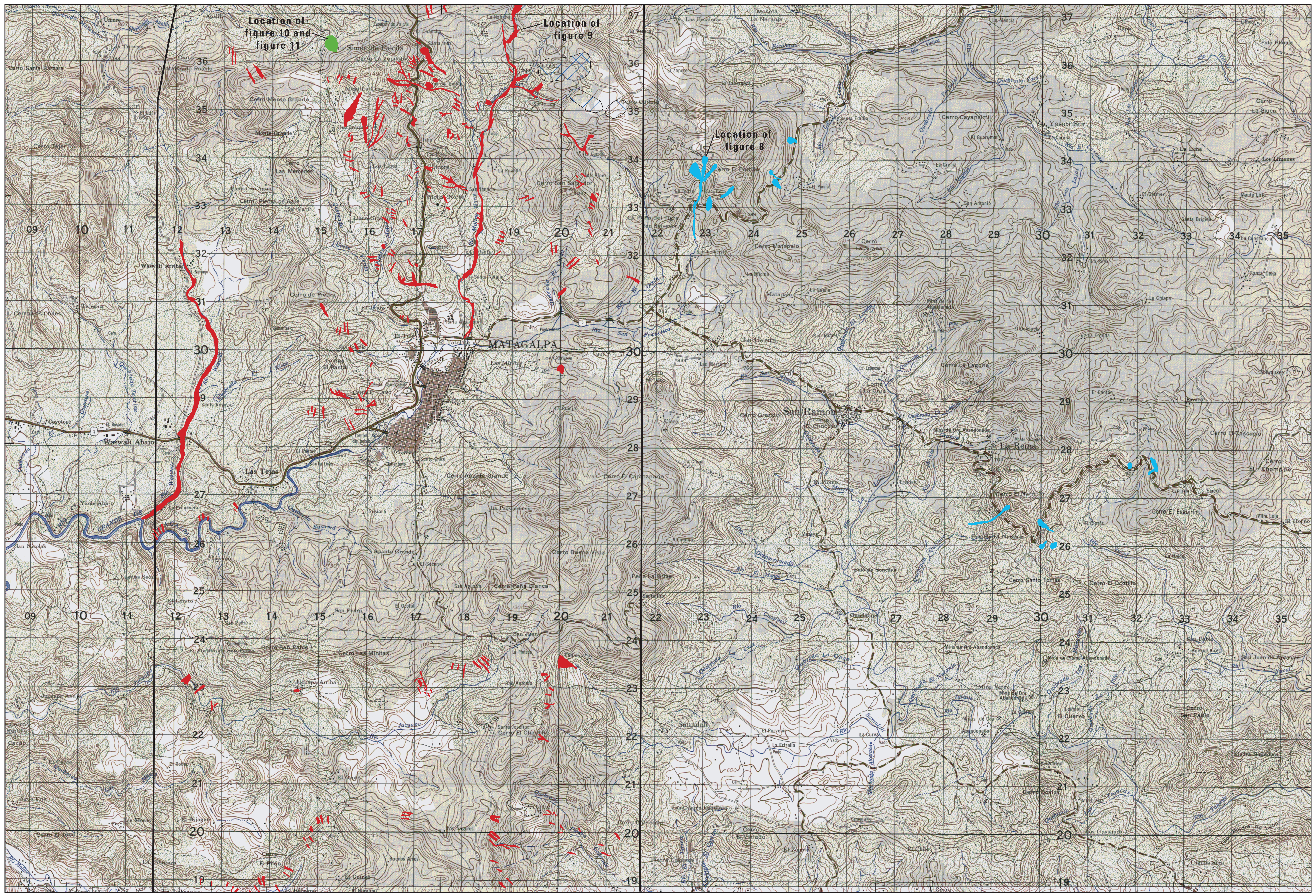
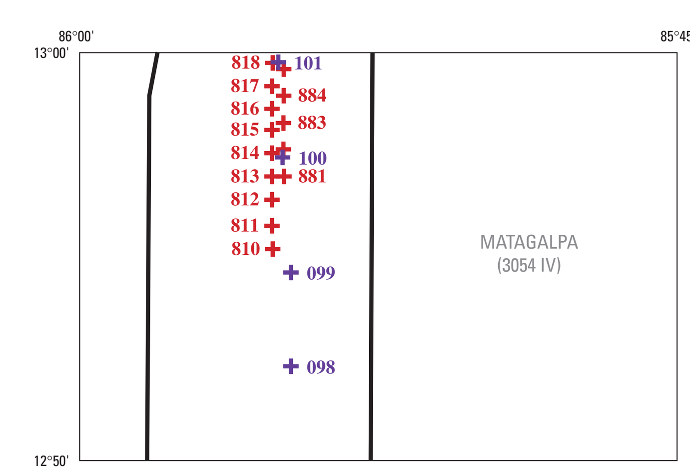


Digital base provided by U.S. Geological Survey
Transverse Mercator Projection
Datum WGS 84

SCALE 1:50,000
1 0 5 MILES
1 0 5 KILOMETERS
CONTOUR INTERVAL 20 METERS

MAP OF LANDSLIDES AND RELATED DOWNCHANNEL EFFECTS TRIGGERED BY HURRICANE MITCH IN PART OF MATAGALPA (3054 IV) QUADRANGLE, NICARAGUA

Location of other plates in this study.



Index to aerial photography and base-map coverage. Topographic base map and reference number from Series E751. Crosses and respective frame numbers represent location of photo centers used in mapping the landslides. Color differentiates between 1:60,000-scale aerial photographs from Open Skies Mission 3 (purple), and 1:30,000-scale photographs from Open Skies Mission 4 (red).

EXPLANATION

- Area impacted by landslides and related downslope effects mapped from aerial photography. Effects include deposition and erosion in downslope channels and on alluvial fans
- Landslides mapped during field reconnaissance
- Earth flows mapped during field reconnaissance
- Extent of aerial photography coverage
- Area not mapped due to cloud cover

This map is one of seven showing areas in Nicaragua impacted by debris flows and other landslides triggered in response to the torrential rainfall that accompanied Hurricane Mitch in October of 1998. The maps provide a record of landslide activity over areas of diverse geology, geomorphology, microclimates, and vegetation. When combined with information on the physical properties of hillslope-mantling materials, hillslope form and gradient, and rainfall characteristics, the inventories provide a foundation for evaluating the susceptibility of other similar areas to landsliding.

We use the term "landslide" to describe all types of slope failures, including slow-moving earth flows, rotational and translational slides (Cruden and Varnes, 1996; Varnes, 1978), and fast-moving debris flows. Most (perhaps 95%) of the landslides that we mapped are debris flows. A debris flow is a rapid downslope movement of viscous slurry consisting of up to boulder-sized material in an abundant muddy matrix (Varnes, 1978; Pierson and Costa, 1987). Debris flows initiate either as rotational or translational landslides that mobilize into muddy slurries, or from concentrated erosion of surficial material by runoff. Debris flows generally occur in response to periods of intense rainfall. With travel across hillslopes and down channels, debris flows can substantially increase in volume by incorporating additional colluvium, channel-fill material, and water. Addition of sufficient volumes of water relative to sediment content may also result in dilution of the debris flow to streamflow consistency. Debris flows may occur with little warning, are capable of transporting large material long distances over relatively gentle slopes, and develop momentum and impact forces that can cause considerable destruction. As a result of these characteristics, mitigation of debris-flow hazards can be more difficult than mitigation of flood hazards. Most of the landslide-related damage and deaths that occurred during Hurricane Mitch resulted from debris flows.

Slow-moving earth flows are the other type of landslide shown on this map. Earth flows are mass movements that form on moderate slopes with adequate moisture in fine-grained, plastic soils as well as rocky soils supported by a plastic silt-clay matrix. These landslides can be a primary agent of erosion in many areas, contributing large amounts of sediment to streams and rivers. Earth flows move in brief periods of episodic movement or in periods of sustained, relatively steady movement, generally in response to above-average rainfall, but also in response to other disturbances such as earthquakes, grading, or irrigation (Keefer and Johnson, 1983; Skempton and others, 1989). Most slow earth flows move primarily by sliding on a distinct basal shear surface, accompanied by internal deformation of the earth-flow material. These deep-seated landslides can cause damage to infrastructure and homes, but do not normally fail catastrophically.

Mapping Approach

Aerial photographs taken between 4 and 19 December 1998 were used to map the landslides shown on this plate. The aerial photographs were taken under the Open Skies program of the Defense Threat Reduction Agency (http://mitchnts1.cr.usgs.gov/data/aerial.html). Photographs at 1:60,000 scale were available for all seven study areas, and 1:30,000-scale photographs were also available for portions of the Matagalpa and the Jinotega/San Rafael del Norte study areas. Digital Raster Graphics (DRG) scanned images of 1:50,000-scale quadrangles projected to Transverse Mercator were used as base maps for mapping the landslides. Landslides and related effects in and adjacent to downstream drainages were mapped by first identifying them on the aerial photographs using a mirror stereoscope. The area visible on the aerial photographs impacted by the landslides was manually plotted by inspection onto the base maps. In some cases, the base maps were enlarged to 1:25,000 scale to facilitate mapping. Locations of landslides mapped using this procedure are estimated to be accurate to within 200 m.

Limited verification of the landslide mapping was performed by field reconnaissance from 25 April through 6 May 2000. Because of the large areal extent of the study areas and difficulties of access, only a few, small areas could be visited. We estimate that as few as 5% of the landslides in some study areas, and as many as 40% of the landslides in others, were observed. During this reconnaissance, locations and extents of some landslides outside of the area of aerial photography coverage were mapped. This mapping represents only features that we observed, and is not representative of all the landslide activity in the area.

Following field verification, the area impacted by the landslides was digitized manually, and the data were then digitally registered to the DRG base map in Arc/Info. The initiation location of each landslide was also digitized. Final maps are presented at 1:50,000 scale.

Geologic information at 1:50,000 scale was compiled for each study area either from digital files or from scanned paper copies of unpublished geologic maps provided by INETER. Comparisons of the landslide initiation locations with existing geologic maps serves to identify those geologic units most susceptible to landslide activity, given rainfall conditions comparable to those produced by Hurricane Mitch. For each study area, we calculated a measure of the relative susceptibility of each geologic unit by dividing the number of landslide initiation locations within each geologic unit by the aerial extent of the unit in the study area.

Mapping Limitations

The small scale of the aerial photographs precludes identification of locations of transitions between debris-flow source areas and debris-flow paths, and transitions between debris-flow and streamflow processes. For this reason, we mapped debris flows as extending from the source areas to the farthest point down channel that appeared to have been affected by flow processes, whether streamflow or debris flow. Also, because of the small scale of the aerial photographs used for this mapping, it is possible to discern between debris flows and slow-moving earth flows, but not between different types of landslides that mobilized into debris flows. In addition, the maps show areas where cloud cover obscured the ground in the aerial photographs. Although landslide features may be present in these areas, it was not possible to map them. If a landslide feature was only partially obscured by trees, shadows, or cloud cover we mapped only what was visible. Finally, the area impacted by each landslide was mapped by filling in a colored polygon that best represented its shape and size. Because each feature is represented by a line at least the width of one pencil lead, the size of very small features may be somewhat exaggerated.

Acknowledgements

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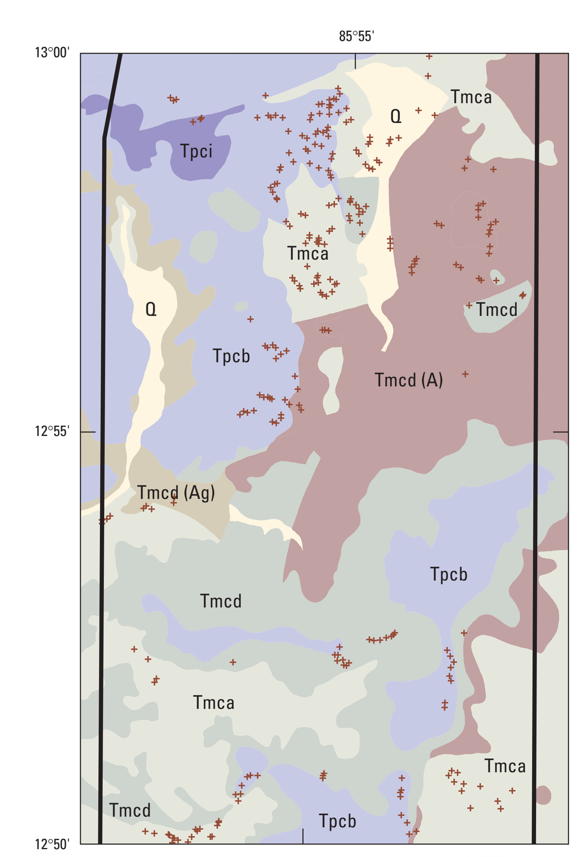

Map showing geologic units (R.L. Williams, unpublished map) and the 274 landslide initiation locations (crosses) within the study area.

Geologic unit		Area (km^2)	Number of initiation locations	Geologic susceptibility index
Q	Quaternary—undifferentiated alluvium and colluvium	8.84	15	2
Tpci	Tertiary—Coyol Superior Ignimbrita y Toba	3.1	3	1
Tpcb	Tertiary—Coyol Superior Basalto y Andesita	45.2	99	2
Tmcd (Ag)	Tertiary—Coyol Inferior Brecha y Aglomerado	9.3	2	0.2
Tmcd	Tertiary—Coyol Inferior Ignimbrita Dacita y Toba	43.4	42	1
Tmcd (A)	Tertiary—Coyol Inferior Ignimbrita Andesita	22.75	25	1
Tmca	Tertiary—Coyol Inferior Aglomerado y/o Andesita	90.9	88	1

ARC/INFO coverages and a PDF file for this map are available at http://geology.cr.usgs.gov/greenwood-pubs.html