## S1 Modelling subsurface pressure head

We made pressure head estimates using the Transient Rainfall Infiltration and Grid-Based Regional Slope-Stability Analysis (TRIGRS) program (Baum et al. 2008, 2010; Alvioli and Baum 2016a, 2016b), version 2.1. In most applications, TRIGRS computes pressure head and factor of safety distributed over a digital landscape to yield a series of grids representing changes in pressure head and factor of safety through time during a rainfall event. For this work, our objective was a landslide susceptibility map that shows where landslides induced by intense rainfall are most likely, so we used a presumed wettest-case pressure head, rather than simulating time-varying pressure head. This approach greatly accelerated the pressure-head computations and eliminated the need to calibrate soil hydraulic parameters. Given the extreme rainfall during Hurricane María and other historical tropical storms, full saturation with the water table at the ground surface and groundwater flow sub-parallel to the ground surface (as determined by the permeability contrast at the soil-saprolite or soil-bedrock boundary) represented the likely wettest-case hydrologic conditions for landslide initiation. This approach neglects effects of suction stress, heterogeneity, and transient pore pressures at the cost of making the susceptibility map more conservative (more false positives). Thus, for this assessment we estimated pressure head for these conditions using the following steady-state formula (Iverson 2000; Baum et al. 2010):

$$\psi(Z) = (Z - d)\left[(\cos\delta)^2 - \frac{I_{ZLT}}{K_s}\right] \tag{S1}$$

In Eq. (S1), $\psi(Z)$ [L] is the pressure head as a function of $Z$ [L], the vertical coordinate direction (positive downward from the ground surface); $d$ [L] is the steady-state depth to the water table measured in the vertical direction (0 m in this case); $I_{ZLT}$ [$LT^{-1}$] is the steady background flux; $\delta$ is the slope angle; and $K_s$ [$LT^{-1}$] is the saturated hydraulic conductivity. The dimensionless ratio $I_{ZLT}/K_s$ in Eq. (S1) accounts for downward percolation and reduces the pressure head from the slope parallel case represented by $H\cos^2\delta$, where $H$ (=$Z$-$d$) is the column height as noted previously. The average rate of downward percolation is strongly controlled by the permeability contrast between the mobile regolith (soil mantle) and underlying weathered bedrock or saprolite. For the problem considered here, $I_{ZLT}/K_s$ = 0.028, consistent with wet initial conditions (averaging 2-25 mm/day of precipitation-induced infiltration, $I_{ZLT}$, for $K_s$ in the range $10^{-5}$ – $10^{-6}$ m/s, typical of soils in the study area). This value of $I_{ZLT}/K_s$ directs flow slightly downward and reduces the pressure head by less than 1% compared to slope-parallel flow in the 25° – 55° range of slopes where most landslides occurred. TRIGRS computes $\psi(Z)$ for a series of equally spaced depths between the ground surface ($Z$=0) and a user-specified maximum depth, $Z$=$Z_{max}$. For this analysis, $Z_{max}$ = $H$ as determined by the soil depth modelled in stage B (Fig. 4, sections 3.4, 3.8) and we used a depth increment of $Z_{max}/10$.

## S2 Computing 1D factor of safety

TRIGRS computes the 1D factor of safety, $F_1$, using the infinite slope analysis (Taylor 1948; Iverson 2000) according to the following formula for the saturated case:

$$F_1 = \frac{\tan\phi\prime}{\tan\delta} + \frac{c' - \psi(Z)\gamma_w \tan\phi\prime}{Z\gamma_s \sin\delta \cos\delta} \qquad \text{(S2)}$$

In Eq. (S2) $\gamma_s$ is the saturated unit weight of soil; $\gamma_w$ is the unit weight of water; and $\delta$ is the true dip of the slip surface at the base of mobile regolith (assumed parallel to the slope of the ground surface in the infinite slope analysis). TRIGRS computes $F_1$ at the same series of depths between the ground surface and modelled soil depth as for $\psi(Z)$. Eq. (S2) is strictly valid for landslides much longer than their depth on planar slopes in which lateral variation in stress is negligible. With the advent of high-resolution topography, the depth-to-length ratios of soil columns at most grid cells have become much greater than 0.1, such that the small depth-to-length landslide assumption of Eq. (S2) is violated. This violation reduces accuracy for nonplanar slopes and for rough DEMs (whether the roughness results from natural surface roughness or from data collection and processing errors). A slope-stability analysis that considers multiple adjacent DEM cells can improve accuracy for nonplanar slopes and rough DEMs.

## S3 Computing 3D factor of safety

To overcome the limitations of $F_1$ for high-resolution topography and to assess the stability of potential source areas similar in size to past landslides, the computed pressure head, Eq. (S1), was used in a separate computer program, Slabs3D (Baum 2023), to compute the quasi-3D factor of safety, $F_3$. Baum et al. (2012) described and tested a preliminary version of the program, which recently was further developed and tested for the work reported here. Slabs3D was designed to rapidly analyze stability of the soil mantle on hillsides to identify potential shallow landslide sources. By using a method of columns, Slabs3D overcomes some of the limitations of infinite-slope computations on high-resolution topography. However, the current version of Slabs3D relies on force equilibrium alone (not moment equilibrium). Thus, the approximations made in computing $F_3$ are suitable only for thin (disc- or slab-shaped) landslides, such as most landslides in the study areas (Figs. 2a, 2b, 3). Potential landslides can be more thoroughly analyzed with 3D slope-stability software such as Scoops3D, which considers moment equilibrium on arcuate trial surfaces (Reid et al. 2015). However, in consideration of the thin, slab-shaped landslide sources and the large area (about 1000 km$^2$) to be analyzed, we deemed the accuracy of Slabs3D sufficient and its speed to outweigh any potential improvements in accuracy offered by Scoops3D. Slabs3D computes $F_3$ as follows (Hovland, 1977):

$$F_3 = \frac{\sum\left[(H\gamma_s - \psi\gamma_w)\ell_x\ell_y \cos\delta \tan\phi\prime + c\prime A\right]}{\sum H\gamma_s\ell_x\ell_y \sin\delta_a} \qquad \text{(S3)}$$

In Eq. (S3), the sums are taken over all the columns within the potential landslide. The quantities $\ell_x$ and $\ell_y$ are the horizontal grid cell dimensions; the column height, $H$, is taken as the modelled soil depth; $\delta_a$ is the apparent dip of the basal slip surface, $b=b(x, y)$, along the (assumed) direction of sliding. $A$ is the true area of the failure surface at the base of the column (Hovland 1977; Hungr et al. 1989).

$$A = \ell_x\ell_y\sqrt{1 + \left(\frac{\partial b}{\partial x}\right)^2 + \left(\frac{\partial b}{\partial y}\right)^2} \qquad \text{(S4)}$$

The choice to take $H$ as the modelled soil depth at each grid cell in Eq. (S3) is consistent with field observations and previous modelling results. As noted previously, our field observations indicated that the base of most landslide sources occurred directly above a strength and permeability contrast. Except for cases of very rapid infiltration, TRIGRS computes the lowest factor of safety at $Z_{max}$. Smoothing the modelled soil depth reduces potential irregularities in the trial surface. Tests indicated that modest irregularities have only minor effect on $F_3$ (Baum, 2023).

In Eq. (S3), the effect of pore pressure has been computed in a manner consistent with the normal application of the principle of effective stress by subtracting the pore pressure or suction stress from the gravity-induced stress rather than computing the resultants of pore pressure and gravity stress acting normal to the trial failure surface separately as in some implementations of the ordinary method of slices (Turnbull and Hvorslev 1967). Despite its limitations, Hovland's (1977) method of columns is always able to compute a factor of safety and is not subject to the convergence problems that occasionally occur with more sophisticated limit-equilibrium methods.

As noted previously in the 1D analysis, Eq. (S2) computes $F_1$ at each grid cell for a range of depths from the ground surface down to a user-specified maximum depth, which in this case is the computed soil depth, $H$, (section 3.4) (Baum et al. 2008, 2010). For the cases tested here, the minimum $F_1$ always occurred at the base of soil, so we limited our search for 3D potential failures to those that follow the base of soil. In computing $F_3$, we searched the entire digital elevation model (DEM) for potential failures to a maximum depth of $H$ using a circle of fixed diameter (in map view) centered at each grid cell to define the base of potential failure surfaces (one per grid cell, Fig. 7). Average dip direction of the base of soil within the circle determined the assumed slip direction. Potential failure surfaces enclosed by partial circles near the edges of the DEM were excluded from the analysis. Consequently, we extended the DEM grid well beyond the area needed for the final susceptibility map so that any inaccurate $F_3$ values near the DEM grid boundaries could be discarded as described in the Sect. 3.12. This approach of using map-view-circular trial failure surfaces resulted in potential landslides having the shape of an oblong slab or disc of variable thickness with tapered edges and rounded ends (Fig. 7), such that the trial surface was shaped somewhat like a gold pan. This oblong shape is consistent with the elongation of landslide sources observed in the field and imagery (Fig 3a, 3b) and contributes to accuracy of the analysis. Beyond the limits of the search circle, the slab thins as the potential failure surface slopes from the approximate base of soil toward the ground surface. The failure surface at the head and flanks of the potential slides was assumed (based on Rankine theory, Lambe and Whitman 1969; Terzaghi et al. 1996) to slope $90°\text{-}\phi'/2$ and beneath the toe to slope $\delta_g – \phi'/2$ (where $\delta_g$ is the slope of the ground surface) from the ground surface down to the edge of the circle (Fig. 7). We estimated the contributions of wedges of material at the head, toe, and sides to total driving and resisting force by substituting formulas for height, length, width, average pressure head, and basal area ($H$, $\ell x$, $\ell y$, $\psi$, and $A$) of each side wedge, into Eq. (S3) (Fig. 7), rather than subdividing the wedges into their component square columns or partial columns and summing their individual contributions. The size of these wedges is negligible with a grid resolution greater than the depth, $H$, as is often the case for our study areas, with soil depth commonly less than the 1-m resolution of our DEM. The wedge formulas are exact only for constant $H$. Although variable $H$ across the trial surface introduces minor uncertainty into $F_3$, the formulas are sufficiently accurate for estimating the value of $F_3$ for assessing stability of the soil mantle over large areas.

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