FIGURE 1.8 Aerial view of destruction of the Trans-Ecuadorian oil pipeline and adjacent highway by a debris flow issuing from a minor tributary of the Coca River. Location is near mouth of the Reventador River.

affected by landsliding were denuded (Pain, 1972). The soil debris and its cover of vegetation flowed off the slopes into drainage channels. Similarly, in 1976, two shallow earthquakes (M=6.7 and M=7.0) struck the sparsely populated SE coast of Panama, causing huge areas of landsliding. Garwood et al. (1979) calculated that the slides denuded approximately 54 km^2 (12 percent of the affected region of 450 km^2). Although the M=9.2 earthquake that struck southern Chile in May 1960 occurred in an area of temperate forest rather than in tropical jungle, it caused slope failures in the Valdivian Andes similar to those in Papua New Guinea and Panama. Veblen and Ashton (1978) estimated that more than 250 km^2 of forest slopes were denuded by mass wasting in the 1960 event.

Given the size of the mass-wasting catastrophe in the Reventador area, damage caused by direct impact of deep-seated slides or slumps was secondary to that caused by thin slips, avalanches, flows, and floods. Although individual slides did some damage to the Trans-Ecuadorian pipeline (Figure 1.8), roads, and structures, the greatest destruction of property was caused by flood surges in the main rivers (Figure 1.9). Because of antecedent precipitation, the rivers were near flood stage before the earthquakes occurred, so that the large volumes of landslide debris that flowed into the

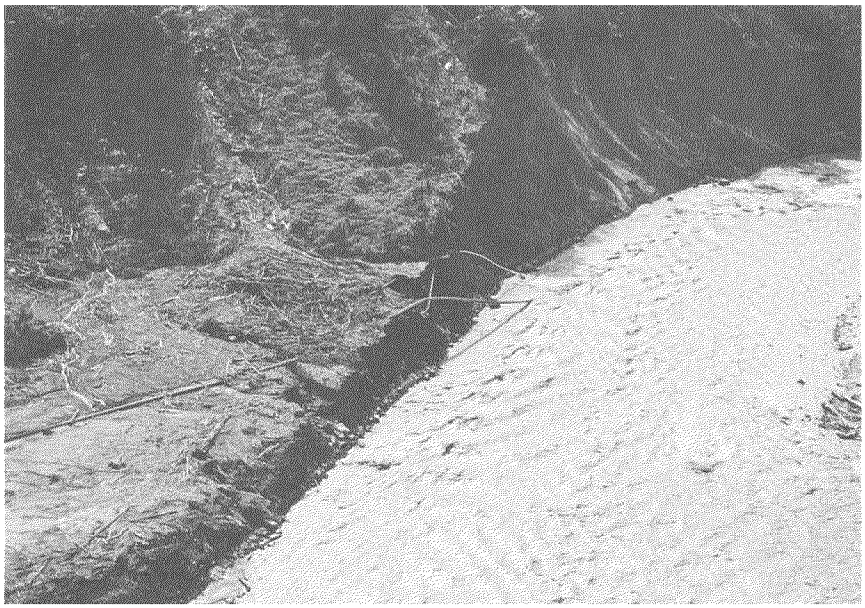

FIGURE 1.9 Destruction of Trans-Ecuadorian oil pipeline and highway by flood erosion on the left bank of the Coca River as a result of the March 5, 1987, earthquakes.

valleys further raised the river stages (Nieto and Schuster, 1988). It is likely that the highest flood surges were caused by breaching of short-lived dams on tributaries carrying large sediment loads, by large debris flows moving directly off valley walls, or by debris blockages at narrow constrictions of the river channels (Figure 1.10).

In summary, interrelated multiple hazards produced the catastrophic events of March 5, 1987, in the Reventador area. The tragic occurrence of two large earthquakes within 3 hr in an area of heavy antecedent rainfall, and steep slopes covered by unstable volcanic and residual soils with high water contents, resulted in massive slope failures of high fluidity. The large volumes of these slope failures and the breaching of the resulting ephemeral debris dams caused the flood surges that were responsible for most of the damage.