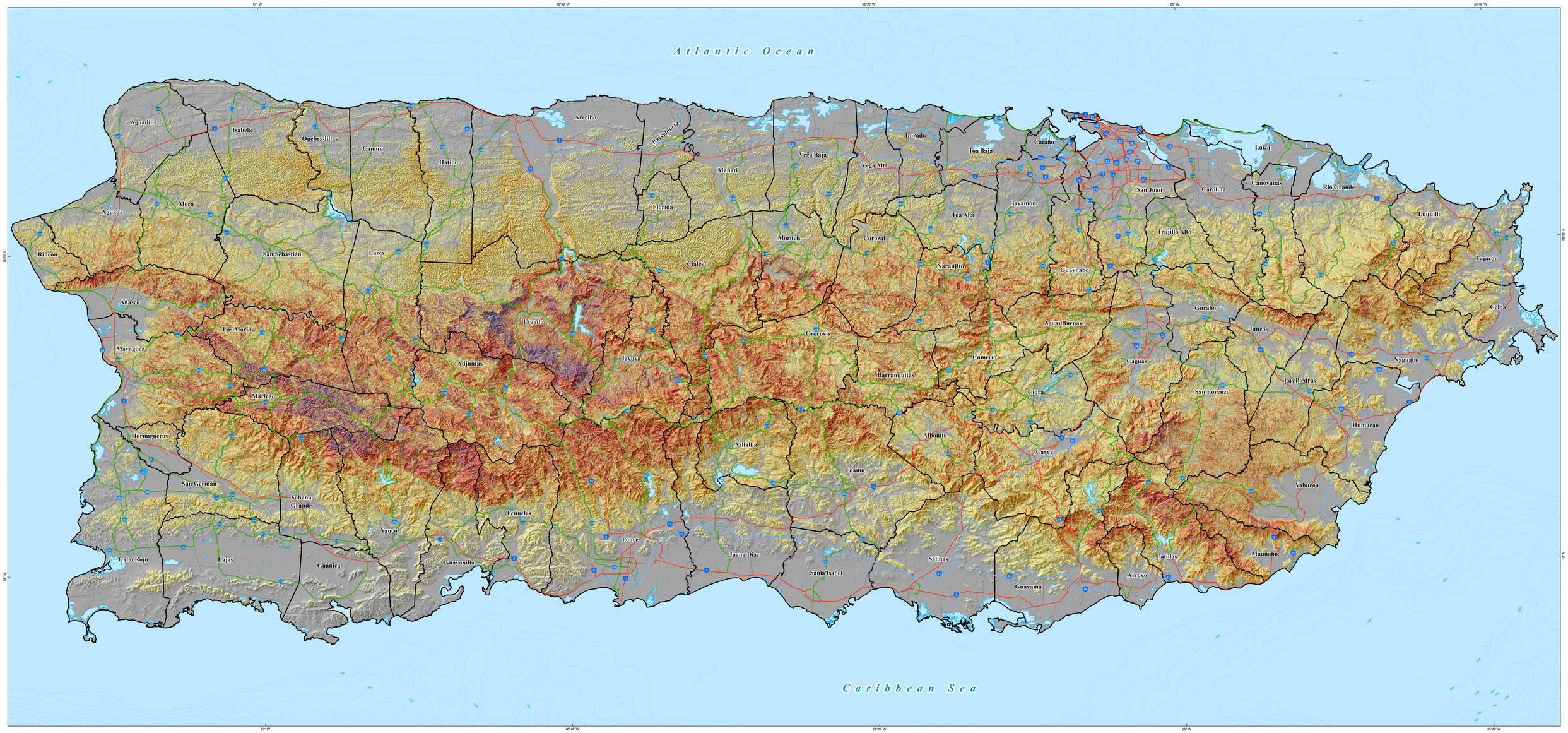
U.S. Department of the Interior
U.S. Geological Survey

Open-File Report 2020–1022
Pamphlet accompanies map



Base topography from U.S. Geological Survey 3D Elevation Program.
Bathymetry from NOAA National Geophysical Data Center. Waterbodies from U.S. Geological Survey National Hydrography Dataset. Roadways from Puerto Rico Department of Transportation and Public Works
World Geodetic System of 1984 (WGS84)

15.5°
DECLINATION AT CENTER OF SHEET, 2019

SCALE 1:150 000
2 0 2 4 6 8 10 MILES
2 0 2 4 6 8 10 KILOMETERS

PUERTO RICO
MAP LOCATION

DEVELOPMENT OF THE LANDSLIDE SUSCEPTIBILITY MAP

Landslides commonly occur in Puerto Rico during or soon after intense rainfall and present significant hazards to the built environment and human safety (for example, Jibson, 1986; Larsen and Torres Sanchez, 1992; Bessette-Kirton and others, 2019). This was illustrated during September 2017, when Hurricane María triggered more than 70,000 landslides (Hughes and others, 2019) across the main island of Puerto Rico that caused loss of life and widespread destruction. We used a statistical approach (see accompanying pamphlet for detailed methodology) along with an inventory of the Hurricane María-triggered landslides and geospatial datasets of ground-surface slope and curvature, proximity to roads and streams, geologic terrane, soil classification, mean annual precipitation, land cover, and soil moisture estimated to result from Hurricane María to develop this 5-meter-resolution map depicting relative susceptibility to landslide occurrence during and soon after intense rainfall. Estimated soil moisture resulting from Hurricane María was used to temper effects on the final susceptibility map from using an inventory of landslides triggered by a single event. The Extremely High classification occurs over 1 percent of the island, whereas the Very High, High, and Moderate classifications occur over 9, 20, and 30 percent of the island, respectively.

USE AND LIMITATIONS OF THE LANDSLIDE SUSCEPTIBILITY MAP

This map depicts estimated relative susceptibility to landslide occurrence during or soon after intense rainfall, such as that produced during tropical cyclones. It is intended to illustrate relative potential landslide hazard to help provide a framework for site-specific landslide susceptibility assessments, plan for future development, and plan for future widespread landslide events. For example, locations with higher landslide susceptibility could (1) be excluded from future development; (2) require slope-stability studies prior to development, and grading, foundation, and drainage design and construction that considers potential slope instability; (3) be targeted for evaluation and mitigation of potentially adverse conditions; (4) be monitored for signs of incipient landsliding, such as cracks in roadways and structures, leaning utility poles and trees, and broken water or sewer lines; and (or) (5) be considered for evacuation prior to forecasted landslide-inducing rainfall and for targeted emergency response activities after such rainfall. When used in consideration of specific atmospheric events, the map should be evaluated alongside event-specific rainfall conditions, with landslides being more likely where larger amounts of rainfall occur in locations with higher landslide susceptibility. Additionally, event-specific, root-zone soil moisture data estimated by the National Aeronautics and Space Administration Soil Moisture Active Passive mission (https://smap.jpl.nasa.gov/ last accessed December 26, 2019) may be combined with landslide susceptibility estimates for this purpose (see "Use and Limitations of the Landslide Susceptibility Map" in the accompanying pamphlet for detailed methodology). The map is not a substitute for site-specific, slope-stability investigation by licensed geologists and engineers. Additionally, many landslides in Puerto Rico move far from the locations where they originate and can result in the loss of life and property as they move downslope; the map does not depict this significant hazard resulting from mobile landslides. Finally, locations of landslides triggered by earthquakes or prolonged, relatively low-intensity rainfall may significantly differ from High, Very High, and Extremely High susceptibility locations shown on the map.

Most landslides in Puerto Rico triggered by intense rainfall are shallow (to several meters deep) and occur in unconsolidated material (soil and saprolite) overlying rock (for example, Jibson, 1989; Larsen and Torres Sanchez, 1992; Bessette-Kirton and others, 2019). These are the types of landslides most well represented by the landslide susceptibility map because the map was produced using an inventory of landslides triggered by Hurricane María (Hughes and others, 2019) and most of those landslides were shallow. Hurricane María also triggered landslides in rock and some reached depths of approximately 30 meters (Bessette-Kirton and others, 2019), so the map also depicts susceptibility to deeper landslides and those in rock. However, landslides such as this are relatively poorly represented by the susceptibility map because relatively few were triggered by Hurricane María so did not provide statistically robust measures with which similar landslides could be forecast. The tragic landslide that occurred at Manneyes in Ponce municipality during 1985 and which killed more than 129 people (Silva-Tulla, 1986) is an example of a type of landslide that is likely poorly represented by the susceptibility map. Additionally, many landslides worldwide are triggered by human activities, such as hillslope grading and redirection of drainage. Local activities such as these cannot be accounted for on the map.

Common to nearly all modeling efforts, accuracy of the landslide susceptibility map relies upon accuracy and completeness of input data utilized for its development. Among others, we expect that the following omissions and conditions detract from the accuracy of the map: (1) variability within given geological terranes of bedrock strength and hydrologic properties, discontinuity orientation and condition; (2) variability within given soil types of soil strength and hydrologic properties; (3) consideration of only part of the road network, including omission of most undocumented farm roads, paths, and trails; and (4) use of a 2015–2016 topographic model that predates landslides triggered by Hurricane María and other topographic changes.

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EXPLANATION

LANDSLIDE SUSCEPTIBILITY

- Low
- Moderate
- High
- Very High
- Extremely High

ROADS AND BOUNDARIES

- Highways
- Primary routes
- Secondary routes
- Tertiary routes
- Municipal boundaries

AREAL FEATURE

- Shoreline—Showing open water

Landslides in Utuado triggered by Hurricane María, 2017. Photograph by E. Bessette-Kirton, public domain.

Landslides in Corozal triggered by Hurricane María, 2017. Photograph by W. Schulz, public domain.

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Map Depicting Susceptibility to Landslides Triggered by Intense Rainfall, Puerto Rico

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2020

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