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

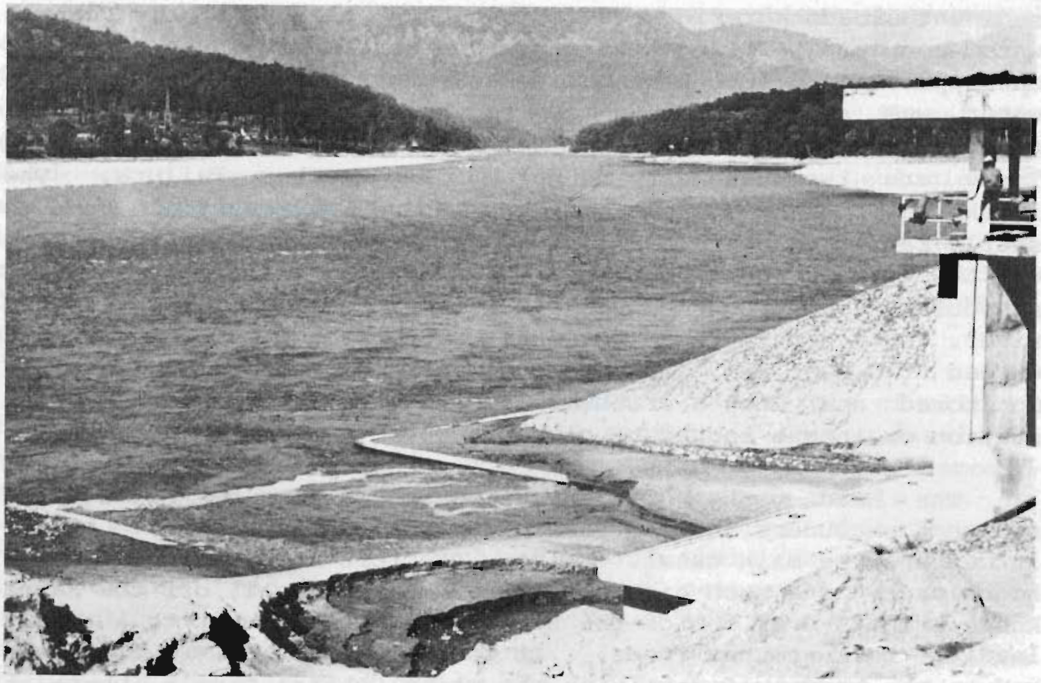

Photo XIV - Narayanghat, Chitwan District - Irrigation intake on Narayani River completely choked with sediment. A better design could have significantly reduced this sedimentation.

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

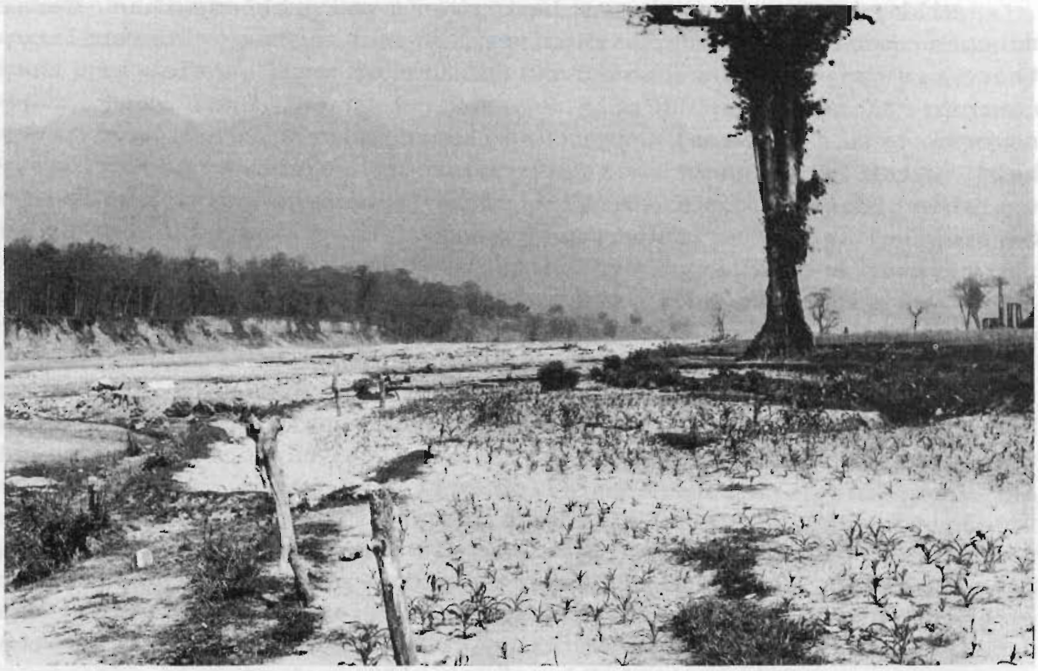

Photo XVI Waebater Village, Marin Khola, Sindhuli District. A long duration rainfall in September 1984 resulted in tremendous flood damage to farmland throughout the Sindhuli District. Here coarse sediment has been deposited on rice fields. This farmer has direct seeded the land with maize and over time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

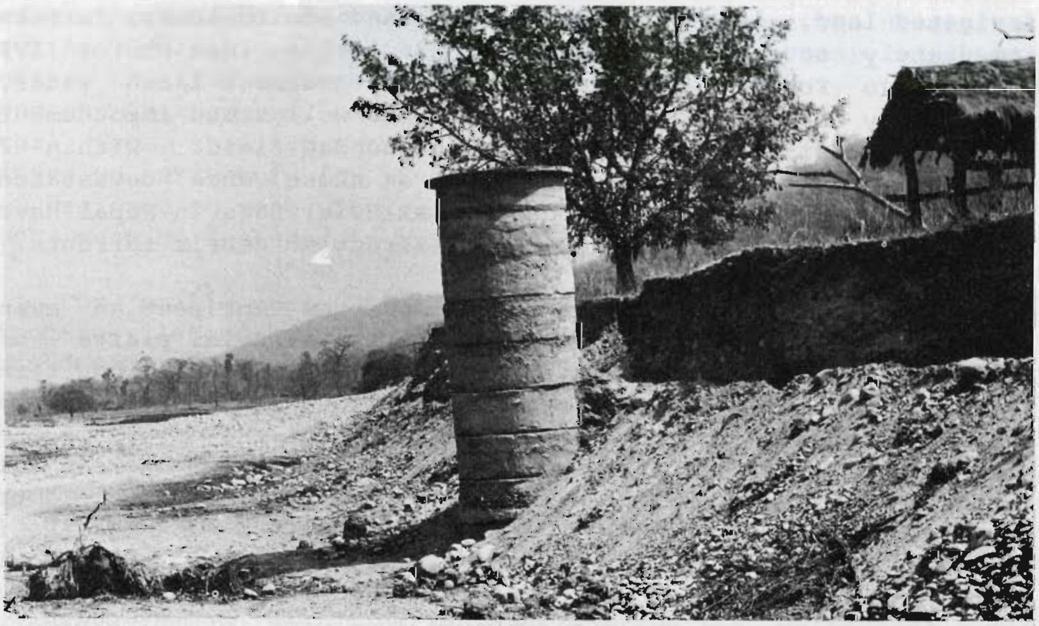

PHOTO XVII - Near Waebater Village, Marin Khola, Sindhuli District. River scouring has exposed 6 rings of this concrete lined well, leaving behind a monument to the fury of the Marin Khola in flood. Throughout the watershed, many river banks were eroded destroying many hectares of farmland.

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.