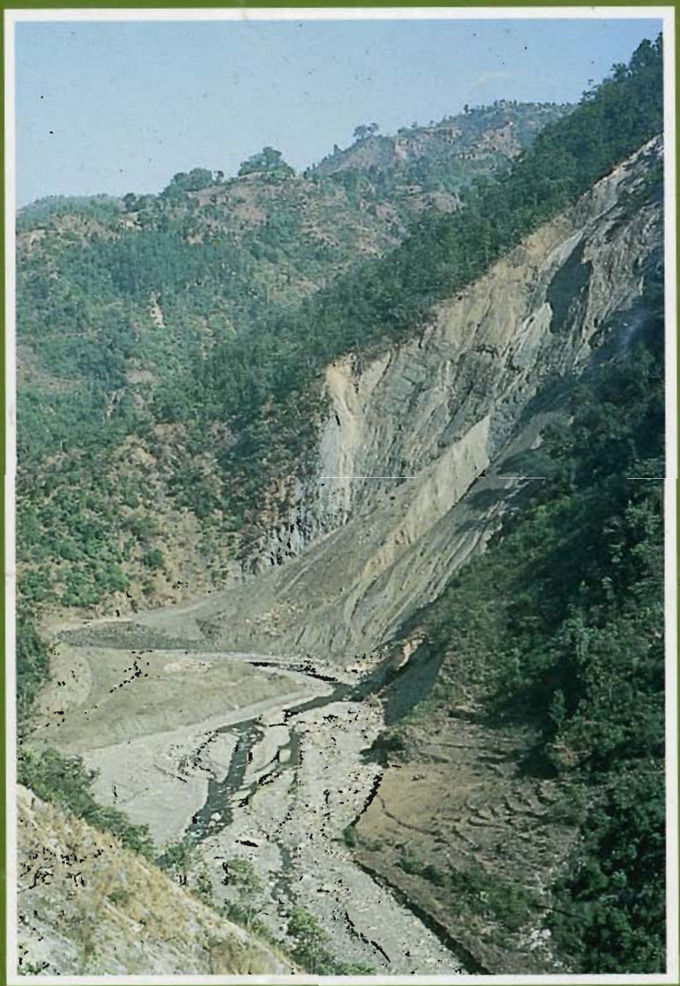
EROSION AND SEDIMENTATION PROCESSES IN THE NEPALESE HIMALAYA

by Brian Carson



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The front cover shows the Tinna River, north of Butwal Palpa District (see p. 20)

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PROLOGUE

The ideas presented in this booklet are not original. Hindu mythology, nurtured in the Himalaya came to similar conclusions about their landscape, thousands of years ago. Hindu gods have good and evil forms and every power has its opposite: Shiva, the noble creator of the world and Kali his female consort, a blood-thirsty goddess of destruction. These opposites characterize the cycles of life, death and rebirth. Such images are paralleled in the Himalayan landscapes: the raging flood vs the fertile silt laid down by that flood; catastrophic landslides vs the gentle sloping landslide runouts upon which agriculture could begin again rejuvenated. During the early periods of Hinduism, the philosophy of "Majaburi" or "Things we must bear" was developed. Landslides, earthquakes, floods and drought are considered the work of gods, beyond man's control. "Majaburi", they must be borne. This is one of the major points of this paper. Man does not cause the major landslides or floods in the Himalaya and so he cannot easily control them.

However, traditional Hinduism has not evolved quickly enough to detect the significance of the changes to the landscape over the last one hundred years. Although cycles of creation and destruction are continuing, unchanged, the insidious loss of topsoil by rainfall erosion is accelerating at an alarming rate and is now threatening the livelihood of the Himalayan hill farmer. Those committed to better land management must learn to differenciate between what is the work of man and what is the work of Kali. This is important to understand for developing appropriate conservation measures in the Himalaya.

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A. INTRODUCTION

Erosion includes all processes that result in the physical wearing down of the surface of the earth. Erosion processes are complex, consisting of "natural" (geological) erosion and "accelerated" (man induced) erosion. Natural erosion rates are very high in Nepal because of the constant tectonic uplifting of the major mountain ranges and consequent downcutting of the river systems. The net result of these unrelenting forces are unstable slopes that cannot maintain their river-canyon form. Natural erosion is characterized by different forms of mass wasting,* particularly rock failures, landslides, slumps, riverbank cutting and gullying.

Over the last century, an increasing proportion of the soil loss is attributable to accelerated erosion induced by an increased population pressure on a limited land resource. Forest clearing, overgrazing, poorly maintained marginal arable lands and fire have greatly altered the natural vegetation of Nepal, leaving the soil open to degradation. Accelerated erosion is characterized by the loss of topsoil by sheet and rill erosion.

Erosion processes profoundly affect the economy of the Nepalese villagers and collectively the health of the nation through the following:

- The most serious problem is the loss of topsoil from cultivated and grazing land. As topsoil is eroded, soil fertility declines and the soil is less able to maintain its productive capacity.

- Mass movement of slopes including rock failure, landslides, slumps, and debris torrents cause tremendous destruction of productive land, irrigation systems, paths, road alignments and villages.

- High sediment loads of rivers quickly reduce the useful storage capacity of man-made reservoirs, silt up irrigation canals, and damage turbines and water control structures.

- Sedimentation, in conjunction with peak discharges results in abrupt river channel changes. These cause tremendous hardships for farmers on the alluvial lands of Nepal.

*Mass wasting refers to the en masse movement of fractured rock, saprolite and other unconsolidated materials, including soil from a slope, whereas surface erosion refers only to the loss of topsoil resulting from rainfall or wind erosion.

Himalayan erosion is discussed here under B) Surface Erosion and C) Mass Wasting.

The inability to appreciate the differences between these two distinct processes has resulted in considerable confusion when implementing soil conservation programmes. It is important to determine which erosion processes man can effectively moderate through appropriate land use techniques.

B. SURFACE EROSION

Surface erosion is less visually apparent than mass wasting but it is much more damaging to the livelihood of the people of Nepal. Loss of topsoil by surface erosion is the direct result of heavy rains pounding unprotected soils. Many of man's activities cause the soil to become less protected than it would be in a natural state. (See Photo I.)

The loss of one or two millimeters of topsoil every year may not make a spectacular visual impact, but the cummulative effect is the impoverishment of the soil base. Topsoil has the highest levels of nitrogen, phosphorous and organic matter and is more productive for plant growth than lower soil horizons. Because of the insidious nature of surface erosion, it is necessary to develop a method whereby surface erosion can be quantified.

1. Factors Contributing To Surface Erosion

Scientists have developed a number of regional assessments characterizing soil erosion throughout Nepal. Such exercises are difficult to carry out because of the extreme variability found throughout the country. Rainfall erosivity, wind velocity, aspect, slope, bedrock type and characteristics, land use, forest type and condition must all be considered in the prediction of surface erosion. Surface or topsoil erosion caused by rainfall can be investigated by the use of the Universal Soil Loss Equation (U.S.L.E.) (Wischmeier and Smith 1978) whereas mass wasting events are virtually unpredictable without very expensive on site investigation.

Briefly the U.S.L.E. is A = RKLSCP

Where A = the amount of soil loss in tons per ha
R = Rainfall erosivity
K = Soil erodibility
LS = Slope length and steepness
C = Cropping management
P = Erosion control measures

The Universal Soil Loss Equation was developed for gently sloping agricultural land in America and direct applicability to the mountainous regions of Nepal cannot be assured. It does however provide some insight into the quantification of topsoil erosion. The factors considered in soil erosion prediction are given below.

a) Rainfall Erosivity (R)

The magnitude of surface soil erosion is directly related to the intensity of precipitation. Since rainfall intensity data is very scarce in Nepal, direct assessment of rainfall intensity throughout the country is impossible. Backed by existing Kathmandu weather station data, Fetzer and Jung, (1978) calculated a moderately low rainfall intensity (R = 70; World values range between 10 and 1000.) It is commonly acknowledged that rainfall intensity decreases with increasing elevation; areas on the Terai have relatively higher rainfall intensity while areas in the High Himal have a relatively lower rainfall intensity. A slope on the Terai or in the Siwaliks experiences more erosive storms than a slope in the High Mountains. Consequently, farmers in Jumla or Solu can cultivate unterraced, 15 degree slopes with only minor apparent damage. The same slope in the Siwaliks would be badly eroded after one monsoon season.

b) Soil Erodibility (K)

Soil characteristics including texture, percentage of organic matter, structure, and rate of infiltration can markedly affect erodibility of soil. In general terms, the less the proportion of fine sand or silt, the higher the organic matter content, the more developed the soil structure and the higher the infiltration, the less erodible the soil will be. Red soils in Nepal are notorious for sheet and gully erosion because of the low infiltration rates, and tendency toward surface crusting. Overgrazing and burning on red soils results in severe soil degradation. Structureless, very fine sands such as excavated in the new Kathmandu airport construction at Gauchaur are also extremely erodible and even low intensity storms result in tremendous surface soil movement. During one storm event in July 1984 over 250 tons per hectare of such material was eroded.

c) Slope Length And Steepness (L,S)

As slopes become steeper and longer the potential for surface soil erosion increases. The higher the velocity and the greater the concentration of water, the greater sheet and rill erosion. Slope steepness is a key factor used when mapping soil erosion hazard and many land managers classify erosion hazard based on slope alone. However, at slopes greater than 30 degrees, mass movements begin to outweigh the effect of surface erosion. On very steep slopes surface erosion rates drop because all unconsolidated material has long since washed away.

d) Cropping Factor (C) (including natural vegetation)

The cushioning of bare soil by crops or vegetation protects the soil from eroding during rainfall events. The greater the density of vegetation, the less is the erosion of the soil surface. Overgrazed lands result in the most severe surface erosion while multistoried forests have the lowest levels of topsoil erosion. Researchers in Nepal tend to overestimate the value of trees and underestimate the value of ground cover in reducing surface erosion.

There has been general discussion on the value of the forest in proper watershed management. However, there is a tendency to stress tree planting and protection while ignoring the fact that trees are only one component of a healthy forest. The primal forest includes trees, shrubs, herbs, grasses and forest litter. The ability to resist erosion caused by the monsoon rains is largely dependant on the percent cover and vigor of vegetation at ground level, the herbs, grasses and litter. Healthy trees alone do not ensure protection from soil erosion. In the heavily used forests of Nepal, Pine and Sal are noted for the scarcity of growth in their understory. In spite of complete Sal or Pine tree cover there can still be severe damage to the soil surface. At the same time, areas demarcated as badly degraded forest, if they have adequate ground cover can provide excellent cover for soil conservation management. The presence or absence of trees alone cannot be linked to rates of topsoil erosion.

e) Erosion Control Factors (P)

By reworking hill slopes into bench terraces, and maintaining lined or vegetated waterways with adequate drop structures, man can achieve positive changes on a cultivated slope. The Nepalese farmer, by constructing and maintaining bench terraces has developed a very stable agricultural system for his cultivated crops.

The area of most severe damage to the land resource is occurring on over-utilized communal grazing and forested land where the individual villager has no motivation for improving management.

2. Wind Erosion

Although rainfall erosion is the major topsoil degrading process occurring in Nepal, wind erosion plays a significant role on certain landscapes associated with cultivation. In general, throughout the Middle Mountains, wind erosion is of minor importance because the soils have medium textures and good structures so they are able to resist wind erosion. Overgrazed and badly compacted sites experience very little wind erosion, although rainfall erosion on these same sites can be severe. Further, cultivated soils are in stubble fallow in April and May when the winds are strongest.

Dust storms occur on, and adjacent to, all major dry river beds, which comprise 1.6 percent of Nepal. Unvegetated, structureless riverbed sediments are easily windborn and can be carried for long distances. Little of the observed dust is actually coming from agricultural lands. The net result is loess deposition on forested and cultivated land, particularly in the Terai and Siwaliks, because the majority of dry river beds are found there. Aeolian sediments can be traced from as far away as the Rajastan desert, brought during the strong winds of April and May. These windborn sediments may have had a net positive contribution to the soils of Nepal by the deposition of silt, often of a calcareous nature.

Wind erosion is significant in areas of semi-arid and arid climate, common in the deep valleys of the High Himalayan Region, particularly in Dolpa, Mustang and Manang. The Kali Gandaki, at Jomsom, experiences tremendous winds daily. These winds are strong enough to move coarse sand along the valley floor. The area is so dry that vegetation is restricted to scattered thorny scrub growing on bare soil. Over time, the removal of fine surface soil materials by wind erosion has left behind a stone pavement, which if left undisturbed, protects the soil from further wind erosion. Obviously any activity in this area that opens the soil must be combined with good erosion management including wind breaks, surface mulches and irrigation to minimize topsoil loss.

Where mechanized cultivation is feasible, particularly in the Terai and in the Dun Valleys of the Siwaliks, there is cause for concern upon the introduction of heavy farm machinery that is capable of working dry, hard soils. Traditional ploughing required that the soil be wetted to field capacity in order to restore the soil to a workable state. Heavy equipment (including chisel ploughs, harrows and rotovators) in the process of making a seed bed on dry soil can create a powdery soil surface that is vulnerable to wind erosion. If harrowing is done during April and May in anticipation of the first rains, severe wind erosion may result. Agronomists must consider the wind erosion hazard in rainfed cultivation if new cropping patterns are introduced.

Wind erosion is a problem on the sandy textured active alluvial terraces of the Terai. Sandy soils are relatively easy to plough, even when dry, and in their ploughed state are susceptible to blowing. The planting of windbreaks with trees such as Dalbergia sissoo can significantly reduce surface wind speeds and thus reduce soil loss. Farmers on the Terai adjacent to major river systems are beginning to use sissoo hedge rows. Riverine forest plantations can be more economic than annual cropping and much more suited for wind erosion control.

In spite of its localized importance, wind erosion is not discussed further in this paper as its significance to Nepalese Himalayan geomorphology is small.

3. Topsoil Erosion Assessment for a Watershed

By an empirical study of erosion on a typical watershed, an attempt can be made to estimate how much topsoil is actually leaving any landscape. One can appreciate the magnitude of rainfall erosion, by actually measuring the soil loss during various types of land use on a given landscape. Literature accumulated by Laban (1978) provides us with a rough estimate of surface soil loss from specific land use types for an otherwise uniform slope. The following soil loss figures are given for a typical watershed in the Middle Mountains of Nepal.

TABLE I ESTIMATED SOIL LOSS FOR DIFFERENT LAND USES (Laban 1978)

Type of Land	Soil Loss (Tons/ha/yr)
Well managed forest land	5 - 10
Well managed rice terraces (bunded)	5 - 10
Well managed maize terraces	5 - 15
Poorly managed sloping terraces	20 - 100
Degraded range land	40 - 200

However these figures are not usually measured data, but estimated, based on known sediment loads of streams. They most likely overestimate surface soil erosion based on the assumption that sediment production is largely a function of land use. Topsoil losses in many areas may not have exceeded 0.5 tons per hectare. These estimates have probably included various forms of mass wasting in the assessment of surface erosion. This complication will be considered in the section on mass wasting.

4. Topsoil Erosion and Soil Fertility Management

Throughout the hill regions of Nepal, soil erosion losses on cultivated and grazing lands are a major factor in soil fertility management. Any techniques used to enhance productivity must consider soil conservation measures. Conversely, any techniques used to reduce soil erosion must consider land productivity. In Table II the magnitude of nutrient losses through soil erosion on different land uses is presented. Well managed irrigated and rainfed terraces experience only minor soil loss which can be matched by compost and fertilizer additions. With land uses such as shifting cultivation, the loss of nutrients obviously cannot be maintained and so fertility declines.

The decline of soil fertility through topsoil erosion is one of the major ecological crises facing Nepal today and it is in this area that soil conservation programmes have an important role to play.

TABLE II ESTIMATED SOIL AND NUTRIENT LOSSES BY RAINFALL EROSION ASSOCIATED WITH DIFFERENT LAND USES*

	Irrigated Rice Land	Level Terraces	Sloping Terraces	Shifting Cultivation
Soil Loss Depth	0.0 mm	0.4 mm	1.6 mm	8.0 mm
Soil Loss (Kg/ha/yr)	0	5,000	20,000	100,000
Organic Matter Loss (Kg/ha/yr)	0	150	600	3,000
Nitrogen Loss (Kg/ha/yr)	0	7.5	30	150
Phosphorus Loss (Kg/ha/yr)	0	5.0	20	100
Potassium loss (Kg/ha/yr)	0	10	40	200

*Based on a topsoil with the following analyses.

Organic Matter	3.00%
Nitrogen	0.15%
Phosphorus	0.10%
Potassium	0.20%
Bulk density	1.3 g/cm

C. MASS WASTING

It is difficult to travel throughout the Nepalese Himalaya without being impressed by the massive landslides that scar the landscape from the Siwaliks up to the High Himalaya. Such landslides are often wrongly considered to be the result of the recent activities of man. Western experience is limited in the Himalaya, particularly in geomorphic studies. However, recent research has concluded that mass wasting is the dominant process in the evolution of natural slopes throughout much of the Nepalese Himalayas. Thouret (1981) has mapped mass wasting of slopes to determine "their speed of evolution". (See Figure 1) Slopes that are experiencing tremendous mass wasting processes, such as in the upper Ankhu Khola, are evolving very rapidly. Their instability is natural and man's effect on this erosion process is incidental at best.

One of the most spectacular geomorphic events to have occurred in historic time, was the glacial dam outburst flood on the Seti Khola in the Pokhara Valley. Around 600 years ago, a ten square kilometer lake behind Machhapuchare broke through its ice-moraine dam and surged down the Seti gorge, picking up colluvial debris as it went. In a relatively short period of time, over 5.5 cubic kilometers of glacio-fluvial material was deposited in the Pokhara Valley (see Photo II). Both Fort and Freytel (1982) and Yamanaka (1982) provide background information on this remarkable landform.

The largest documented landslide in Nepal occurred when a 15 cubic kilometer chunk of a Himalayan peak fell into the Langtang Valley some 30,000 years ago (Heuberger et al 1984). Many of the high alluvial terraces in Nepal can be explained by such catastrophic events higher up in the watershed. Certainly the major geomorphic events that have shaped the Himalayan landscape are natural, not the result of the misutilization of the land.

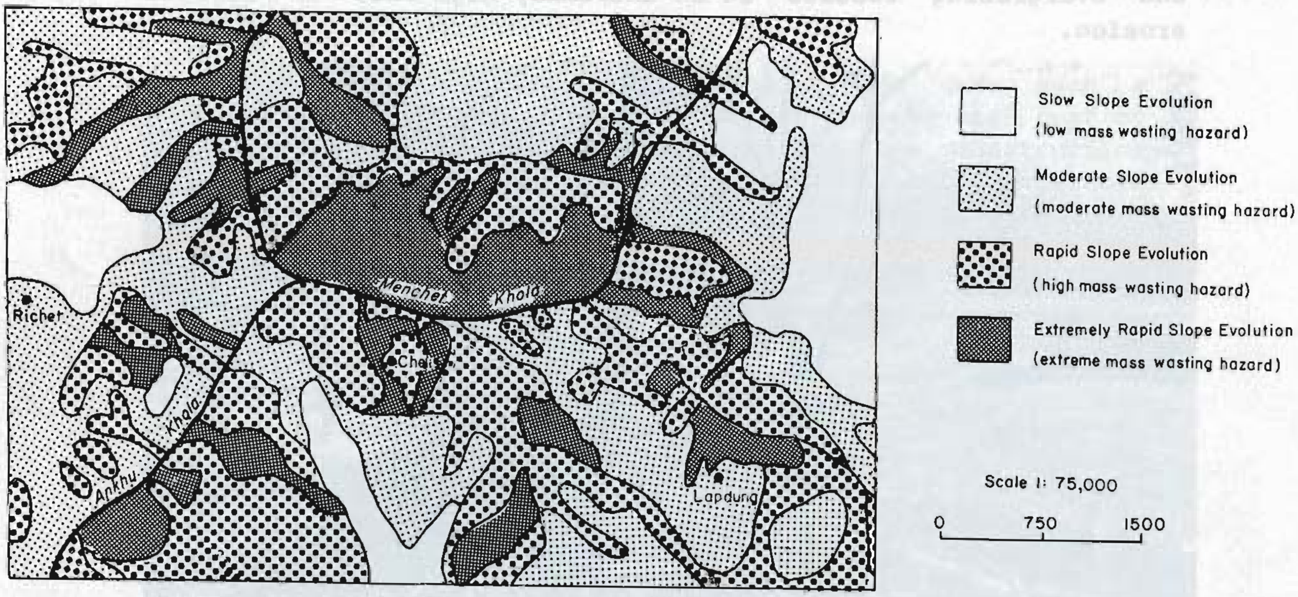
1. Factors Contributing To Mass Wasting

Research has been carried out on the causes of mass wasting processes with engineers stressing soil mechanics; geologists, rock type; hydrologists, prolonged precipitation; foresters, deforestation; and so on. Mass wasting processes are extremely complex, a result of a number of interdependent factors. It is not suprising that there is considerable confusion in the literature. Wagner (1983) in his study of mass movements along road alignments throughout the Middle Mountains of Nepal considered the following factors as significant.

- Structure and incline of slope
- Number and density of natural fracture planes
- Type of rock or mineral and state of weathering
- Presence of water

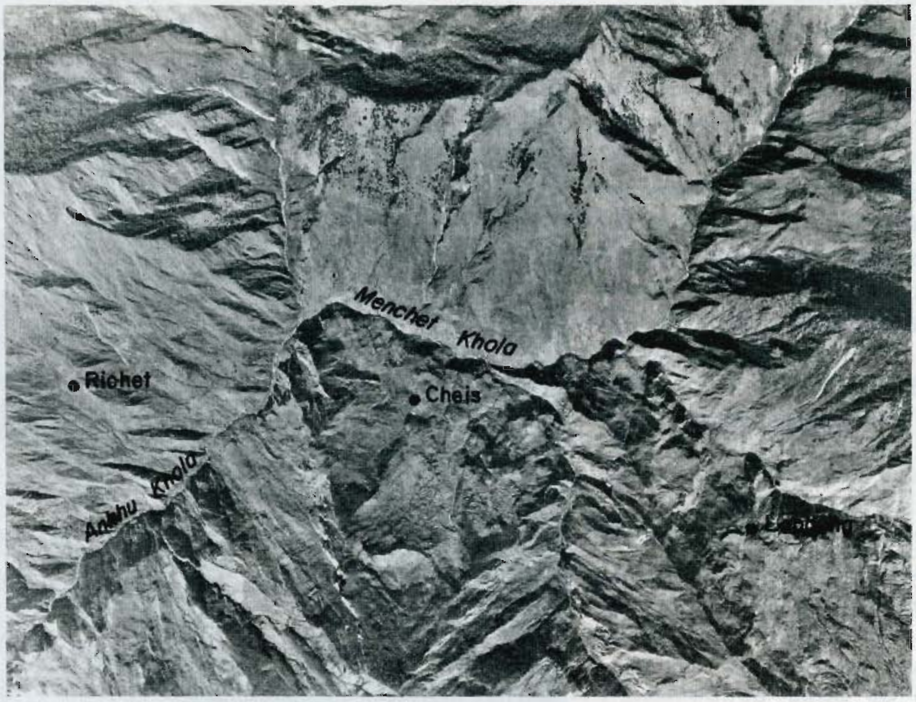
Figure I

Geomorphic Nature of Upper Ankhu Khola (after Thouret 1981)



AERIAL PHOTOGRAPH OF UPPER ANKHU KHOLA

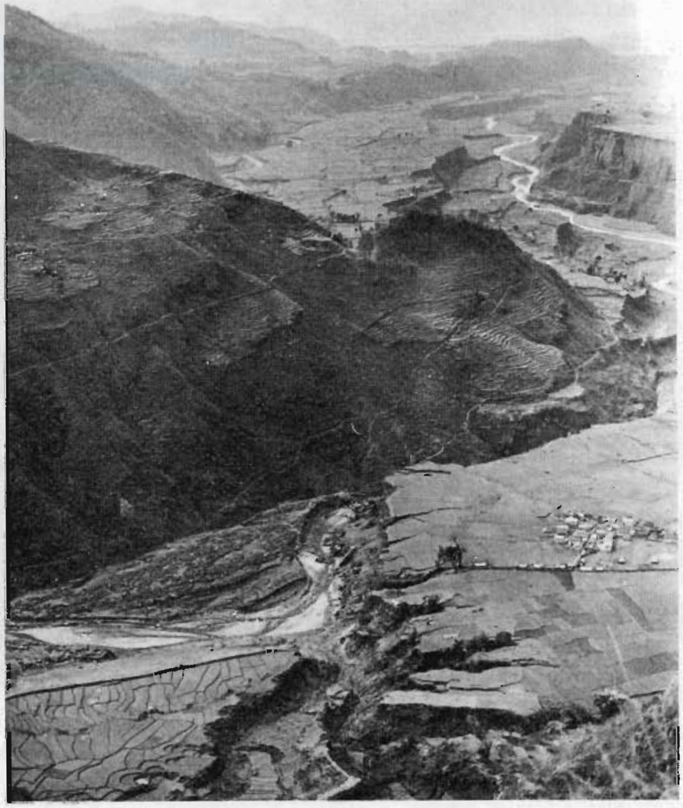
The interpretation of the above features requires a trained eye.



Roll 7940 No. 24

Photo I. - North of Nepalgunj, Banke District, dissected alluvial upland. High intensity rainfall combined with repeated burning and overgrazing results in an extremely high rate of surface erosion.

Photo II - The Pokhara Terraces, looking Southwest towards Gachok, Kaski District. These terraces are the result of a glacial dam outburst flood that occurred just 600 years ago.



By rating the above factors, predictions were made regarding the inherent stability of slopes. Besides site inspection, Wagner mapped a small area north-east of Tansen using the same parameters.

When constructing roads, canals, and dams such a detailed methodology is appropriate because the high cost of the survey can be easily absorbed into the construction budget. However, for the majority of Nepals' mountainous regions, such a survey is prohibitively expensive and one must weigh results against their possible utility. The exhaustive work in the Kakani area, by Kienholz et al (1981) was very useful for demonstrating the geomorphic character of the Himalayan Middle Mountains. The mapping on 1:10,000 scale topographic maps revealed tremendous density and diversity of mass movements (see Figure 2) and it was hoped would shed some light on the role of the forest in preventing mass movements. Unfortunately, the forested areas were on a different rock formation, and the lack of slides in the forested areas could not be correlated with improved forest cover as had been anticipated.

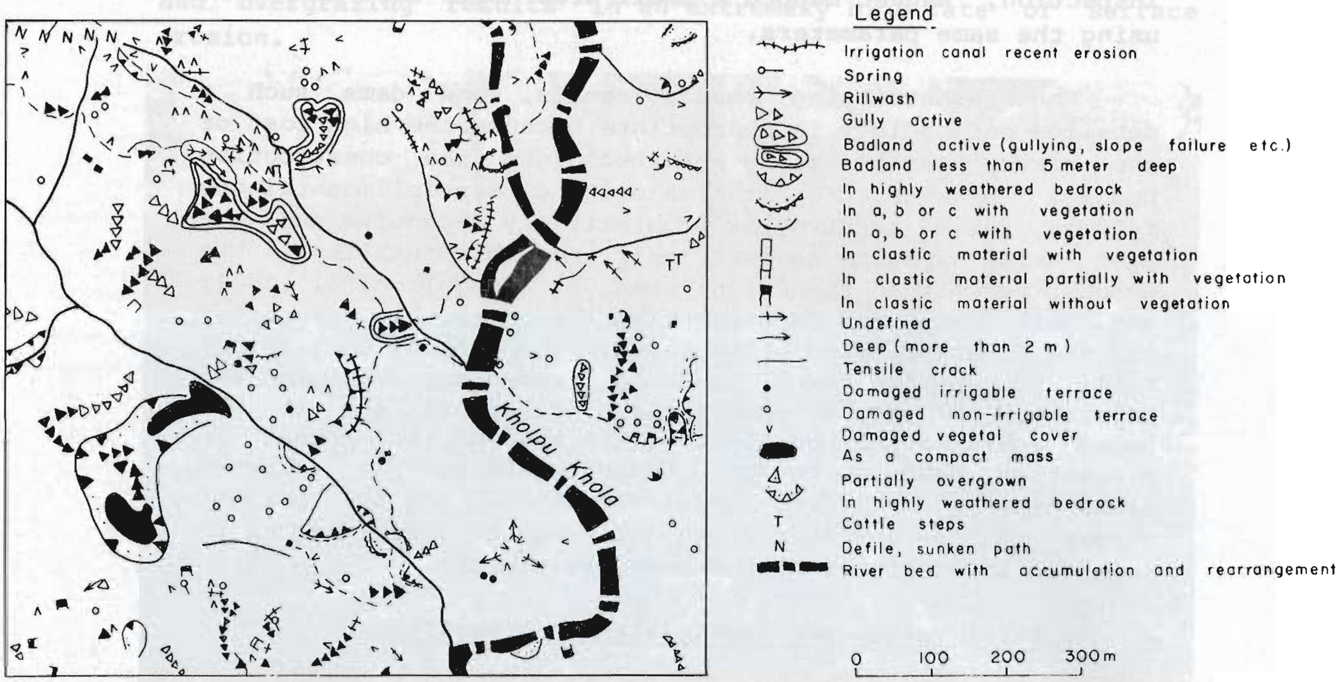
a. Natural Versus Man-Accelerated Mass Wasting

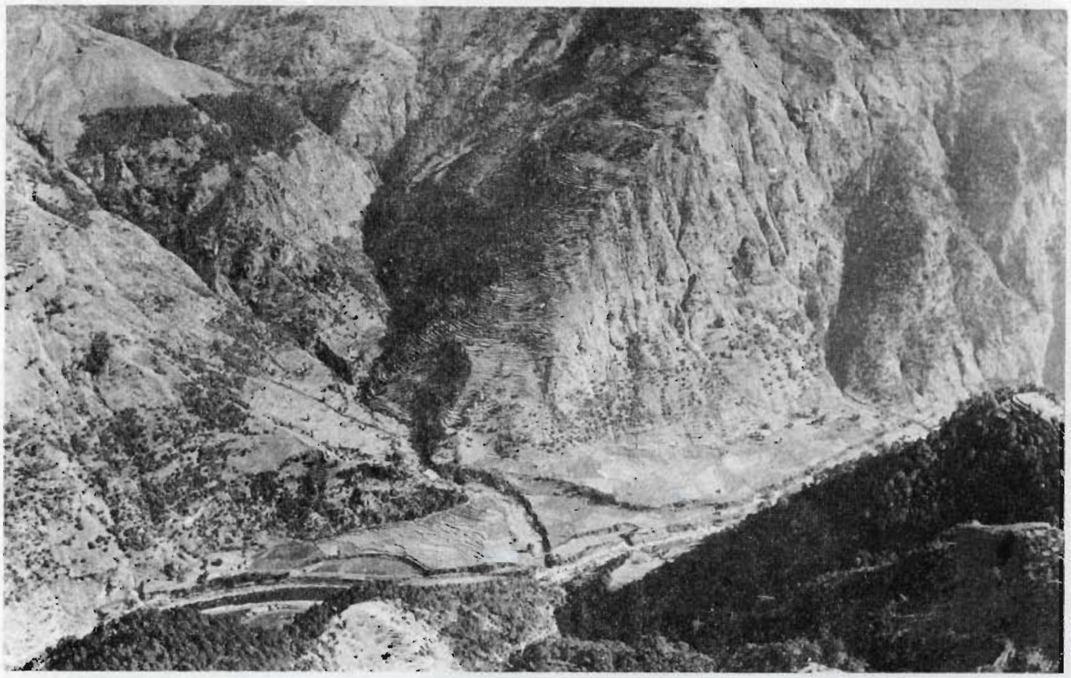
Laban (1979) after reconnaissance overflights, concluded that at least 75% of all landslides in Nepal were natural. By necessity the methodology was simplistic; if a landslide occurred in a forest it was considered natural: whereas, in cleared or cultivated areas it was considered as man caused. Brunsden et al (1981) working in the Middle Mountains of Eastern Nepal, stated that landsliding should be considered as a normal process rather than an exceptional one for the study area. Phyllites, shales and schists showed no significant differences in degree or type of mass wasting, while the deeply weathered gneisses seemed considerably less subject to landsliding but much more prone to piping and gully formation. Erosion processes, although different were nevertheless intense.

Many Himalayan landscapes appear to have a period of relative stability of slopes when mass wasting is not a dominant process, followed by a spell of instability during which a large number of landslides occur almost simultaneously on an otherwise undisturbed slope. (See Photo III.) Villagers often tell stories about extreme precipitation events, occasionally concurrent with earthquakes, that trigger large scale slope failures. In one area south-west of Banepa the villagers acknowledged that the landslides still visible had all occurred during two heavy rainfall events, one in 1934 and the other in 1971. In spite of heavy, more recent rains, no major sliding had occurred since the 1971 monsoon. Such processes tend to be similar throughout much of the Middle Mountains of Nepal.

Figure 2

Geomorphic Damage; Kakani Area (after Kienholz et al 1981)





Phyllitic landscape similar to the Kakani area. Note the wide variety of erosion processes and their significance to landscape formation. Gullys, slumps, slides and debris torrents are common.

Starkel (1972) in his study of an extremely intense precipitation event in Darjeeling (500 mm in 24 hr) found that many new landslides had been initiated and old slides reactivated resulting in ten times more than the average yearly rates of erosion. During such catastrophic rainfall events, there was not a direct relationship between the amount of mass wasting on forested versus nonforested slopes. Starkel considered that catastrophic events should be considered the most significant for normal slope evolution.

Information such as presented above suggests that in many cases mass wasting is unavoidable, a result of discrete levels of increasing instability of slopes over time.

b. Effect Of Vegetation On Mass Wasting

Brunsden et al (1981) found that during a particularly heavy storm in 1974 on phyllite in Eastern Nepal, mass wasting was common on steep forested land but not common in cultivated areas. In these areas it appears that slopes were originally gentle and the Tamur River downcutting has resulted in areas of local high relief. These areas, although forested, are subject to ongoing mass wasting slowly cutting back into the more stable gently sloping cultivated terrain.

Winiger (1983) considered that many of the cultivated slopes are indeed unstable even in their natural state; but, that the local farmers have a remarkable stabilizing input by the maintenance of terrace systems. Providing agricultural activity remains economical, the landscape remains in a stable state. Sastry and Narayana (1984) found that bunding agricultural land in a Dun Valley in India reduced soil loss and runoff considerably compared with adjacent forested land. However, if agricultural productivity declines and the farmer has less interest in terrace maintenance, slope degradation can occur at a greatly accelerated rate.

There is disagreement over the role of vegetation in reducing landslides. Singh et al (1983) postulated that deep rooted tree are required to stop landsliding and that grasses and shrubs have little effect on holding soil in place. Better rainfall infiltration, enhanced by well vegetated soil surface, can actually result in higher rates of mass wasting by increasing slope pore pressure. Singh acknowledged that sediment production was a result of mass wasting and inexplicably assumed that mass wasting was largely a man accelerated process. On the other hand, Wagner (1983), in his work on landslides, did not find it necessary to include vegetation as a factor in assessing on-site risk of mass failure. Between these two extremes one finds many other opinions that probably reflect conditions in the watershed that the researcher was

Photo III Near Lele, Lalitpur District. After a prolonged rainfall in Sept. 1981, this slope failed en masse in spite of thick shrub cover. Such catastrophic events are common on certain landforms within the Nepal Himalayas but are difficult to predict.

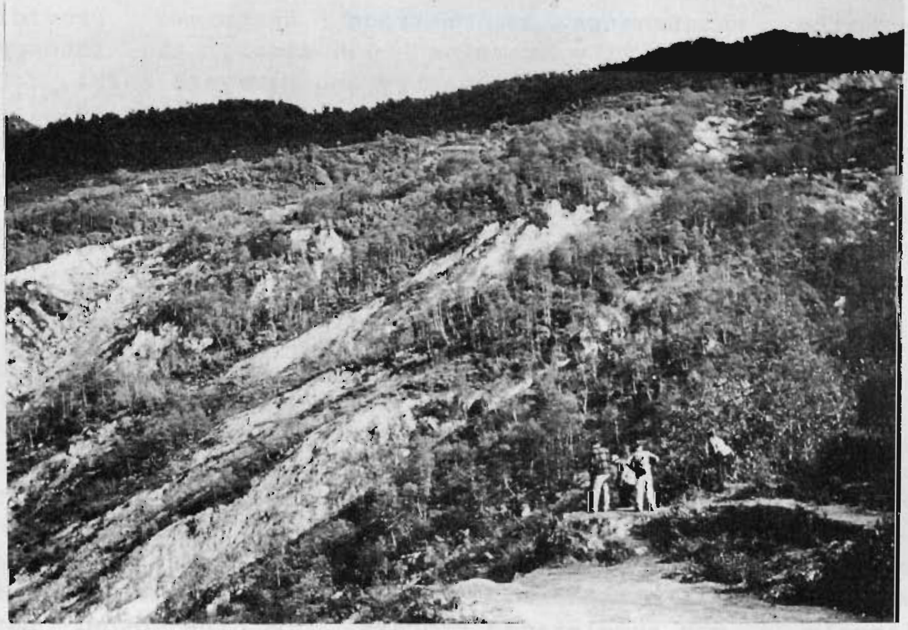


PHOTO IV. - Large landslide north of Taplejung, measuring over one km wide, three km long and over 20 meters deep. In the past fifty years over one hundred million tons of soil material has washed into the Tamur River from this slide. The progressive destruction of the hillside is difficult to blame on man's activities, as the land is generally well managed.

studying. There is a great diversity of landscapes in the Nepalese Himalaya, and for each hillslope one must consider somewhat different contributing factors. Landslides occur on all types of slopes; vegetated, unvegetated, treed, barren, terraced and nonterraced throughout the hills. The majority are initiated on slopes between 32 and 45 degrees. Small, shallow slides tend to occur more frequently on unvegetated slopes while much larger, deeper slides tend to occur independent of vegetation cover. The existence of forest may increase the period of time between slides, but in the long run may not prevent them if the terrain is inherently unstable. Over a sufficiently long period of time the net contribution of sediment might be similar. In Nepal, the largest, deepest landslides such as at Jharlang and north of Taplejung often occur in forested or otherwise well managed land. (See Photo IV). If a slope is inherently unstable, as must be the case on many Himalayan landscapes, mass wasting is such a complex process that one must start with the premise that the effect of vegetation on slope stability is not clear and that other factors are probably more important.

c. Effect Of Man's Engineering Activities On Mass Wasting

i. Roads

Disturbance of slopes by man's activities, particularly slope cutting and changing drainage patterns introduces serious mass wasting onto otherwise "stable" slopes. Road construction in particular is responsible for the initiation of many landslides. (See Photo V.) Deep side hill cuts and side-cast material result in initiation of cycles of instability. Proper location of roadways, by avoiding potential slide areas, appropriate drainage works, avoiding or at least minimizing cuts when unstable slopes are encountered and prohibiting side casting of cut bank material can all greatly reduce the destabilizing effect of road construction.

Although there is no doubt that proper road engineering can solve many of these problems, methods are very expensive. One of the best engineered roads in Nepal, the Dharan - Dhankuta road cost over $1 million U.S. per km to construct and annual maintenance costs are astronomically high, certainly beyond the budget of the Nepalese government. In spite of the care made in the assessment of the alignment and during construction, this road has been closed during part of the last two monsoons by serious landslide activity. In the 1984 monsoon over 5 million dollars of damage was done by slope failure.

Considering the present stage of economic development in Nepal, single lane roads with pullouts, suited to farm tractors with trailers and open only in the dry season might be more appropriate. Such a road design for feeder roads in the hills could result in a great reduction of engineering and maintenance costs and greatly reduce the number of landslides produced by road construction.

ii. Irrigation

Irrigation of hillslopes is also a source of accelerated mass wasting. Generally, bunded rice terraces represent a stable land use in which one can often measure net additions to the soil surface by sediment laden irrigation water. However, in certain cases the extra weighting of slopes and increased pore pressure, caused by irrigation water within slopes can cause slopes to fail, especially when coinciding with earth tremors. The introduction of new water sources onto slopes rarely occurs because all easily irrigable areas have been irrigated. Those areas that were likely to fail have often already done so. Obviously, newly planned irrigation on presently unirrigated sloping land must take into account the increased likelihood of major slope failures. Smaller slumps and terrace riser failures frequently occur in rice terraces but are quickly repaired by the farmer. (See Photo VI.) Without constant attention, terrace, and eventually slope degradation proceeds rapidly.

iii. Dam Construction

Large dam construction projects can have a significant effect on the stability of a watershed. The flooding of a valley by a reservoir may result in watering the base of unstable slopes. Increase in pore pressure within the slope followed by rapid drawdown may be enough to set such a slope into a phase of active sliding even after a long period of relative stability. Below the dam, the sediment load has been interrupted and without a source of sediment to protect the river bed, a cycle of river cutting and land degradation may begin. With the increase in river cutting, adjacent slopes could be destabilized, initiating a cycle of mass wasting shortly after completion of the dam.

In spite of the increased number of slides introduced by man's engineering activities, they have as yet constituted only a small increase to the already enormous magnitide of mass wasting processes. However, they are extremely important for road construction and maintenance and irrigation water, distribution. Consequently, mass wasting strongly affects the cost of economic development in Nepal.

PHOTO V. - Feeder road construction northeast of Dharan Severe erosion has been initiated by the poor layout, design and construction technique of this road. This alignment has since been abandoned as too costly to construct and maintain.

PHOTO VI. - Irrigated rice terraces in Accham. Irrigated lands are generally worth at least twice the value of nonirrigated lands. Small slope failures such as seen in this photo are quickly reclaimed as long as soils remain productive.

D. ESTIMATES OF SEDIMENT PRODUCTION

It is difficult to estimate surface soil erosion and even more difficult to estimate meaningful sediment delivery ratios for surface erosion. To further complicate the problem, on many Himalayan landscapes, mass wasting is a dominant process and its contribution to sedimentation can greatly overshadow the surface erosion contribution. As yet, the prediction of the mass wasting proportion for sediment loads has not been attempted.

Major errors have been made in the estimation of surface soil erosion for the hilly regions of Nepal. This is because the researchers are trying to account for sediment loads, by assuming the majority of sediment comes from man accelerated surface erosion. There is virtually no surface soil erosion under a dense, multi-layered forest, and yet estimates of between 5 to 10 t/ha/yr are "predicted" to be eroding. On some well constructed and managed rice fields there is also very little surface erosion, and in some cases there is a net deposition of sediment carried with the irrigation water. Watershed managers sometimes have difficulty in recognizing the significance of mass movements and gullies advancing on slopes, independent of land use. By analyses of measured sediment yields downstream, they attempt to "predict" from where soil is eroding. Based on the preconceived idea that the majority of the sediment is caused by accelerated erosion, the researcher looks primarily to differences in land use to explain the high sediment yields. Existing sediment yield data is misleading because it gives the impression that sediment yields are invariably directly related to land use. This is a major fallacy in sediment prediction in the Himalaya.

Figure 3 shows the relationship between rainfall erosivity and the ability of surface vegetation to resist surface erosion throughout the year. Surface erosion is the most severe when vegetation is sparse and rainfall intensity is high. This period coincides with the beginning of the monsoon. Intuitively, one might expect the highest rates of sedimentation during this period. However, all existing sedimentation data shows no such correlation. Peak sediment loads occur sporadically throughout the monsoon with no noticeable relationship to the improved vigour of vegetation over the monsoon. The daily sediment discharge for the Narayani River over the 1979 monsoon, which is typical for major Nepalese rivers, is provided in Figure 4. The numerous peak discharges, occur independently of any protection provided by surface vegetation. This must indicate mass wasting is very active in the watershed and that surface erosion may be accounting for only a small portion of the sediment load of the Narayani River. One has only to observe a river system in Nepal in the late monsoon to appreciate the significance of point source sediment contribution in the Himalaya. The major rivers are heavily sediment laden and yet the tributaries are, for the most part, sediment free. The occasional tributary, however, has extreme sediment loads that markedly discolour the main river. These tributaries are muddy because of major mass slumping into

Figure 3

RELATIONSHIP BETWEEN EROSIVITY OF RAIN AND CONDITION OF SURFACE VEGETATION THROUGHOUT THE YEAR IN THE MIDDLE MOUNTAIN OF NEPAL

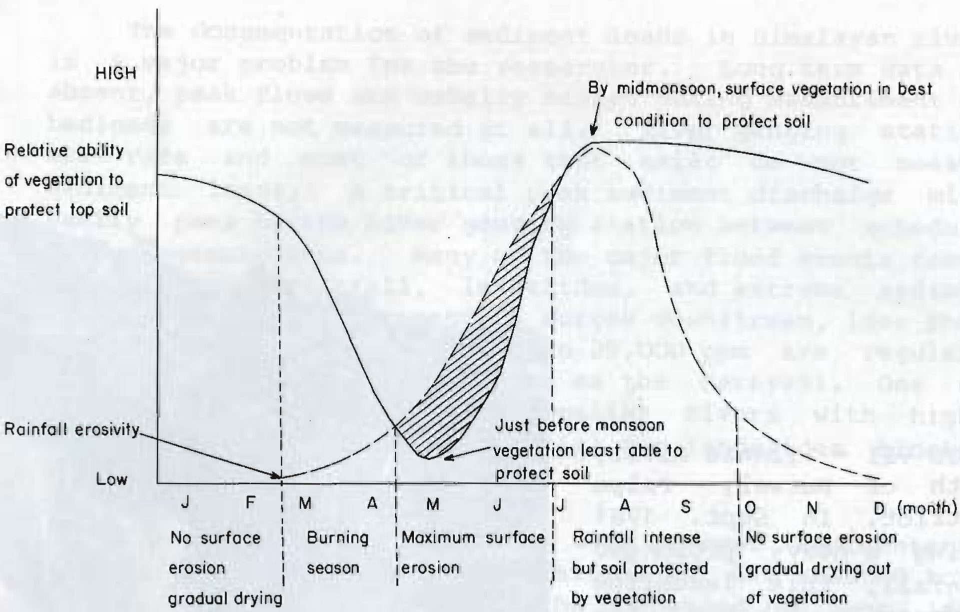


Figure 4

DAILY INSTANTANEOUS SEDIMENT LOAD FOR NARAYANI RIVER, NARAYANGHAT (JUNE, JULY AND AUGUST 1979)

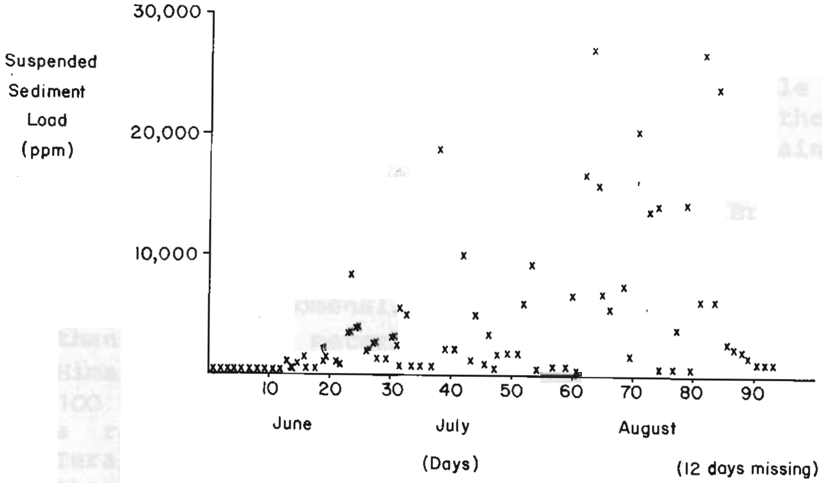
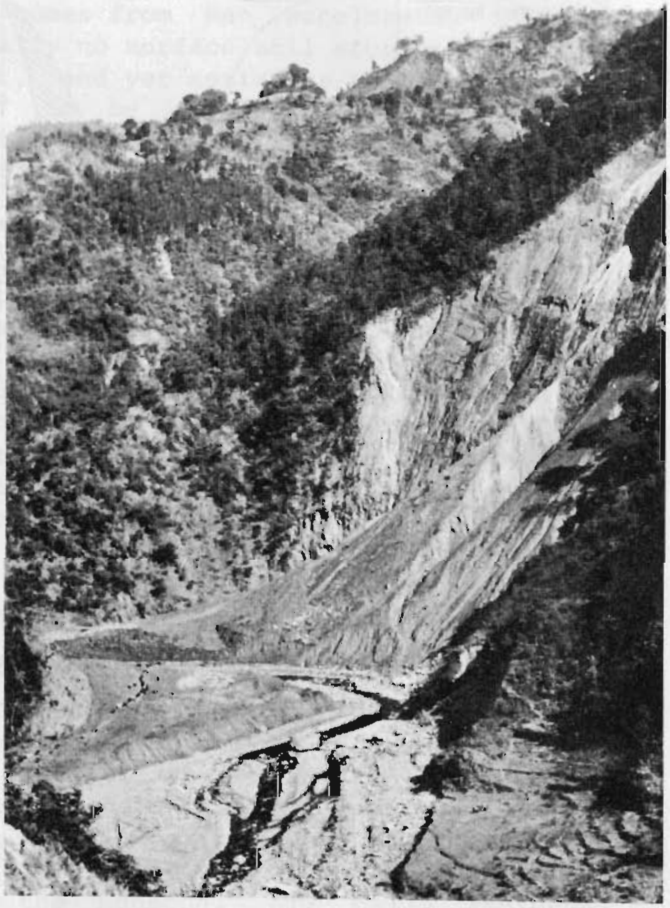


PHOTO VII - Tinnau River, North of Butwal. Palpa District. In Sept. 1981 during a heavy prolonged rainfall, this landslide temporarily blocked the Tinnau River. The break through of this dam resulted in a downstream surge that killed at least two hundred people on the Terai below Butwal.



the stream, that is supplying virtually all the sediment to that river system at that time. Point source sediment contributions, caused by mass wasting, are the major contributors of sediment for many Himalayan Rivers.

1. Measurement Of Sediment Loads In Himalayan Rivers

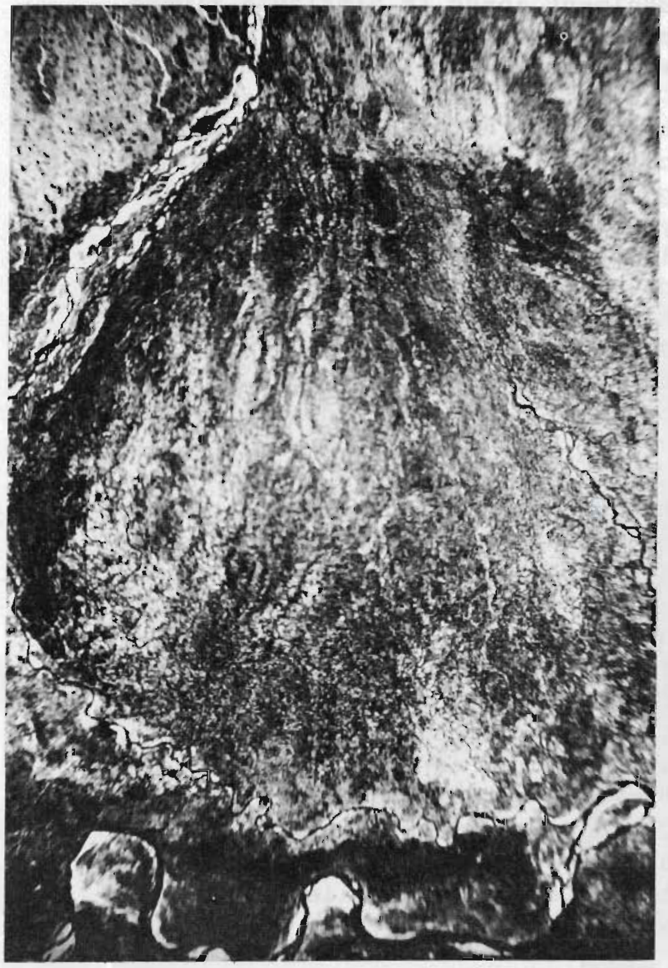
The documentation of sediment loads in Himalayan rivers is a major problem for the researcher. Long term data are absent, peak flows are usually missed during measurement and bedloads are not measured at all. River gauging stations are rare and most of those that exist do not measure sediment loads. A critical peak sediment discharge might easily pass by the river gauging station between scheduled daily measurements. Many of the major flood events result from prolonged rainfall, landslides, and extreme sediment load, resulting in tremendous surges downstream, (See Photo VII.) Sediment loads as high as 25,000 ppm are regularly recorded on major rivers such as the Narayani. One can expect even higher loads on smaller rivers with higher stream gradients and more potential for landslides blocking the whole valley.

The other major limitation with present sedimentation data is that bedloads are not measured but are assumed to be a small portion (10 - 20%) of the suspended sediment load. In mountain rivers, where gravels and boulders dominate the bedload, commonly applied hydraulic formulas cannot properly account for observed bedload movements, especially those resulting from catastrophic glacial dam outburst floods and landslides. (See Photo VIII.) Scour depths of rivers often exceed 5 meters and have been measured as deep as 20 meters. It is obvious that such phenomenal bedload movements must be considered in any hydro project development. Until sediment and bedload data improves, the hydrologist must be aware that sediment budgeting for Nepalese rivers relies on rough estimations rather than precise measurements.

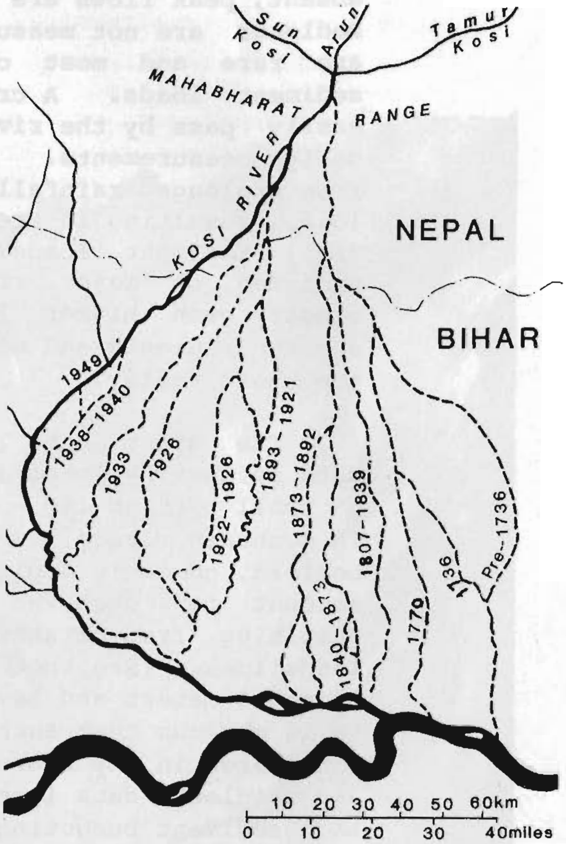
2. Effect Of Deforestation On Terai Flooding

Geographers, citing highly questionable data, have blamed deforestation in the Himalaya for the tremendous floods that occur each year on the Ganges Plain. However, throughout history as described in ancient Vedic tales to the careful chronicles kept during the British Raj, the Ganges appears to have been behaving in exactly the same manner as it behaves today. The extent of Himalayan river action is phenomenal. Drill holes have intersected more than 5,000 meters of alluvial sediments adjacent to the Himalayan foothills. The Sapta Kosi River has moved over 100 km to the west in the past 230 years (see Figure 5), as a result of on going erratic sedimentation. The Nepalese Terai receives on average 1 cm of sediment per year. (See Photo IX.) In order to make appropriate management decisions, one must be aware of the unavoidably high rates

Figure 5 - Shifting of the Kosi River Since 1736
Over the past 250 years, the Kosi has shifted progressively 120 km to the west in more than 12 distinct channels.



Landsat Imagery March 1975
The Kosi River from the Himalayan Foothills to the Ganges.



Previous channels of the Kosi River over the past 250 years.

PHOTO VIII- Tamur River below Wallunchung Gola. Taplejung District. A massive surge, resulting from a glacial dam outburst flood above Yangma caused tremendous damage. At this point, over thirty kilometers downstream, all trees were stripped 20 meter above the river bank. Such events move a tremendous amount of sediment and are often not considered by existing hydrological models.

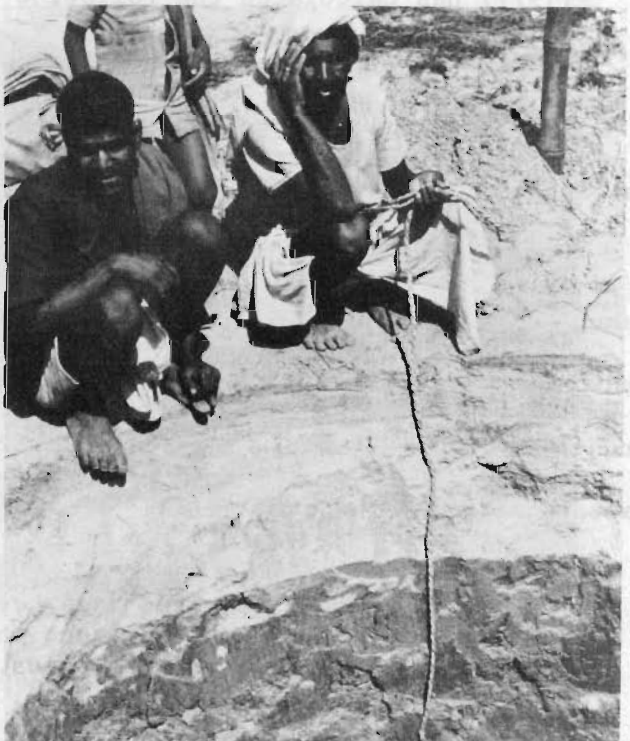


PHOTO IX - Sedimentation on the Terai, Ratu Khola, Mahottarai District. This farmer, in the past 45 years has witnessed the deposition of over two meters of sediment on his farmland. With the rope he indicates the soil he ploughed as a boy. Such rates of sediment deposition result in great hardship for the farmer, but rarely irreversibly destroy the land.

of sedimentation and the erratic flooding common to the Himalayan rivers. One cannot expect markedly different hydrological characteristics of major rivers, no matter what types of soil conservation programmes are carried on in the hills. However, the need for proper soil management is crucial for the future livelihood of the Himalayan villager and it is in this context that valuable soil conservation programmes can be effectively initiated.

3. Regional Denudation, Erosion And Sedimentation

The assessment of erosion and river sedimentation in a mountainous region, such as the Middle Mountains of Nepal, is a complex and difficult undertaking and at every turn the worker is leaving himself open for misinterpretation of the poor quality and incomplete data available. This poor data is often employed in equations and models developed for landscapes that are very different from the Nepal Himalayas. The net result is numbers that are virtually useless at best and possibly misleading in assessing the significance of erosion sedimentation processes. In the following hypothetical example, major gaps in data, and lack of appropriate models to understand the erosion processes become apparent.

One method of estimating the amount of erosion is from regional denudation rates as calculated from sedimentation measurements of major river systems in Nepal. Williams (1977) has calculated the following denudation rates:

Table III Rate of Denudation of Watersheds in Nepal

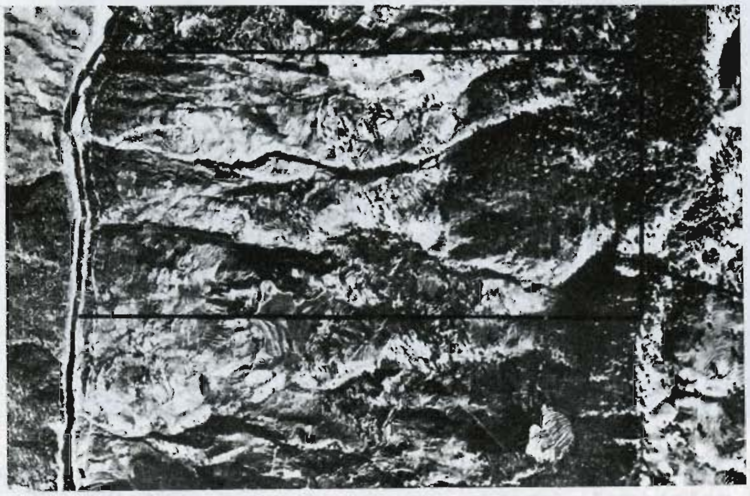
Watershed	Rate of Denudation of Landscape mm/yr	Area of Basin sq. km	Average Sediment Contribution over Watershed t/ha/yr.
Tamur	2.56	5,770	38
Sunkosi	1.43	18,985	21
Arun	0.51	34,525	7.6
Sapta Kosi	1.00	59,280	15

These denudation rates have been cited in international literature on hydrology as among the maximum rates recorded for such large size of watersheds. It is interesting to note that in the Nepalese Himalaya, regional tectonic uplift has been keeping pace with regional denudation. Iwata et al (1984) estimated uplift in the order of 1 mm per year, a figure on par with William's denudation rate for the Sapta Kosi basin.

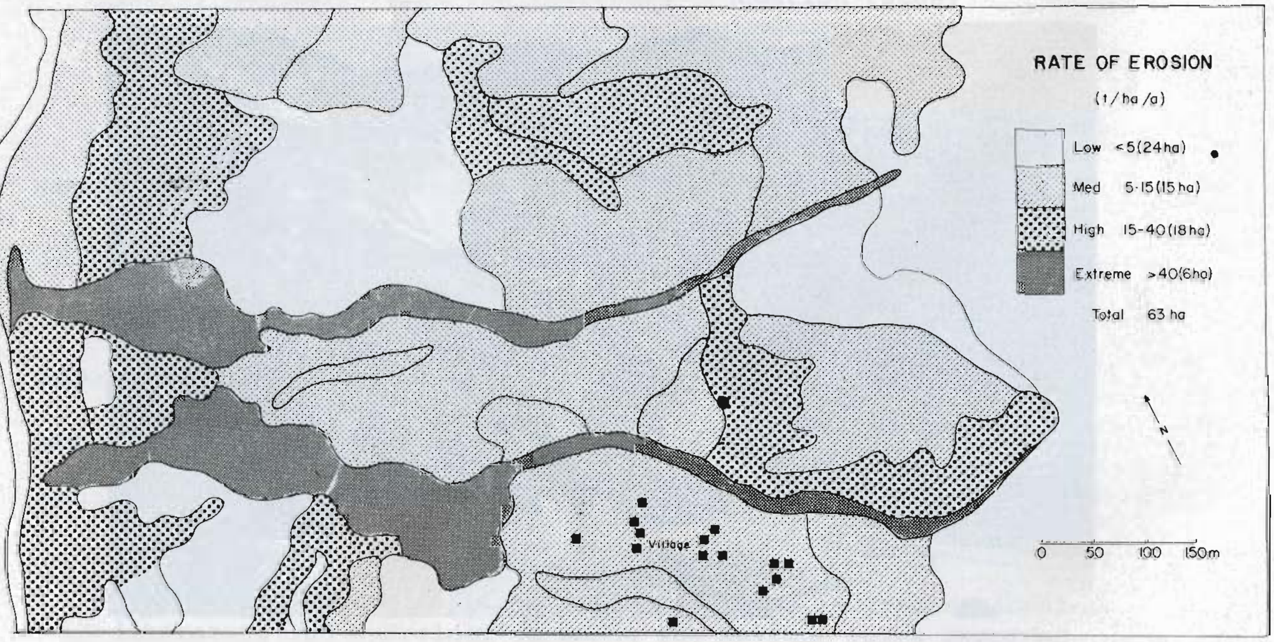
Photo X - South of Jumla, Jumla District (2400 m). Low intensity precipitation and relatively stable convex slopes result in low surface erosion and only minor mass wasting on this High Mountain landscape. Sediment yields from such areas are also relatively low.

PHOTO XI - Andhi Khola - Syangja District (600m) Rugged local relief, unstable slopes and relatively high intensity precipitation result in high surface erosion and mass wasting on this particular Middle Mountain landscape. Consequently sediment yields are very high.

Figure 6 - Aerial photograph of Lohore River Area, Dailekh District



Area interpreted below



Rate of Erosion for 63 ha of watershed based on Aerial Photograph Interpretation. Extreme erosion, largely natural, is experienced adjacent to major drainage ways flowing into Lohore River. Areas of forest and rice cultivation have very low rates of erosion; rainfed land, moderate levels; and grazing, high levels.

If we assume that the Sunkosi is draining an area typical for the Middle Mountains of Nepal, this means that an absolute minimum of 21 tons of unconsolidated material is, on average for the whole basin, leaving each hectare of land each year. Immediately, there is a major unknown, i.e. how much sediment is eroding from a landscape as compared with how much is actually entering the river system. This factor is called the Sediment Delivery Ratio. If 21 tons of unconsolidated material is entering the river from each hectare, the amount actually eroding from the landscape might be considerably larger. There are many sediment traps that recapture temporarily eroded sediment. Trimble (1977) has stated it is unwise to compare regional denudation with present sediment loads of streams, as assigned sediment delivery ratios are unreliable. In world literature, for watersheds of the size of the Sunkosi, generally less than one third of the unconsolidated material eroding from the land actually reaches the river as sediment. However, reliance cannot be put on such world averaged data - it is not appropriate for the Himalayan landscape. Considering the steepness of the terrain, and the amount of mass wasting directly associated with river systems, the sediment delivery ratio is probably much higher.

Another common simplification is that all areas are producing sediment in equal amounts. This is not true for such varied landscapes as found in Nepal with equally varied climates, geology and gemorphology. (See Photos X and XI.) Data such as presented in Table I can be used to get a first approximation of accelerated erosion within a watershed by assigning soil loss values for various land use types*. Taking the example of a typical Middle Mountain slope in Dailekh District, one can develop an erosion profile. In Figure 6 a 1:10,000 aerial photograph and accompanying interpretation is provided. The interpretation and areas of Table IV are taken from these figures.

* Based on the best estimates available in the literature.

TABLE IV Estimated Soil Loss For A Small Watershed

Watershed Area 63ha
Lohore River, Dailekh District (based on photo interpretation of large scale aerial photography)

Land use	Area (ha)	Estimated Soil loss tons/ha/yr	Estimated Total Soil loss tons/yr
Undisturbed forest	10	5	50
Scrub forest, surface protected	7	5	35
Degraded scrub forest	17	15	255
Irrigated bench terraces; good condition	7	2	14
Non irrigated bench terraces; good condition	15	7	105
Abandoned terraces (grazing)	1	20	20
Area of observable mass wasting (scrub)	6	not known	
Total topsoil eroded			440 tons
(Assumed sediment delivery ratio =	0.5)	441 X 0.5 = 220	220
Estimated total sediment reaching stream			220 tons plus mass wasting contribution

Such an estimate has value in directing soil conservation efforts and gives important clues as to the potential contribution of point source sediment. In this case erosion from 6 hectares of land has not been included as it is predominantly mass wasting.

Table II presents the calculations of surface soil loss under various forms of landuse in which an estimated 220 tons has entered the stream from surface soil erosion. Assuming this watershed is typical for the Middle Mountains, then we can also calculate the total sediment contribution of the watershed (based on average watershed sediment loads of 21 tons/ha/yr X 63 ha = 1320 tons/year. It is readily apparent that the Table IV calculation of surface erosion (220 tons/year) represents only a small portion of the total sediment contribution from the watershed to the rivers. The majority of sediment entering the river is a result of mass

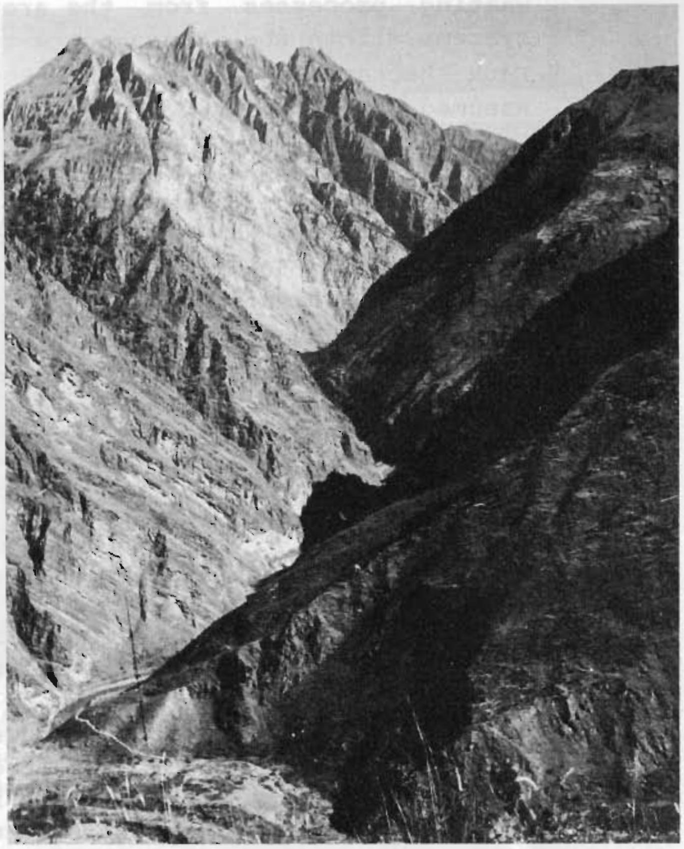


PHOTO XII - North of Tarakot, Dolpa - Arid alpine climate and deep regional river cutting results in a very rugged landscape with average slopes in excess of 45 degrees.

PHOTO XIII - South of Tansen, Palpa, Humid Subtropical Climate and a local absence of river cutting results in the deep chemical weathering of bedrock which produces a rounded convex landscape with average slopes less than 20 degrees.

wasting processes from the area along the two drainage systems within the watershed, a total of 6 hectares of land. Each hectare mapped as undergoing mass wasting can be assumed to be providing over 180 tons of sediment per year. Better management in these drainage areas may only marginally reduce mass wasting processes unless prohibitively expensive engineering techniques are employed. So although these areas are producing the majority of sediment load they may not represent the first priority of soil conservation projects.

4. Erosion Processes And Their Effect On The Landscape

It is interesting to compare landscapes on the south side of the Himalaya, where precipitation averages 2000 mm per year, with those on the north side of the Himalaya, such as in Dolpa, where precipitation averages 200 mm per year. The dry climate of inner Dolpa, combined with the aggressively cutting streams, results in a very steep canyon landscape with average slopes of 45 degrees compared with around 20 degrees for the more humid Middle Mountains. The Dolpa canyons are near their angle of repose for free standing fractured rock, and so rockfalls are the dominant erosion process. In many of those valleys, slopes are so steep that man has not attempted to penetrate them. The lack of slope moisture greatly reduces the weathering of rock and thus the slopes' tendency to fail as slumps or landslides. Similar rock types on the southern side of the Himalayas are subject to aggressively weathering monsoon rains and the deep weathering of rocks is instrumental in reducing the gradient of slopes. (See Photos XII and XIII.)

E. SEDIMENT MANAGEMENT IN PROJECT DESIGN

The preceeding discussions have attempted to show that natural erosion and sedimentation rates are extremely high and management of the land or water resources must accommodate these processes. Man made reservoirs should be designed to facilitate heavy sedimentation. If calculations show that a reservoir will be rapidly filled at present rates of sedimentation, it would be foolish to continue the project assuming that reforestation will greatly extend the reservoir's life. Engineers have often had to work within a vacuum or with poor sedimentation data. Even when preliminary data pointed to serious sedimentation problems, engineers have been slow to change designs originally suited to low sediment rivers. The Chitwan Irrigation Project is such an example. The intake for the pumping station and the pumps themselves at Narayanghat were not designed to operate under the normal high sediment levels of the Narayani River in the monsoon. (See Photo XIV.) Sediment loads in the Narayani gorge, a few kilometers north of the pump intake, regularly exceeded the concentrations that the pump was designed to handle. During three measured storms, sediment discharge on the Narayani exceeded 20,000 ppm. Even with such high sediment loads, no attempts were made to stop the pumps to reduce the disasterous

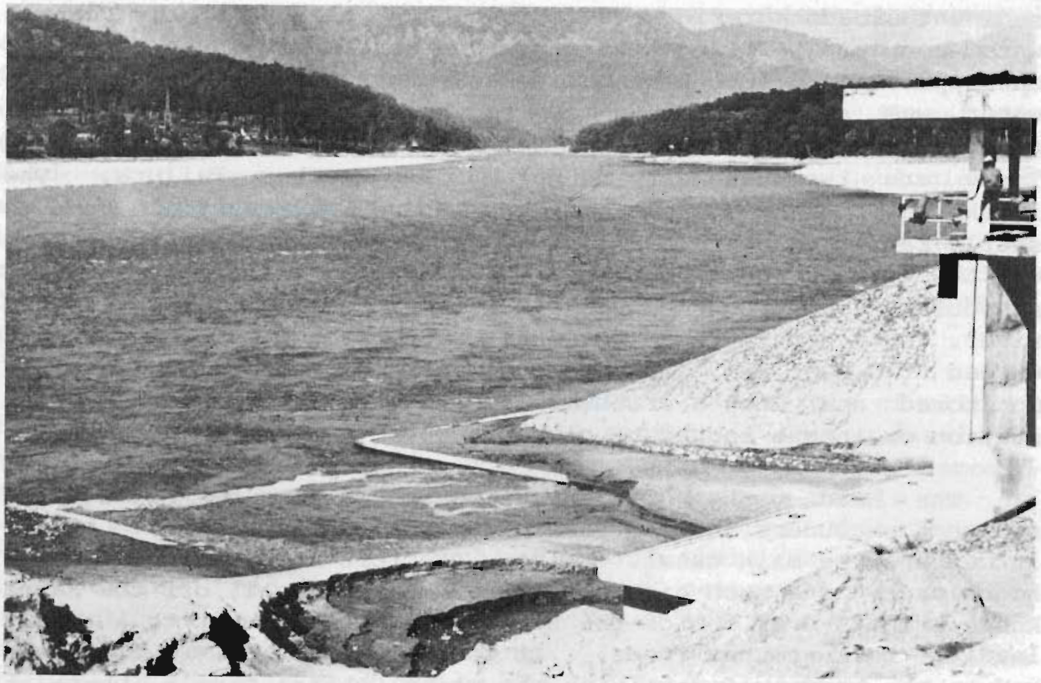


Photo XIV - Narayanghat, Chitwan District - Irrigation intake on Narayani River completely choked with sediment. A better design could have significantly reduced this sedimentation.

Photo XV Narayanghat, Chitwan District - Sediment removal from the main canal, Chitwan Irrigation Project. Over 2.5 meters of fine sand were deposited in this canal during the 1984 monsoon, completely blocking irrigation water flow. Better use of available data could have warned designers of such a hazard.

sediment loads entering the irrigation system. The main canals were completely filled with fine sand after only three months of such operation. (See Photo XV.) Damage was so extensive that no water was supplied to farmers for the 1985 winter irrigation season, only 8 months after the pumping station was opened. There are two lessons to be gained from such a failure. The intake was positioned in a backwater where sediment would tend to settle rather than be carried away by the river and the operators of the pumping station were maintaining inflexible pumping schedules, oblivious of the fluctuating sediment loads in the river. In a country such as Nepal, where sediment loads commonly exceed 10,000 ppm, river sediment concentrations must be monitored and when a critical level is exceeded, the pumping station or intake should be closed down.

The head works of irrigation canals can be built with sediment excluders that by pass a portion of the sediment before it enters the main canal. Also, ejectors in canals can remove high loads. One such ejector on the Chhatra canal, off the Sapta Kosi removes over 50% of the sediment and returns it to a drain leading back to the river. It is hoped that this will help reduce the burden of desilting the major Chhatra Canals, where at present over 200,000 cubic meters of sediment is removed each year. All permanent large scale irrigation projects should include such sediment removal structures as part of a normal design. Their initial cost should quickly be recovered by greatly reduced maintenance costs. Smaller rivers and streams also have severe problems when diversions are constructed because it is very expensive to efficiently divert low discharge levels and at the same time to accommodate the peak flows. The diversion on the Tinnau River for Butwal's hydro plant was badly damaged during the 1981 monsoon. The heavy bedload severely eroded the concrete structures and removed more than 1/2 cm of stainless steel from the hydro turbines for the Butwal Power station. Diversion structure for river hydro and irrigation schemes must be designed to cope with such sediment loads, and these extra costs must be included in original cost estimates.

For small scale irrigation and hydro schemes, with a discharge less than 1 cubic meter per second, engineers might consider building a permanent main canal and intake structure and have a locally built temporary diversion feeding the intake. When river discharge and bedload exceeds a certain level, the temporary diversion is washed out, permitting the flood to pass by the intake relatively harmlessly. Immediately after the flood, the diversion can be remade by local materials and methods and water returned to the canal with minimum disturbance. The problem with permanent diversions is that it is rarely economical to build them to resist periodic peak flows and villagers lack the means to repair damaged concrete structures. Confining rivers improperly can cause them to jump to new channels, a great hardship for the villagers living downstream.

Hill irrigation schemes have even more problems than Terai schemes because, along with diversion and intake instability, there is a constant hazard of failure of main canals as they contour along steep slopes to the command areas. There are several canals in Nepal over 10 kilometers long, that have never held water throughout a full monsoon season. Geologically unstable slopes combined with canal seepage can result in massive slumps and landslides on which it is very difficult to reconstruct a canal. These unstable areas must be well lined or in some cases bridged in order to prevent the disruptive effect of seepage into the slope.

Designers and planners must be aware of the role of silt in hill irrigation schemes. Whereas the sediment clogging canals on the Terai is largely fine or medium sand and can only be removed at great cost, sediment entering hill irrigation canals can be vital to the success of the project. In some areas it is necessary to design steep canal gradients where the downcutting into unlined canals beds can be quite severe. The coarser sediment carried by the irrigation water acts to protect the canal bed and reduce downcutting. Even more important to the farmers is the silt provided by the irrigation water to maintain the fertility of the land. The silt reaching the field generally has a high water holding capacity and contains a high proportion of organic matter. Traditional rice crop yields of one and one half tons per hectare are sustained without significant compost addition based in part on nutrients supplied by irrigation water.

When mountain streams occasionally destroy areas of irrigated land, leaving behind coarse sand and boulders, farmers immediately set about to reclaim their fields (see Photos XVI and XVII.) For this they require heavily sediment laden water, which they channel onto their land. One well timed impoundment can drop 2 or 3 mm of sediment onto the bunded field. Within 2 monsoon seasons, rice can be grown on those once devastated fields. Many of the most productive alluvial fans in Nepal have been at least partly reclaimed from destructive debris torrents.

Flooding and abrupt river channel changes represent an even more serious problem for inhabitants of the alluvial plains of the Himalayas and unfortunately, one with no reasonable long term solution. The Sapta Kosi barrage and training works is presently confining the river to its western bank whereas the nature of the river being that of an alluvial fan, rapid jumps from one channel to the next are normal. A 1980 flood discharge of the Tamur caused by a glacial dam outburst flood resulted in the Kosi changing direction. This caused great concern as the Kosi rapidly eroded the east bank and threatened the Chhatra Canal. Only 200 years ago the Kosi flowed just west of Biratnagar. Given the buildup of the bed of the Kosi River within the barrage works, it is difficult to predict how or if the Kosi can be maintained in its present channel.

Galay (1983) has shown that in Bangladesh attempts to protect alluvial areas from the Khowai River flooding have not

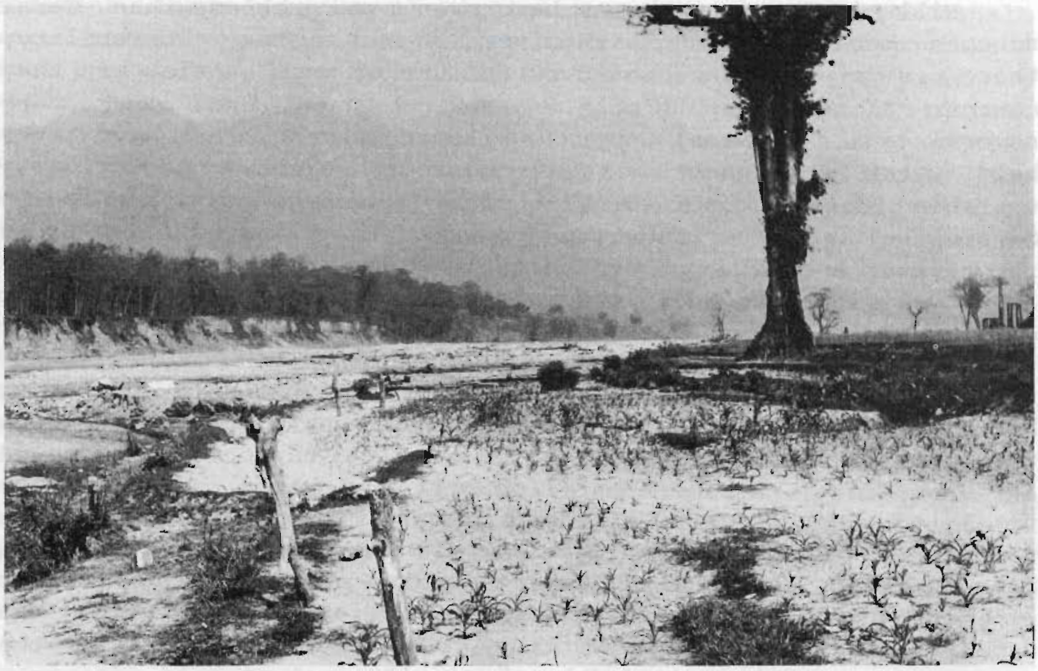


Photo XVI Waebater Village, Marin Khola, Sindhuli District. A long duration rainfall in September 1984 resulted in tremendous flood damage to farmland throughout the Sindhuli District. Here coarse sediment has been deposited on rice fields. This farmer has direct seeded the land with maize and over time it will be reclaimed for irrigated rice.

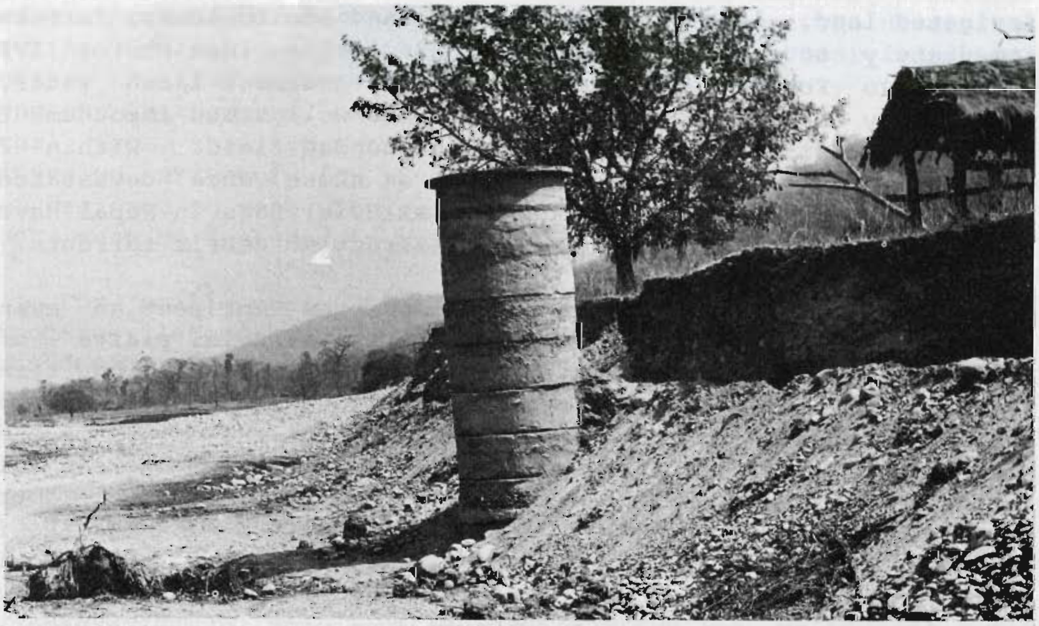


PHOTO XVII - Near Waebater Village, Marin Khola, Sindhuli District. River scouring has exposed 6 rings of this concrete lined well, leaving behind a monument to the fury of the Marin Khola in flood. Throughout the watershed, many river banks were eroded destroying many hectares of farmland.

been too successful. Increases in the height of protection dikes has been quickly matched by rapid sedimentation and higher river bed levels. River flooding is now even more prevalent than before the dikes because the river at bank full stage can accomodate less discharge than before the dikes were built.

Bridges present another engineering problem, as deep scouring and peak discharges of rivers result in high construction costs. Concrete river bed level bridges offer a relatively cheap alternative to conventional bridging. Low flows pass through drainage culverts beneath the structure and the occasional large flood passes harmlessly over the structure, only temporarily closing the road to traffic. Such structures built on the Manohari and Lothar Kholas were still functioning in 1985 in spite of having been abandoned upon completion of the new bridges in 1981.

F. CONCLUSIONS

Erosion processes profoundly affect the economy of Nepal. The Nepalese Government is aware of the serious nature of the erosion problem and has attempted to implement programmes that reduce erosion. The main agency to deal with erosion has been the Department of Soil and Water Conservation within the Ministry of Forests. With their limited budget and narrow scope for activities, the Department of Soil and Water Conservation has had little opportunity to positively influence the overall erosion problems facing Nepal. The lack of a government wide mandate to approach erosion problems on all fronts hampers attempts towards soil conservation. Briefly, the technical solutions offered by the Department of Soil and Water Conservation cannot produce significant results without major policy changes throughout the government. Soil conservationists should be first asking themselves why the land is being so poorly managed. Soil conservation programmes must consider the political, social and economic problems facing the villagers. The technical solutions are generally equally obvious to the villager.

In order to determine realistic goals for a government committed to soil conservation but with a limited budget, the following points should be considered.

1. Soil erosion is probably the most serious resource problem facing Nepal. It should have high priority in government planning and policy making in a number of Ministries.

2. Rainfall induced topsoil erosion is greatly increased by man; better land management could reduce this form of erosion significantly. Mass wasting processes are not usually directly related to man's activities. Consequently, intervention by man to reduce mass wasting can be very expensive with less clear cut results.

3. The most serious surface erosion occurs on marginal agricultural lands and overgrazed agriculture - forest fringe areas. These areas should be the primary targets for soil conservation programmes.

4. The most significant improvements in watershed management generally requires minimal monetary support. By handing over control of communal lands and government forests to responsible panchayats or in other ways increasing local control, tremendous advances are possible. Although a few districts have come a long way in this regard, the majority of districts have seen little real change because of the reluctance or inability of the forest department to transfer authority to the panchayat or other groups.

5. The most important single goal for improving watershed conditions is to improve sustained productivity on a per unit basis. Agricultural, grazing and forest lands can be managed more intensely with increases in production and decreases in erosion.

6. Each watershed will respond in a unique manner to soil conservation measures. Generally speaking, the larger the watershed and the greater the regional river cutting, the less the effect of soil conservation measures on river characteristics. Dam sites planned for major river systems such as the Karnali with a high proportion of erosion as mass wasting cannot expect that soil conservation programs will markedly reduce sediment loads. On the other hand smaller, more isolated watersheds with minimal mass wasting may show significant hydrological improvements from soil conservation measures. Watersheds such as the Kulekhani, may experience significant sediment reductions by integrated soil conservation programmes.

7. Flooding and sedimentation problems in India and Bangladesh are a result of the geomorphic character of the rivers and man's attempts to contain the rivers. Deforestation likely plays a minor, if any role in the major monsoon flood events on the lower Ganges. Better management of existing forest lands and marginal agricultural lands is mandatory however, to ensure the continued livelihood of the Himalayan hill farmer.

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