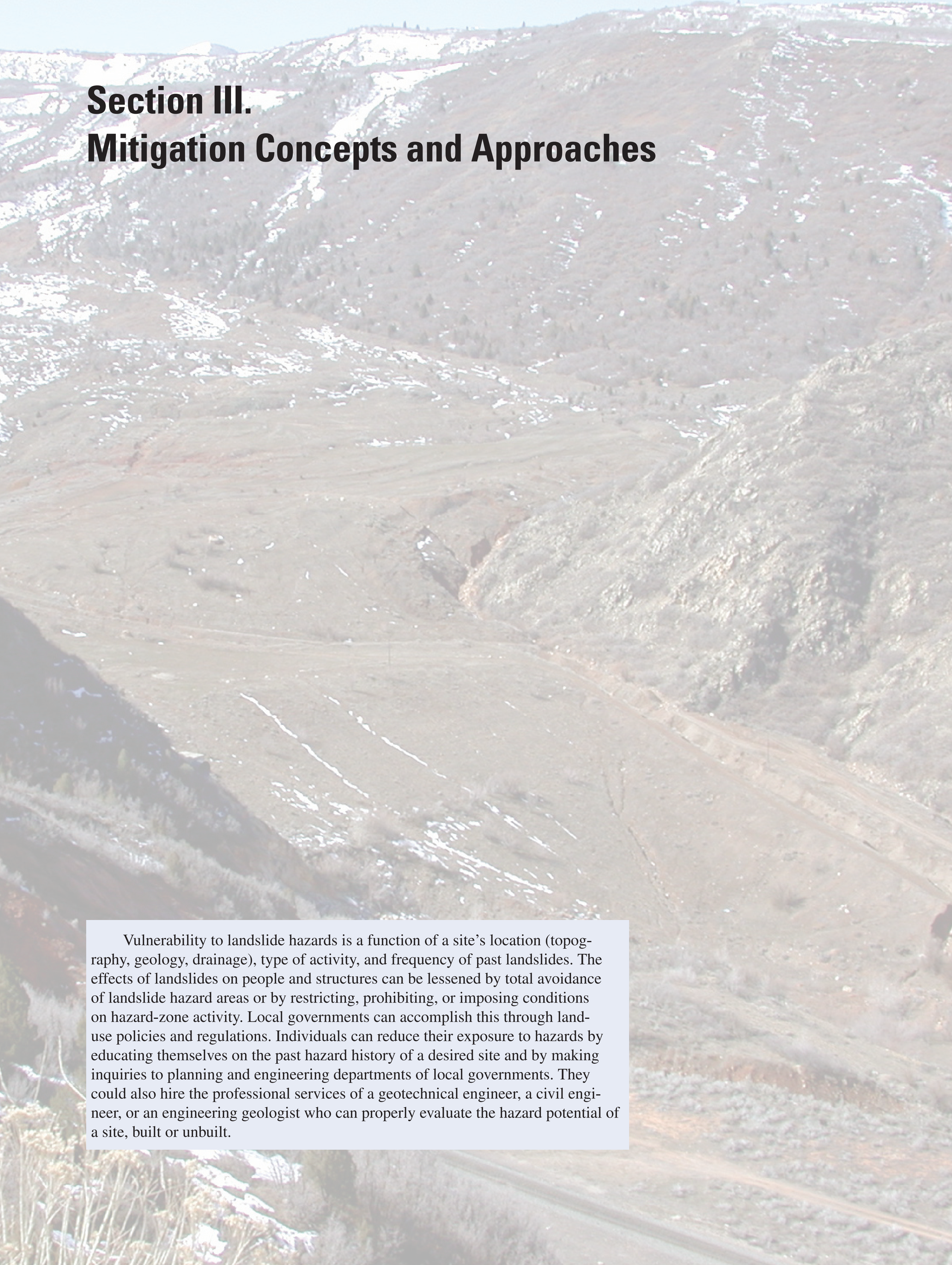

# Section III. Mitigation Concepts and Approaches

Vulnerability to landslide hazards is a function of a site's location (topography, geology, drainage), type of activity, and frequency of past landslides. The effects of landslides on people and structures can be lessened by total avoidance of landslide hazard areas or by restricting, prohibiting, or imposing conditions on hazard-zone activity. Local governments can accomplish this through land-use policies and regulations. Individuals can reduce their exposure to hazards by educating themselves on the past hazard history of a desired site and by making inquiries to planning and engineering departments of local governments. They could also hire the professional services of a geotechnical engineer, a civil engineer, or an engineering geologist who can properly evaluate the hazard potential of a site, built or unbuilt.

# *Part A.* Overview of Mitigation Methods for Various Types of Landslide Hazards

Seeking the advice of professionals is always advised where possible, but managers and homeowners should be educated about mitigation in order to make informed decisions concerning construction and land use. A few of these measures are discussed in this section. More detailed information on landslide mitigation is available in Appendix C and in Turner and Schuster (1996) ( Reference 39).

The simplest means of dealing with landslide hazards is to avoid construction on steep slopes and existing landslides; however, this is not always practical. Regulating land use and development to ensure that construction does not reduce slope stability is another approach. Avoidance and regulation rely on landslide maps and the underlying definitions of landslide areas to reduce hazard (Appendix B). In cases where landslides affect existing structures or cannot be avoided, physical controls can be used. In some cases, monitoring and warning systems (Appendix B) allow residents to evacuate temporarily during times when the probability of landslide activity is high.

## Soil Slope Stabilization

Stability increases when ground water is prevented from rising in the slide mass by

- directing surface water away from the landslide,
- draining ground water away from the landslide to reduce the potential for a rise in ground-water level,
- covering the landslide with an impermeable membrane, and (or)
- minimizing surface irrigation. Slope stability is also increased when weight or retaining structures are placed at the toe of the landslide or when mass (weight) is removed from the head of the slope.

Planting or encouraging natural growth of vegetation can also be an effective means of slope stabilization—this is further discussed in the section on biotechnical mitigation methods and Appendix C.

An example of one means of slope stabilization is the use of retaining walls. Retaining walls are structures built to support a soil mass permanently. They also are used whenever space requirements make it impractical to slope the side of an excavation, or to prevent sloughing of loose hillslope soils onto roads or property. Retaining walls are also used to prevent or minimize toe erosion by river scour or to retard creep. They cannot, however, be used to stop landslides from occurring. Several basic types of wall are timber crib, steel bin, pile, cantilever, sheet pile, plastic mesh, and reinforced earth. Each of these types has advantages in certain situations, but cost is usually what determines which is type is adopted. More information about retaining walls is given in Appendix C.

See Appendix C for more information on stabilization methods.

## Rockfall Hazard Mitigation

Rockfall is common in areas of the world with steep rock slopes and cliffs. Commonly, these are mountainous or plateau areas, whether in coastal areas or among isolated rock formations. Rockfall causes extraordinary amounts of monetary damage and death, the former mostly by impeded transportation and commerce due to blocked highways and waterways and the latter as direct casualties from falling rocks. Diverting paths and highways around rockfall areas is sometimes implemented but is not always practical. Many communities post danger signs around areas of high rockfall hazard. Some methods of rockfall hazard mitigation include catch ditches, benches, scaling and trimming, cable and mesh, shotcrete, anchors, bolts, dowels, and controlled blasting.

See Appendix C for more information on mitigation means for preventing and diverting rockfall.

## Debris-Flow Hazard Mitigation

Due to the speed and intensity of most debris flows, they are very hard to stop once they have started. However, methods are available to contain and deflect debris flows primarily through the use of retaining walls and debris-flow basins. Other mitigation methods include modifying slopes (preventing them from being vulnerable to debris-flow initiation through the use of erosion control), revegetation, and the prevention of wildfires, which are known to intensify debris flows on steep slopes.

See Appendix C for more information on methods for debris-flow hazard mitigation.

## Landslide Dam Mitigation

Many problems arise when landslides dam waterways. Dams caused by landslides are a common problem in many areas of the world. Landslides can occur on the valley walls of streams and rivers. If enough displaced material (rock, soil, and (or) debris) fills the waterway, the landslide will act as a natural dam, blocking the flow of the river and creating flooding upstream. As these natural dams are frequently composed of loose, unconsolidated material, they commonly are inherently weak and are soon overtopped and fail due to erosion. When breaching happens quickly, the backed-up water rushes down the waterway, potentially causing catastrophic downstream flooding. An example of a landslide dam is the 600-meter-high Usoi landslide dam in Tajikistan, one of the largest landslide dams in the world. A large earthquake-induced landslide dammed the Murghab River, creating Lake Sarez. The dam poses a hazard for people living downstream. Also, future seismic action may cause more landslides to slide into the dammed lake, causing a seiche (a tsunami-like wave in a closed water basin), which may weaken and (or) overtop the landslide dam. Figure 42 shows a landslide dam caused by the sliding of saturated slopes, and figure 43 shows a landslide dam caused by an earthquake.

See Appendix C for more details on mitigation methods for landslide dams.

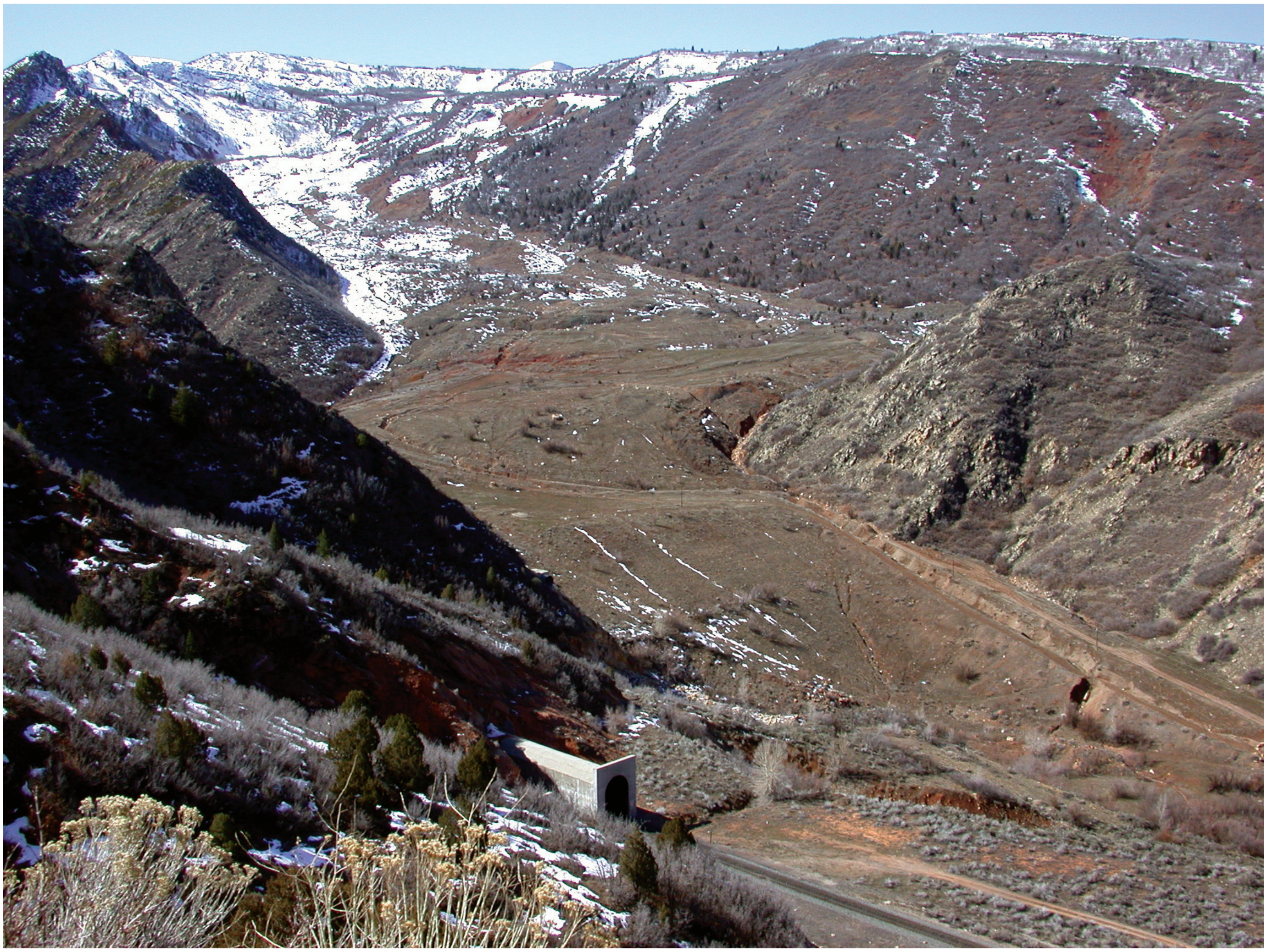

**Figure 42.** The Thistle landslide in Utah, USA. This 1983 landslide dammed the Spanish Fork River, backing up water that flooded the town of Thistle. Many landslide dams are much smaller than the one shown here and potentially can be overtopped by backed-up water, or eroded through. Some are much larger, and roads and railroad lines that are blocked or damaged must be diverted around the landslide mass. The concrete tunnel at the lower part of the bottom photograph shows where the rail line was rerouted around the Thistle slide and excavated through an adjacent mountain.

**Figure 43.** The great earthquake that struck China on May 12, 2008, caused extensive damage in the mountainous terrain of Beichuan County. In many cases, landslides in steep valleys formed landslide dams, creating new lakes in a period of hours. This pair of high-resolution, photo-like images from Taiwan's Formosat-2 satellite on May 14, 2006 (top), and May 14, 2008 (bottom), before and after the earthquake, show the large landslide that blocked the Jiangjian River, forming a dangerous landslide-dammed lake.

## Methods of Biotechnical Landslide Mitigation

This type of slope protection is used to reduce the adverse environmental consequences of landslide-mitigation measures. When used for landslide remediation or mitigation, conventional earth-retaining structures made of steel or concrete usually are not visually pleasing or environmentally friendly. These traditional "hard" remedial measures are increasingly being supplanted by vegetated composite soil/structure bodies that are environmentally more friendly; that is, a process that has come to be known as biotechnical slope protection. Common biotechnical systems include nets of various materials anchored by soil nails that hold in place soil seeded with grass. Research has been done on using plants to stabilize soil to prevent excessive erosion and also to mitigate the effect of landslides. One of the most promising types of plants is Vetiver, a type of grass that works very well to stabilize slopes against erosion in many different environments. See Appendix C for more information on Vetiver grass uses and its geographical suitability.

See Appendix C for more information on mitigation techniques.

## *Part B.* Simple Mitigation Techniques for Home and Businesses, Managers, and Citizens

There are simple and low-technology means for homeowners and others to implement methods and techniques that are effective and lessen the effects of landslides. First, it is always best to consult a professional, such as a geotechnical engineer or a civil engineer, as they have had the training and experience to solve instability problems; a local company or professional may be the best, as they may be familiar with the geology, soil types, and geography of the area in question. This is not always the case, but it is a basis for making inquiries. When there are local jurisdictions such as county and (or) city municipal offices, individuals within these institutions may be professional geologists, planners, and (or) building experts who can answer questions, provide maps, and explain building regulations and inspection procedures. Access to these types of officials varies widely around the world, and local situations may be handled differently. When consulting a professional is not possible, some steps can be taken in the meantime, as detailed in Appendixes C and D.

*For further reading:*
*References 4, 8, 11, 19, 20, 28, 30, 31, 32, and 37*

See Appendixes C and D for detailed information on mitigation techniques for property owners, citizens, and managers.

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