V CONCLUSIONS

V.1 THE CURRENT SCIENTIFIC CONSENSUS

On the basis of the evidence collated in the preceding chapters, what can we conclude regarding the two questions posed in the introduction, viz. "What is the role of forest and land use in the uplands with respect to flooding, dry-season flows and sedimentation in the plains?", and: "What downstream benefits can be expected in this regard from upland rehabilitation programmes?"

Probably the most important point to be made in this respect, is that one first needs to define the scale for which one's statements are supposed to be valid.

Messerli has proposed a framework, which was summarized by Hamilton (1987) as follows: "at a ***local level***, sediment load is strongly influenced by human activity, stream discharge characteristics much less, and, on the whole, human activity has less impact than natural factors on flooding and siltation within the Himalaya. At the ***medium level*** downstream of the catchment being impacted, we are still uncertain of the quantitative effects of human activity, but the high variability of natural factors dominates both stream discharge and sediment load. At the ***macro level*** in large basins, human impacts in the upper watershed are insignificant on lowland floods, low flows, and sediment, but these effects can be significantly in-fluenced by human activity in the lower reaches of the river".

Much has been made of the "Himalayan uncertainty" surrounding much of the information on which to base our conclusions. Although this may be true for a number of socio-economic issues, we do feel that the material on bio-physical aspects brought together in the present paper does provide one with a clear and consistent picture, which by and large confirms the contention presented in the last paragraph.

Summarizing: vegetation and land-use practices do exert clear influences on amounts (total water yield) and timing (peakflows, dry-season flows) of streamflow in catchment areas of less than 500 km^2 (cf. Tables 7 and 10). The effect tends to disappear as the area under consideration increases (see below).

Conversion of forest land to agricultural uses (grazing, cropping) will lead to increased total water yields as a result of a reduction in evapotranspirational demand of the new vegetation; dry-season flows may in- or decrease following the conversion, depending on the maintenance of infiltration characteristics of the soil; where the latter deteriorate as a result of poor soil management, more or less severe reductions in low flows can be expected, and vice versa.

Reforesting degraded grass- or croplands with fast-growing trees will generally lead to reduced total and dry-season flows, as the associated increase in water consumption will override the effect of improved rainfall infiltration under Himalayan conditions.

As already indicated, the hydrological effects of land-use manipulations tend to be "diluted" as the area under consideration increases. This holds especially for peakflows, generated by heavy rains. Peak discharges may be increased locally due to poor land management in some parts of a basin, the spatial extent of the phenomenon becomes limited by the size of the rainfall field. Although stormflow volumes generally add up in a downstream direction, the effect is moderated by differences in time lag between tributaries and by the desynchronization imposed by spatial and temporal variations in rainfall.

Truly devastating and widespread flooding is usually the result of an equally large field of extreme rainfall (cf. Figure 33), especially when the event occurs at a time when soils have become wetted up thoroughly by antecedent rains, leaving little opportunity to accommodate the extra water. The process is then governed by ***storage*** capacity rather than ***infiltration*** capacity of the soil. Phrased differently, the presence or absence of a forest cover has become almost negligible under such extreme circumstances.

Floods generated by glacial lake outbursts or the failure of temporary landslide dams are in a class of their own; they are particularly damaging as they carry huge amounts of coarse debris; their occurrence is highly unpredictable and unrelated to land-use practices (cf. Plate 17).

Finally, the extent of flooding in the lowlands is also significantly affected by the occurrence of torrential rains in the plains themselves (cf. Figure 13), the discharging of which from fields is often hampered by high groundwater tables and river stages; "backwater" effects near river junctions (cf. Figures 34-36) or river training works (preventing the lateral spreading of the water) are sometimes important in the generation of high water levels as well.

Although the actual magnitude of major floods in the Ganges-Brahmaputra river basin has most probably not increased significantly over time, the associated economic losses have grown dramatically for a number of reasons. Clearly, the two aspects should be kept separately when discussing the severity of flooding in the area.

Rates of surface ("on-site") erosion are strongly controlled by the degree to which the soil surface is exposed to rainfall or disturbed otherwise; therefore, soil losses from non-terraced cropped fields (e.g in the context of shifting cultivation), and from overgrazed grass- and scrubland (trampling) ranked among the highest recorded in the area (Tables 11 and 12).

Although the physical aspects of soil conservation in the Himalaya are well-understood, the application of certain conservation measures (e.g. closure to grazing, construction of inward-sloping bench terraces, mulching of the surface) may meet with problems of acceptance; given the loss of soil productivity associated with surface erosion on the upper parts of hillslopes, conservation is a must, however; reforestation for erosion combatment should only be promoted if all other measures could be expected to fail.

Rehabilitation of gullied lands can generally only be achieved by a combination of mechanical and vegetative measures; reforestation alone is usually not enough to check this form of erosion.

In many parts of the Himalaya, mass wasting in the riparian zone via lowlevel undercutting by incising streams is the dominant mechanism of sediment supply to the streams; in addition, mass movements on the hillsides are dominated volumetrically by a limited number of very large failures, that are usually found in heavily fractured zones with concentrated groundwater flow; these features are purely geological in nature and are not in any way caused by the presence or absence of a forest cover.

In contrast to these deep-seated slides, the occurrence of shallow (less than 3 metres) landslides is strongly influenced by the presence of a deep-rooting vegetation cover; as such, their number can be expected to decrease in due time following reafforestation of overgrazed or otherwise degraded hillslopes; shallow slips are usually not connected with the overall stream network.

In the light of the above considerations, any effects of land rehabilitation programmes will mainly be felt "on-site" in the form of reduced surface erosion and shallow-landslip incidence; in areas where deep-seated slides dominate sediment production (i.e. in most of the Middle Himalaya), the effects will be negligible or minor at best, even at the scale of relatively small catchment areas (see the computations presented in Section IV.2.3)

Where (accelerated) surface erosion is the most important supplier of sediment to streams (Duns, Siwaliks?, Southern Plateau's), significant improvements have been demonstrated following restoration measures (cf. Table 12).

However, the effect of land improvement schemes on basin sediment yield tends to become more difficult to demonstrate as the size of the catchment area increases. This is due to the fact, that the larger a basin, the more numerous the opportunities to (temporarily) store eroded sediment.

The observation, that the sediment load of the Brahmaputra river in the Assam Valley remained influenced for more than twenty years after the area was hit by a severe earthquake (which released large volumes of sediment into various major tributaries), proves this point rather well.

Clearly, the frequently voiced claim that upland reforestation will solve downstream siltation problems does not pertain to the Himalayan situation. Rather, the bulk of the sediment is generated through natural processes, which are beyond the capacity of man to manipulate. In addition, even if it were possible to cut off all sediment supply to the streams as of today, it would take decades, if not centuries, before any reduction in stream sediment loads would be noticed, especially in the lower reaches of the main rivers.

V.2 GAPS IN OUR KNOWLEDGE

Although a number of general trends have been identified regarding the hydrological and erosion effects of changes in land use in the Himalaya, their detailed quantification at the three scales distinguished earlier requires additional work.

For example, we can be relatively confident that reforestation of degraded scrubland with chir pines or eucalypts, will lead to a reduction in streamflow after several years at the local level. We are much less certain, however, of the amounts of water involved.

Peakflows from small catchment areas in the Dun-Siwalik zone have been reported to respond vigorously to changes in land use. Experimental work of this kind in the Middle Mountains, the area for which this kind of information is most needed, is hardly available. In addition, those studies conducted so far, are largely of a black box type, i.e. not supported by process studies, and therefore difficult to extrapolate.

Overgrazing of grass- and scrublands has been shown to be a major contributor to total accelerated (onsite) erosion, but experiments to determine the carrying capacity of Himalayan grazing grounds seem to be lacking.

At another front, a loss of soil fertility has been noticed in parts of the Middle Mountains. Yet, the rate of the decline in productivity is questionable (J. Dunsmore, personal communication), let alone that a detailed nutrient budget analysis of hill farming systems is available.

These are, we feel, a few of the more pressing questions (from the perspective of the physical sciences) with respect to local environmental management problems in the Himalaya, . By their very nature, these questions will need to be addressed at the "micro" scale, but within the various major physiographic zones, so as to ensure their proper positioning within the regional framework.

Naturally, most of this work will need to be of an interdisciplinary nature, and should take full advantage of locally available environmental knowledge. It is suggested, that such research be conducted in a number of carefully selected, well-instrumented catchment areas, which would enable one to use statistically sound techniques for the evaluation of the hydrological effects of changes in land use or management (Figure 44).

In order to separate land-use effects from climatic effects, such studies need to be conducted over a fairly long period of time. However, much can be learned from well-designed short-term process studies (Gilmour et al., 1987), especially when carried out in the context of a catchment experiment (Sklash et al., 1986; Bruijnzeel, 1987).

As we have seen in the preceding chapters, an evaluation of the role of land use in determining streamflow and sedimentation patterns at the meso- and macro-scales, is much more difficult. Not only will there be a variety of land-use types in a single basin, each exerting a specific influence, but also, and arguably more importantly, there will be major variations in the spatial and temporal distribution of rainfall. As such, the issue can hardly be approached experimentally.

Ives et al. (1987) formulated an outline for a research strategy, which aimed at determining the downstream impacts of "perceived" human activity in the mountains. They proposed the selection of several major Himalayan basins for the long-term monitoring of streamflow and sediment patterns, to be linked with a "minimal network of observation stations" in the various physiographic zones. This should in turn be supplemented by a number of "experimental watersheds at different altitudes, and with different slope angles and aspect, vegetation and land-use types", where "routine climatological, hydrological, and geomorphological data should be collected from sites selected to become focal points for a full range of human science research".

However, at the meso- to macro-scales, the "routine collection of basic hydrological and climatic data" has been in operation for decades in the Indian Himalaya (see various reports summarized in Anonymous, 1981a; Sakthivadivel & Raghupathy, 1978; Seth & Datta, 1982; Dhar et al., 1982b). As such, if the problem of highland-lowland interaction is to be approached through time-series analysis of hydrological data, it is obviously advantageous to use data that go back in time as far as possible. Also, it will be much more difficult to distill any (further!) deterioration in river regimes from a recently initiated monitoring programme (cf. Figure 43), as shown by similar attempts in Thailand (Dyhr-Nielsen, 1986) and Southern China (Qian, 1983).

As the sole possessors of such long-term streamflow records in the region, the Indian political and scientific communities have a special responsibility in this respect.

More promising may be the organization of a network of representative (erroneously called "experimental" by Ives et al., 1987; see Simmers, 1984) catchments in the Himalaya. However, such a strategy will only yield meaningful data (i.e. in the context of land-use influences), if it is lifted from the level of routine collection of basic data (as proposed by Ives et al., 1987) to truly experimental work involving actual "treatments" (see Chapter IV.1).

Although it is beyond the scope of the present report to discuss these matters in any detail, it would seem that ICIMOD could play a very useful coordinating role in this respect (Alford, 1988b).