# 5. Towards effective management of landslide risk

There are various complementary methods to manage landslide risk. Typically they are applied at two geographic scales: individual slopes within a subcatchment, and upland landscapes ranging in size from subcatchments to entire river basins.

For individual slopes, the options are the use of plants, including trees and shrubs, to reduce landslide hazards, or mitigating landslide impacts through site reclamation also using trees and shrubs.

At the landscape level, forest-related options include retention, rehabilitation or restoration of forest. The latter two options are referred to as 'protective forestation'. Retention of intact natural and plantation forests in upland areas is the first and best way to protect uplands from landslides.

## 5.1 Protection of landslide-prone landscapes

Control of landslides in upland areas requires an integrated approach. Tree planting alone will not meet the challenge of increasing incidence of landslides and erosion. Landscape-level planning of land use, good land management practices in cropping, grazing and forestry, careful road construction, terracing and other contour-aligned practices in fields and plantations, and participation of local communities are also needed.[8]

Within agricultural and other areas, individual slopes with unstable soils or perched water tables[‡] are best left as forest, or reforested if already cleared, due to the high risk of landsliding. Because landslide hazards are concentrated in critical areas of least stable topography, soil and land use, reforestation of highest risk areas results in disproportionately large reductions in landslide incidence and sediment yield.[12] For instance, it has been calculated that reforestation in the Waipaoa catchment, North Island, New Zealand of just 9.3 percent (159 square kilometres) could decrease the total sediment inputs from landslides by about 20 percent.[160]

‡ Water tables that occur above the regional water table.

A greater diversity of forest species improves slope stability through more complete coverage of available rooting zones. Inclusion of fruit trees or species that provide products without the need for felling can also support socio-economic needs. Protective forestation on severely degraded soils found in many parts of Asia will probably require soil fertility treatment. Planting will also be required in many areas to restore species composition, forest structure and the ecological functions typical of mature natural forests.[33]

## Forestation options

At the landscape level, there are several forestation alternatives depending on local ecology and local socio-economic conditions. The options range from assisted natural regeneration and providing protection that allows forest recovery – as pursued in China under the 'mountain closure' scheme[192] – to intervening directly by planting indigenous and/or exotic species.[152]

Managing upland forests, including planning and implementation of protective forestation activities, is a complex task. Protective forestation is not a one-off 'plant and run' affair; regular tending during the initial stages is of critical importance. In relation, management structures that include local participation from the outset of the planting programme should be implemented.

The International Tropical Timber Organization's *Guidelines for the restoration, management and rehabilitation of degraded and secondary tropical forests* recommend a holistic approach taking into account other local landscape components.[104] The guidelines should help decision-makers to identify strategies that benefit local communities while preserving site-specific ecosystem integrity.[38]

**BOX 5 - Species selection**

On slopes susceptible to landsliding there is a need to select appropriate species for land stabilization. Species characteristics that are effective for erosion control are also desirable for the rehabilitation of landslide areas. In general order of importance, they are:[54,215]

1. Good survival and growth on impoverished sites;
2. Ability to produce a large amount of litter;
3. Strong, deep and wide-spreading root system with dense, numerous fibrous roots;
4. Ease of establishment and need for minimal maintenance;

5. Capacity to form a dense crown and to retain foliage year-round, or at least through the rainy season;
6. Resistance to insects, disease, drought and animal browsing;
7. Good capacity for soil improvement, e.g. high rates of nitrogen-fixation, appreciable nutrient content in the root system;
8. Provision of economic returns or service functions (preferably fairly quickly) such as fruit, nuts, fodder or beverage products;
9. Absence of toxic substances in litter or root residues; and
10. Low invasiveness.

Tolerance to soil infertility, acidic or toxic soils and exposure to desiccating wind and sun is critical. Erosion reduces soil fertility, while high rainfall causes leaching, acidity and sometimes aluminium toxicity. Species known to have exceptional physiological tolerances belong to the genera Acacia, Eucalyptus and Pinus.[55] In Malaysia, *Melastoma malabathricum* and *Leucaena leucocephala* are effective slope stabilizers and have superior resistance to acidity and aluminium toxicity.[135 166,165]

## 5.2 Slope protection and reclamation from landslides

Trees, shrubs and other plants may be used to stabilize landslide-prone slopes as preventative measures.[192,36,85] On slopes that have already failed there is generally a need to control ongoing impacts from the slide, such as sediment release into rivers where fisheries resources may be damaged. There may also be pressure to quickly rehabilitate productive assets, such as forests or agricultural lands. In these cases, reclamation techniques may be appropriate.

### Protecting agricultural landscapes

Deforestation does not always lead to large soil losses from erosion and landsliding; much depends on how the land is subsequently managed.[76] People in upland areas have lived for many years with the risks of landsliding and other erosion hazards. Over time cultivation technologies that minimize risk and reduce degradation of land, such as terracing and agroforestry, have often been implemented. Such innovations, although primarily developed to maintain soil fertility by controlling surface erosion and capturing nutrients and organic matter,[139] can also reduce landsliding in some cases.

Many production systems in the uplands of Asia are characterized by multiple land-use patterns in typically marginal, stressed agricultural ecosystems.[82] These systems range from pure agriculture to production from either planted or natural forests. In between are agroforestry systems, which mix herbaceous and woody plants and in some cases livestock.[132] In numerous and diverse forms, agroforestry includes most of the traditional systems practiced in Asia.[10]

In terms of landslide protection, agricultural systems with a high proportion of trees or shrubs may provide increased root density to reinforce the soil mantle. Generally, systems mimicking natural forest with respect to plant diversity and multilayered structure above and below ground will provide the greatest landslide protection.

### *Shifting cultivation transitions*

Shifting cultivation periodically opens a window of susceptibility to landslides when patches of forest are cleared for cropping. Depending on how quickly roots decay and new woody vegetation re-establishes, this period may last from three to more than 20 years. Forest regeneration after abandonment of shifting cultivation sites may be slower than after logging as a result of nutrient depletion resulting from burning and crop production.[183] In cases of severe surface erosion and nutrient depletion, vegetation more suited to drier and more fire-prone environments such as grassland may develop. In the case of Imperata (*Imperata cylidrica*) grasslands in Southeast Asia, frequent burning prevents re-establishment of forest.[53] While such grasslands may provide some protection from landslides, Imperata grasses are of little use to farmers and rehabilitation may be achieved through assisted natural regeneration of forests including fire suppression, restrictions on grazing or establishment of agroforestry.

### *Agroforestry*

Much of the impetus behind current agroforestry development in tropical uplands has been to help stabilize shifting cultivation and related land degradation.[156,73,10] Attempts to provide alternative cultivation systems in the mountain areas of Yunnan[216], and rehabilitate abandoned fields colonized by Imperata grass in the Philippines and Indonesia through 'agroforestation[69,199] are two examples.

Surface erosion, gullying and landsliding can be mitigated by incorporation of rows of contour-planted trees, which help level the slope between rows over long periods of time.[203,215] Among the Ikalahan people of the northern Philippines, former shifting cultivators now plant rows of nitrogen-fixing trees 5-20 metres apart depending on the gradient.[9] On the steepest slopes, Sloping Agricultural Land Technology (SALT) guidelines suggest spacings of 3-5 metres.[144] While planting crops along the contour without alternating pasture or rows of woody vegetation can cut soil losses by half, incorporating trees can reduce losses by 90 percent.[14] SALT design also includes the use of diversion ditches to prevent water runoff from flowing onto the slope.[31]

Although conversion of forest to agroforest makes hill slopes more susceptible to landsliding,[182] the ultimate effect depends on the type of system established. If there is sufficient density of trees or shrubs, slope stability may not be significantly altered. Some systems such as home gardens, multilayer tree gardens[128] and some types of forest farming[47] will likely have levels of protection close to that of forests, once mature. However, if systems are associated with roads and terraces, as is the case of coffee and tea plantations, susceptibility to landsliding will rise, as seen in Darjeeling, India[188] and Tanzania.[91]

## *Forest farming*

Within agricultural landscapes, slopes susceptible to landsliding (steep areas, depressions and other areas of water convergence, and areas close to valley heads) are generally left under forest cover when land is not scarce. With increasing demand for land, these areas are increasingly being developed, leading to higher rates of landsliding and erosion.

One possible solution may be improved forest farming. The production of food, forage and other products from the forest without cropping has been practiced in natural and semi-natural tropical forests for millennia. A good example is the Kalahan Forest Reserve in Northern Luzon in the Philippines.[52] Newer management systems, termed 'closed-canopy high-diversity forest farming systems', are being employed in the Leyte Islands, Philippines as a means to replace environmentally destructive forms of land use between the lowland areas and the protected mountain forests.[129,80,175]

Gallery forests along inland valleys, where landslide susceptibility is greater and where forest farming would be most suited[47,83] are also favoured for irrigated rice production.[130] In these situations, terraced systems may have slope stability capacity comparable to forest but slope degradation can occur at a greatly accelerated rate if terraces are not maintained, as has been documented in Nepal.[29]

### *Land-use rationalization*

Rationalization of land use according to productive capacities and biophysical constraints is necessary to avoid or reduce landslide risk while maintaining production where possible. In this context, Barker (1984) made the following recommendations:

> "… continuous annual crop production in level, high-productivity areas; use pastures and production-oriented agroforestry on gently sloping land and agroforestry systems more closely resembling the native forest on steeper slopes; and leave undisturbed forest cover on extremely erosion-prone soil and watersheds."[9]

Land evaluation guidelines have been produced for different purposes including rainfed agriculture, irrigated agriculture, extensive grazing and forestry.[57,58,59,61,64] Because top-down approaches are not always successful, participatory approaches including farming systems analysis have also been introduced.[60,62] These have resulted in methods and applications for ecosystems and landscape analysis in agroforestry [164,157] and the Land Use Planning And Analysis Systems (LUPAS) methodology[98] which are suitable for resolving land-use conflicts in upland areas.

## Reclamation of landslide scars

Following landslides, timely stabilization of affected sites can help reduce sedimentation of streams, prevent further landslides and mudflows, and re-establish livelihoods of local communities. In the Sanko catchment in Central Japan, sedimentation from some landslides has continued for 45 years.[100] Usually because of the expense and difficulty of reclaiming land only the most essential slopes are considered for reclamation.

Appropriate techniques depend on the soil and slopes must also be sufficiently stable if slope stabilization work is to be carried out. Soil biomass takes time to redevelop and different species may be more suited to new conditions than those previously present.[185]

Due to poor soil and exposure to desiccating sun and wind, plus the need for rapid revegetation, the range of tree, shrub and other plant species available for reclamation work is limited. Typically these are exotic species, but research into native species known to possess the necessary attributes for reclamation purposes is developing in some countries.

Rapid, successful reforestation with larger seedlings shortens the period without vegetative cover or root reinforcement and higher seedling densities may result in more rapid canopy development and root recovery. Although individual species play an important role, higher levels of plant diversity generally associated with natural regeneration, may increase slope stability above that offered by single species and even age plantings.[74]

In addition to ecological factors, a range of other issues is also of importance in rehabilitation following landslides including the economic and social benefits of trees in comparison with other vegetation types or engineered ground stabilization measures. Land tenure and regulatory conditions prevailing in the target area are also of importance in determining the suitability of different slope stabilization options.

### *Vegetation establishment*

Because larger/older seedlings are best for successful establishment, reclamation may be expensive. Compared to conventional engineering solutions, however, planting of trees and shrubs is generally the most economical means to reclaim landslide scars. However, without additional erosion control measures, tree planting on eroding slopes stands a high chance of failure. Slopes where vegetation has been stripped are highly erodible, particularly during the rainy season. Therefore, it is crucial that some form of physical barriers be erected to prevent soil movement so that roots are given a chance to anchor.

Tree planting usually requires site preparation including terracing, contour trenching or bund construction. Rehabilitation of the denuded Swat River catchment in Pakistan illustrates that planting chir pine (*Pinus roxburghii*) mixed with broadleaved tree species and also constructing stone check dams is effective in reducing surface runoff and soil erosion compared to tree planting alone.[8] Controlling soil movement is particularly important in mountain regions where torrents are frequent and cause both direct soil erosion and soil saturation, which increase landslide risk.

### *Natural regeneration versus planting*

The choice between natural regeneration of vegetation or tree and shrub planting is likely to depend on the degree of disturbance, the total landslide-affected area, the proximity to potential colonizing vegetation and the urgency with which the land needs to be stabilized. Where quick stabilization is not urgent, assisted natural regeneration may be best and in many parts of Asia, high rates of rainfall and weathering promote rapid natural regrowth.[181,70,34] These factors also increase susceptibility to surface erosion and landsliding, however, which makes reclamation more difficult.

> "Promotion of the recovery of self-sustaining [plant] communities on landslides is feasible by stabilization with native ground cover, applications of nutrient amendments, facilitation of dispersal to overcome establishment bottlenecks, emphasis on functionally redundant species and promotion of connectivity with the adjacent landscape."[206]

If infertile subsoils are exposed or the distance to natural seed sources is great, or where the need to stabilize land is urgent, planting may be necessary. Tree and shrub species suitable for land stabilization will differ from those used for forest rehabilitation. Characteristics outlined in Box 5 also apply but species robustness is of greater importance. Because of the difficulty in establishing vegetation on inhospitable sites, proven exotic species are usually used. Testing of native species is, however, being carried out in countries including China, Thailand and India and new possibilities may become available.

In general, nitrogen-fixing species have been used successfully as many can tolerate the harsh environment and nutrient-deficient substrates that are typical of landslide scars. For example, a study of trees planted on mining waste in India found that acacias are superior to eucalypts in improving the soil.[154]

## 5.3 Identification and monitoring of landslide hazards

Because many Asian countries are geologically and geomorphologically active and socio-economic conditions may be poor, levels of vulnerability are often high.[2] Poor populations in marginal areas are especially at risk and vulnerability is increased by rapid and uncontrolled expansion of industry, agriculture and settlements in landslide-prone areas. Consequently, there is a need to develop programmes to minimize risks associated with landslides. Strategies to manage landslide risk need to be based around scientific data collection including maintenance of an up-to-date landslide inventory, permanent monitoring of natural processes, research on natural phenomena and geomorphological mapping.[97] Developing risk mitigation options and planning their implementation is the next logical step, followed by monitoring to facilitate programme improvement.

Zoning of potential landslide areas according to risk, together with regulations excluding some activities and requiring geological evaluation for others, are the most common measures for mitigating landslide risk. Zoning backed by regulation is a fundamental component of disaster management and an important basis for promoting safe human occupation and infrastructure development in landslide-prone regions.

Remote sensing for continuous monitoring of landslide-prone areas and information systems for decision support are becoming increasingly sophisticated. GIS-based systems are of great practical use in assessing landslide susceptibility, hazard and risk, and in supporting land management decisions to reduce vulnerability. Even in countries with limited financial, technical and data resources, such systems are proving to be cost-effective and well suited to such purposes.[7]

Maps are the primary tools for decision support and can be used to delineate zones of varying landslide susceptibility, hazard or risk. Susceptibility mapping aims to differentiate land into areas according to stability threshold estimates.[201] Based on the susceptibility map, hazard maps identify slopes where there is potential for causing negative impacts with respect to 'elements at risk' (people, buildings, engineering works, economic activities, public services, utilities, infrastructure and environmental features). Risk maps attach probabilities and economic and social costs associated with such consequences. These exercises rely on understanding mass movement processes and require high quality data.

The ability to accurately predict landslides is of great importance if hazard assessments and zoning regulations are to prove useful. The accuracy of current hazard assessments is reasonably good in Asian countries where landslide risk is being studied. Verification of model results against inventories of actual landslides showed accuracies in the range of 70 to 90 percent, depending on the type of model used and how well it represents a particular geological setting.[137,138,153,35]