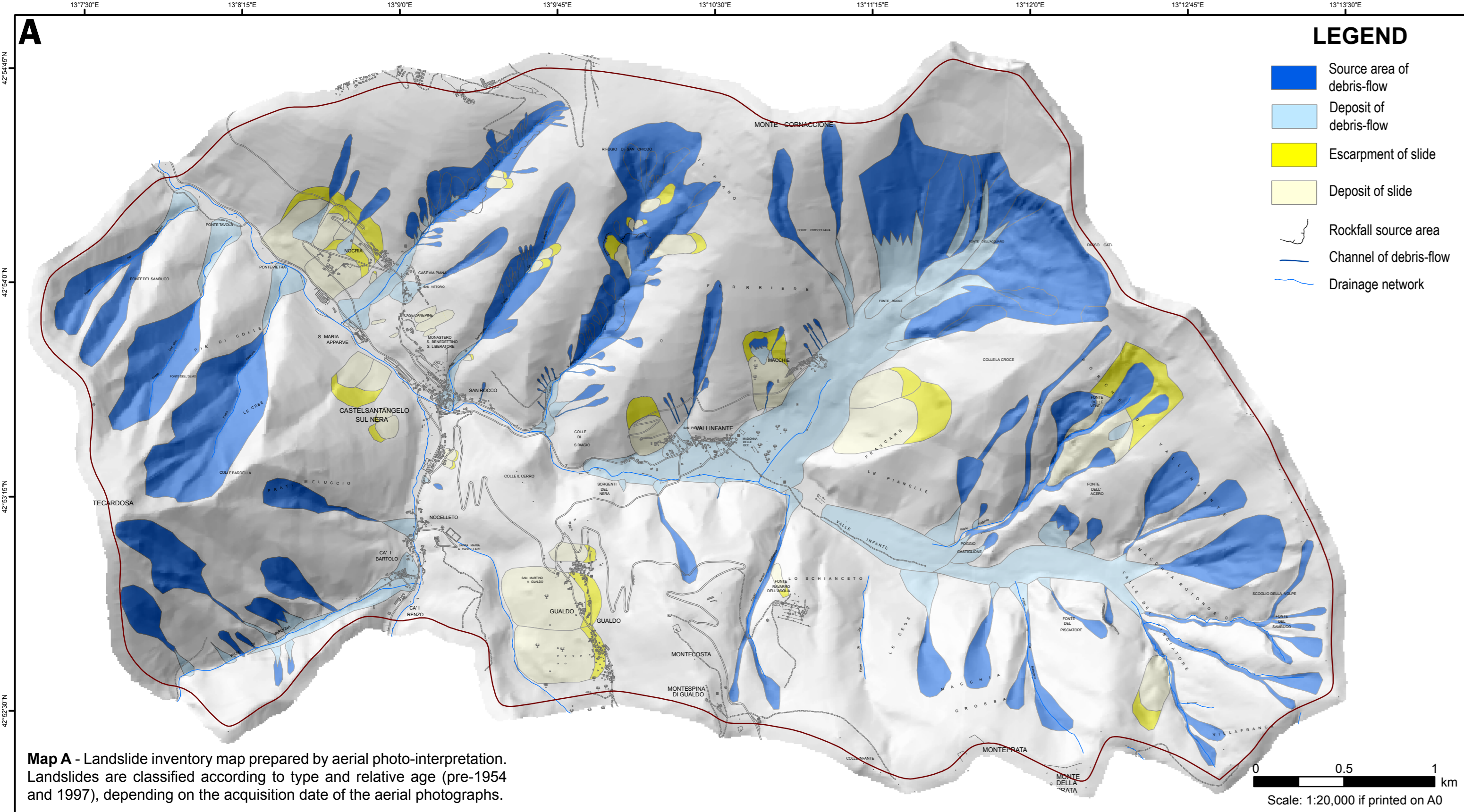
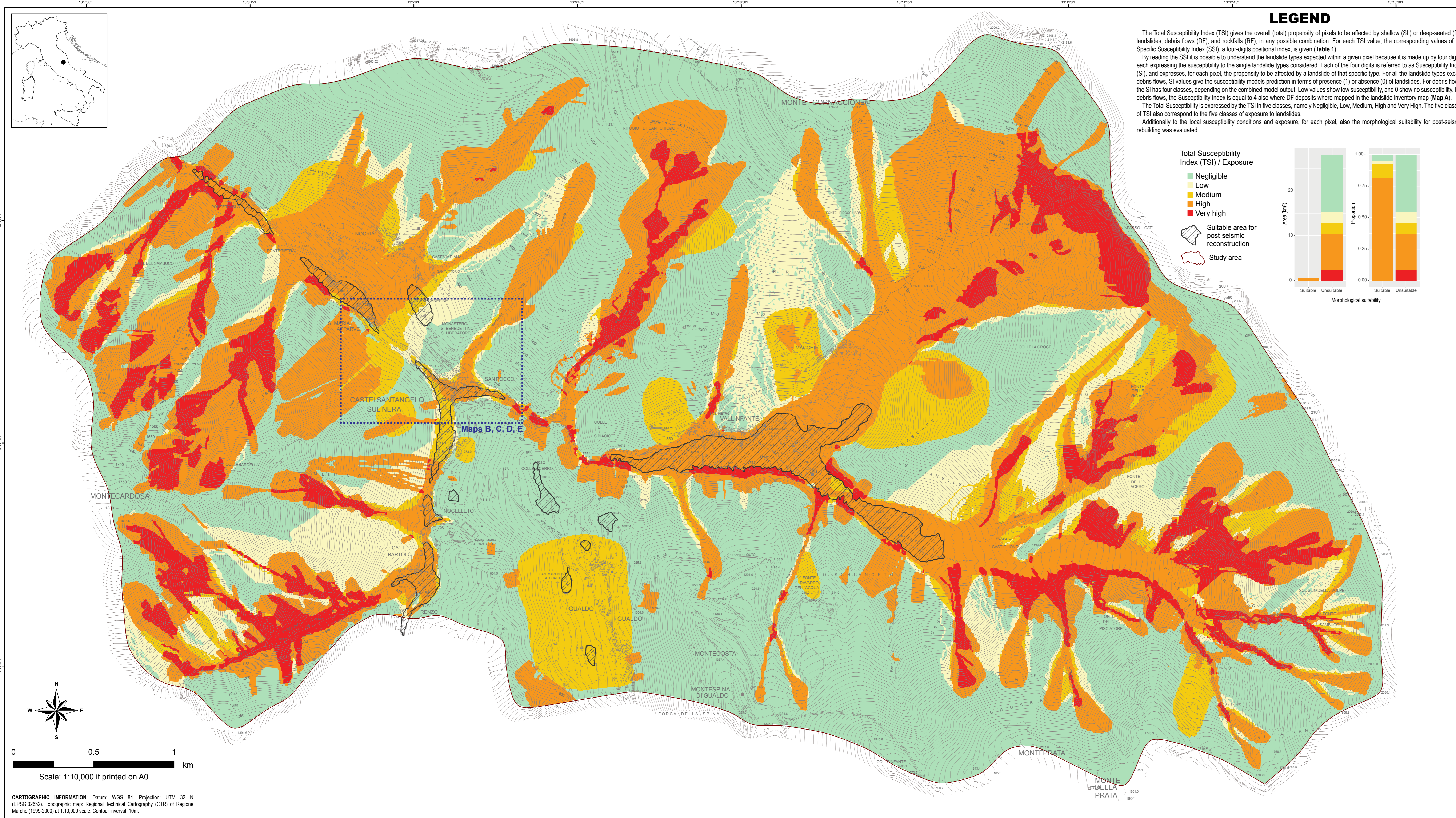


# EXPOSURE TO LANDSLIDES IN RURAL AREAS IN CENTRAL ITALY

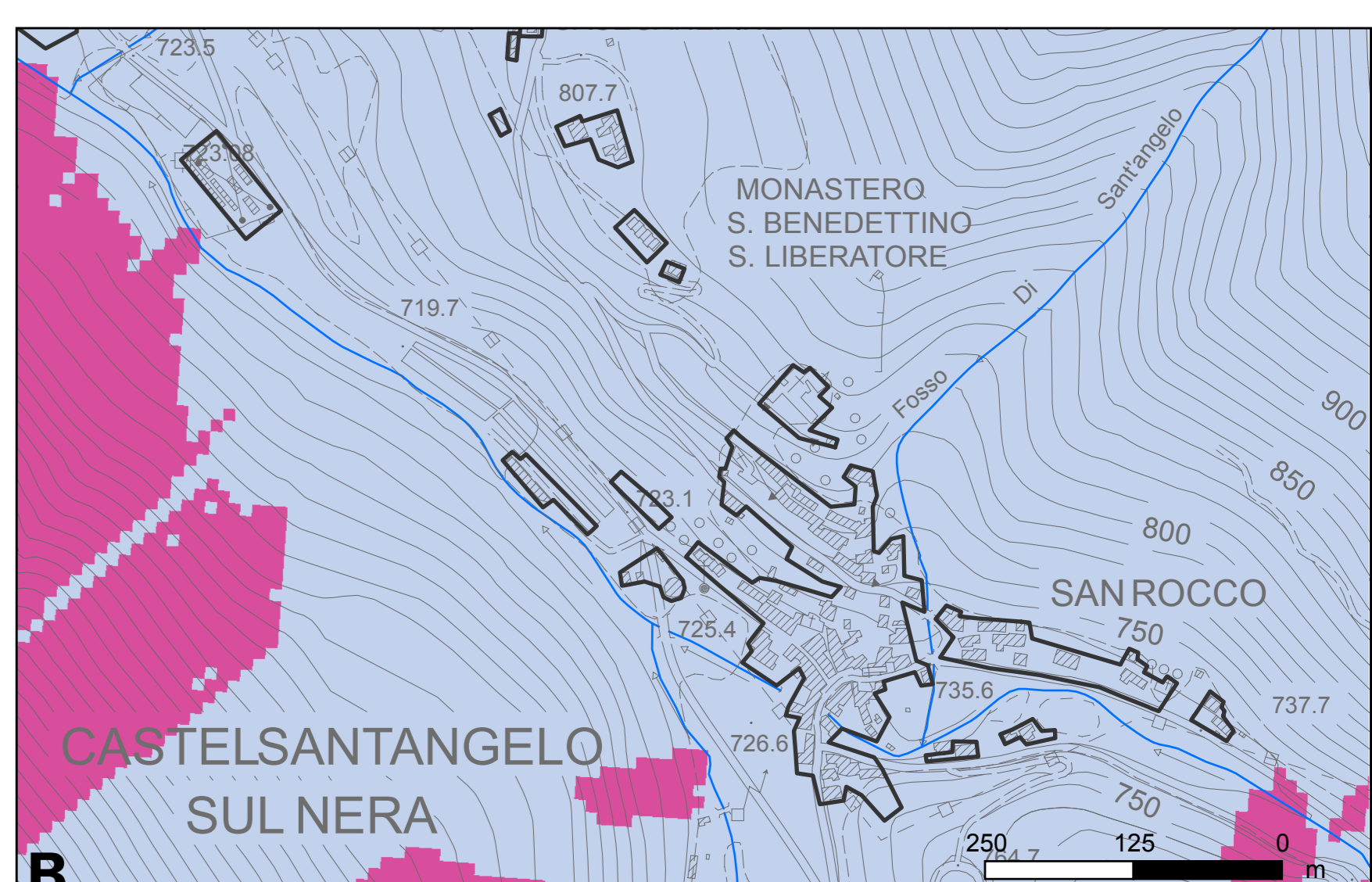
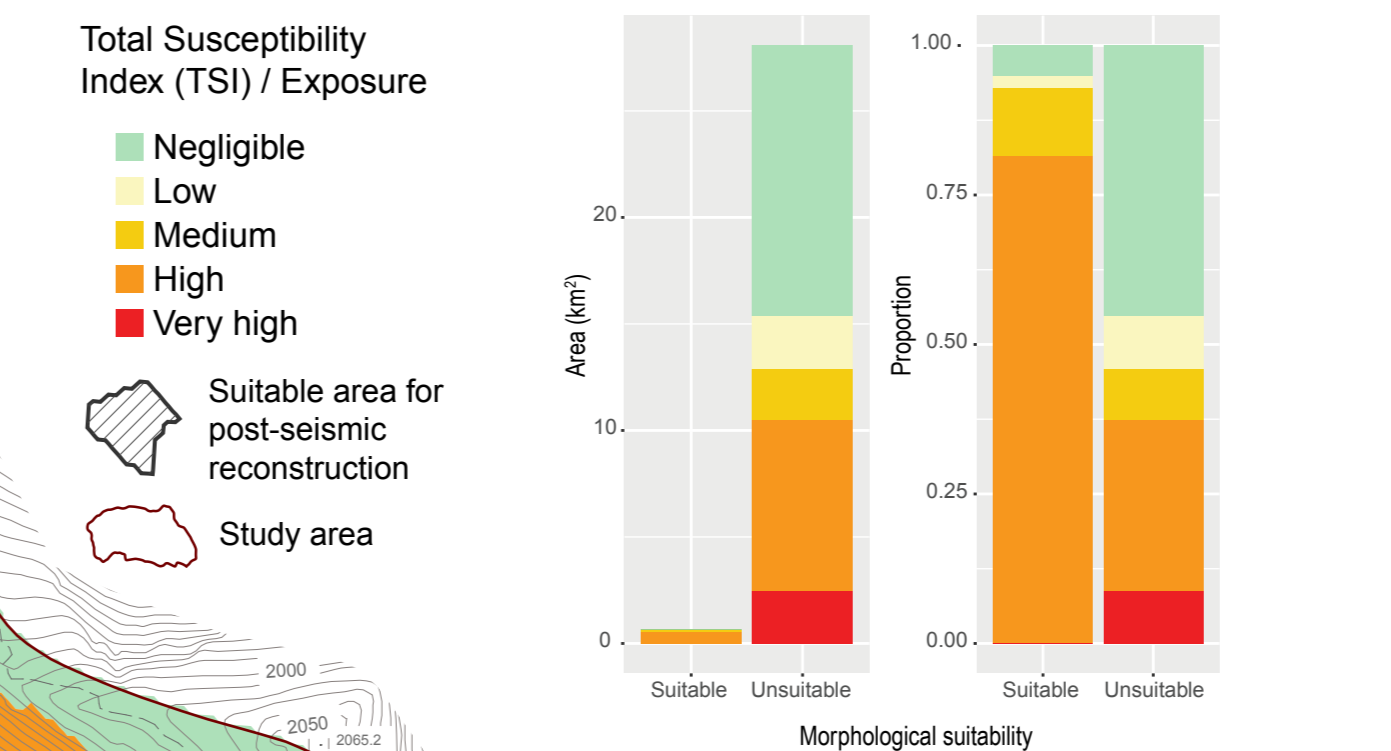
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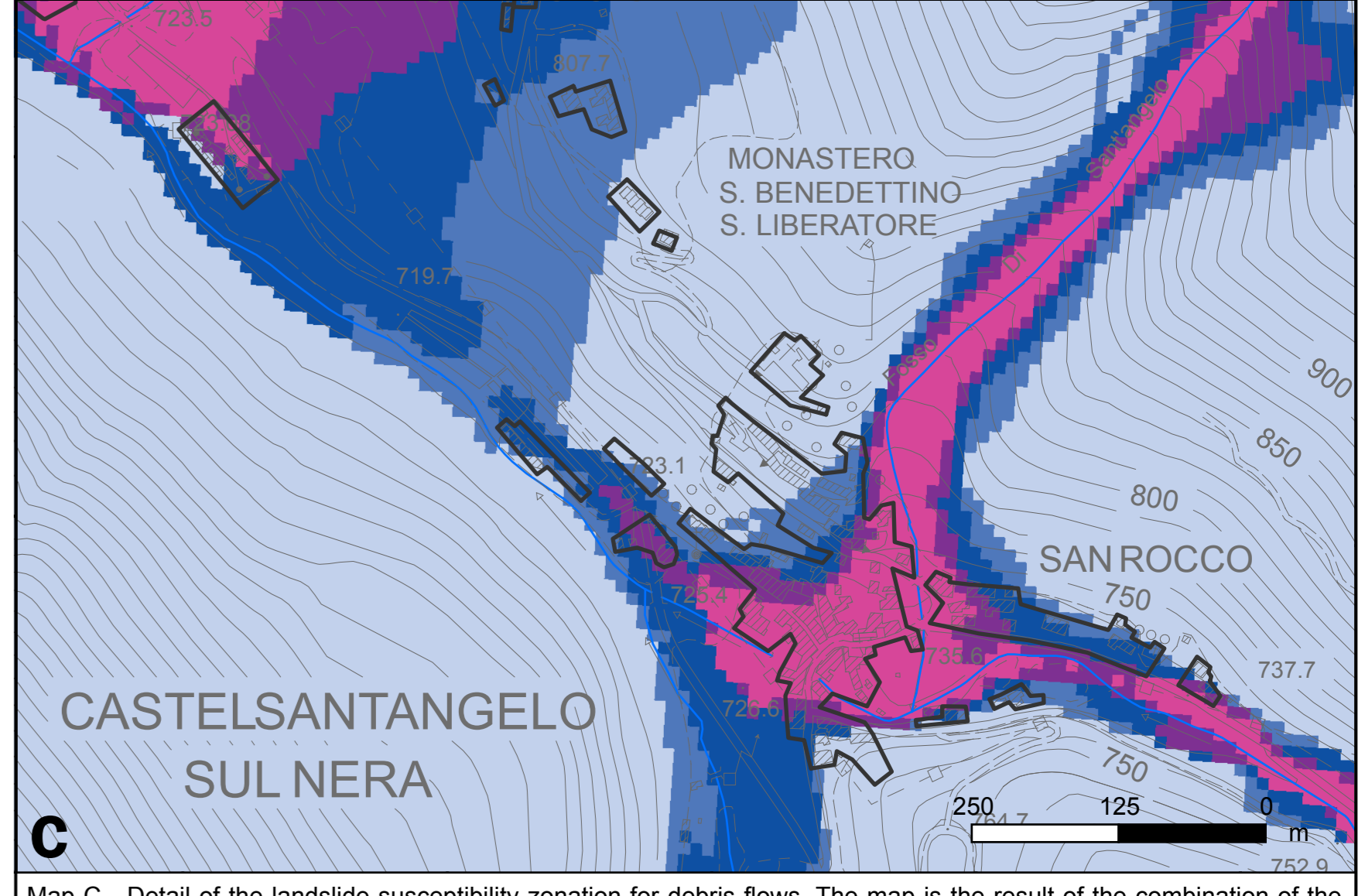


## LEGEND

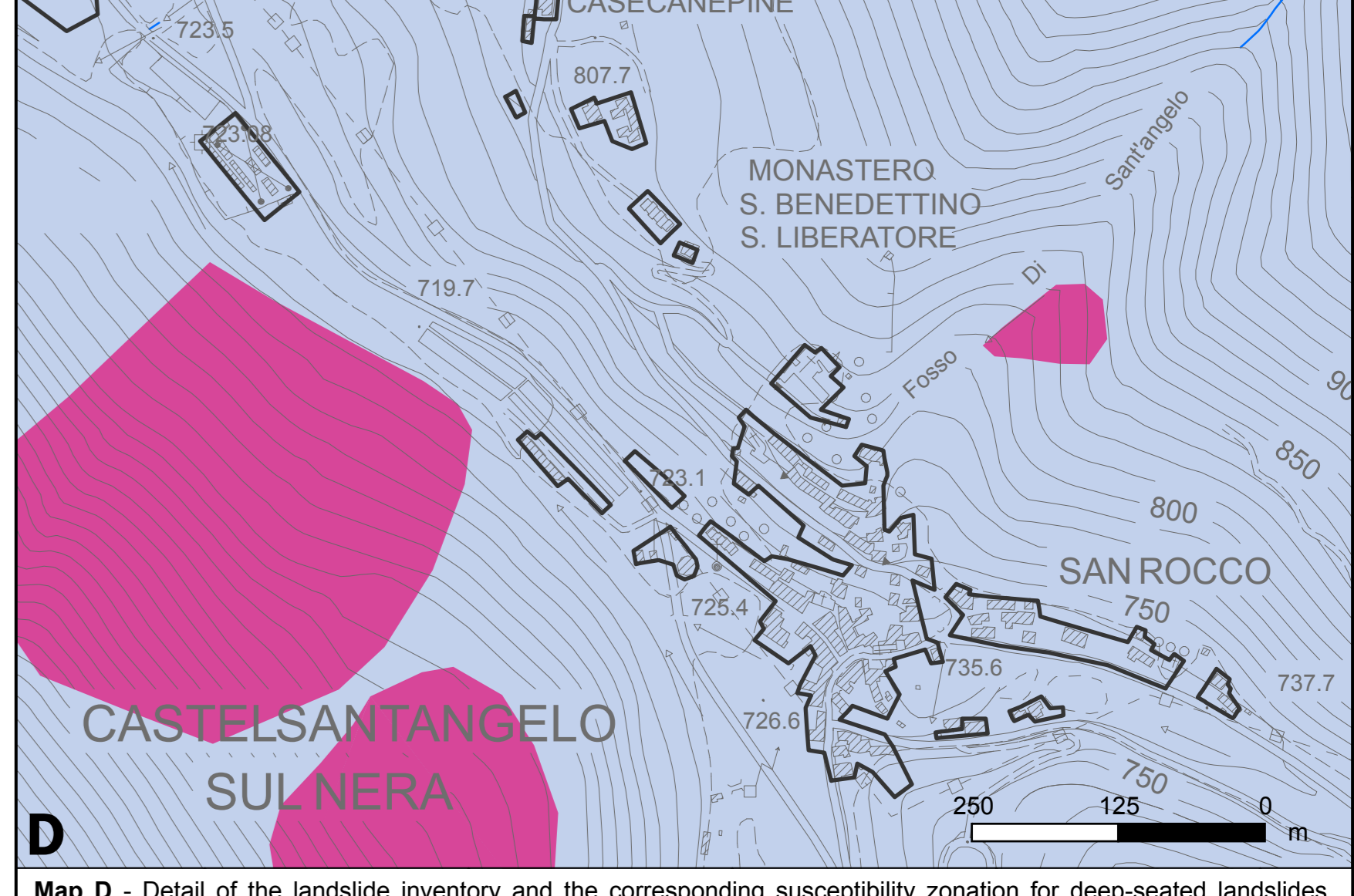
The Total Susceptibility Index (TSI) gives the overall (total) propensity of pixels to be affected by shallow (SL) or deep-seated (DL) landslides, debris flows (DF), and rockfalls (RF), in any possible combination. For each TSI value, the corresponding values of the Specific Susceptibility Index (SSI), a four-digits positional index, is given (Table 1).  
By reading the SSI it is possible to understand the landslide types expected within a given pixel because it is made up by four digits, each expressing the susceptibility to the single landslide types considered. Each of the four digits is referred to as Susceptibility Index (SI), and expresses, for each pixel, the propensity to be affected by a landslide of that specific type. For all the landslide types except debris flows, SI values give the susceptibility models prediction in terms of presence (1) or absence (0) of landslides. For debris flows, the SI has four classes, depending on the combined model output. Low values show low susceptibility, and 0 show no susceptibility. For debris flows, the Susceptibility Index is equal to 4 also where DF deposits were mapped in the landslide inventory map (Map A).  
The Total Susceptibility is expressed by the TSI in five classes, namely Negligible, Low, Medium, High and Very High. The five classes of TSI also correspond to the five classes of exposure to landslides.  
Additionally to the local susceptibility conditions and exposure, for each pixel, also the morphological suitability for post-seismic rebuilding was evaluated.



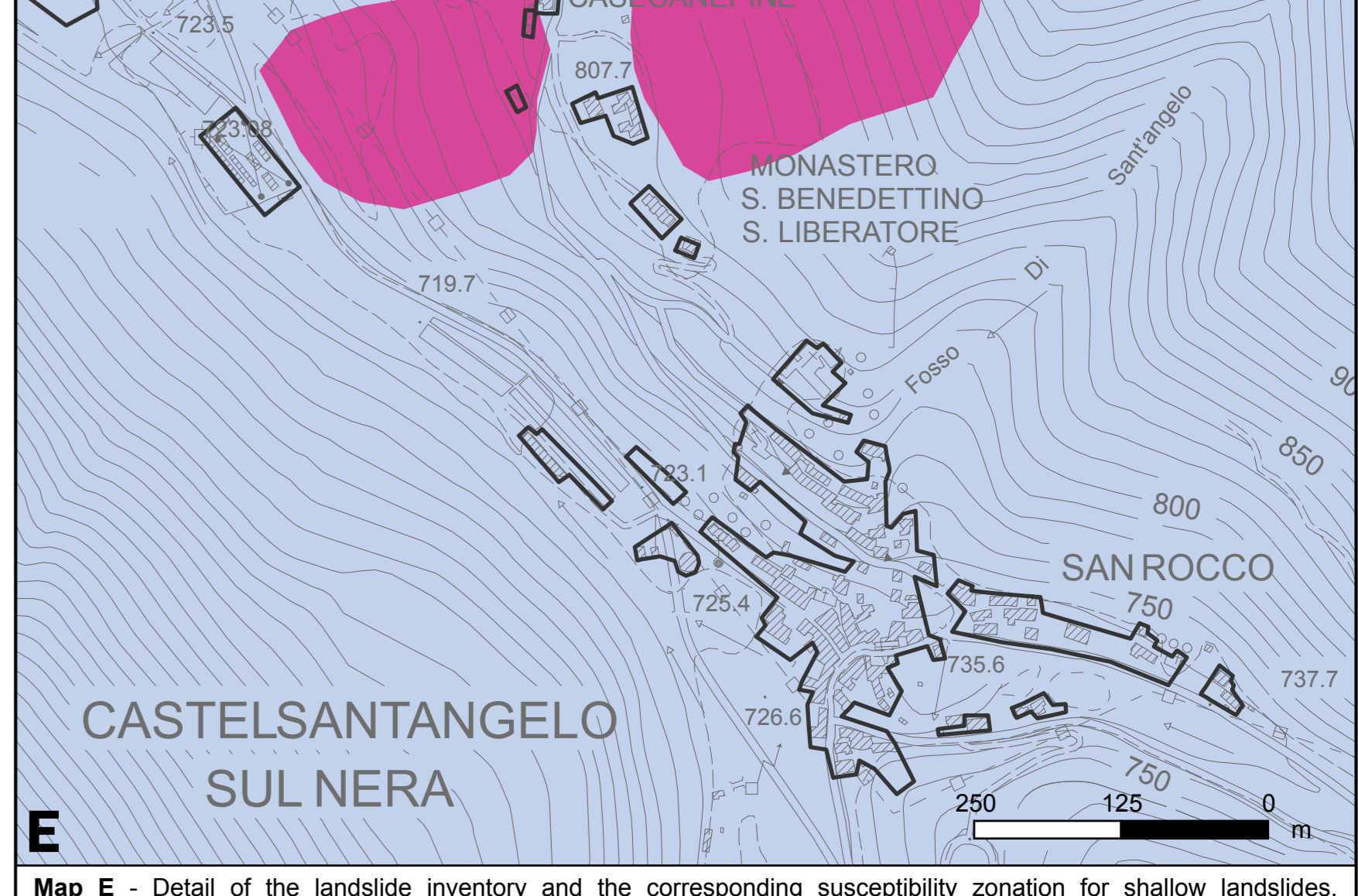
Map B - Detail of the landslide susceptibility for rockfalls. The map is the result of the output of the model STONE. The map is equal to 0 where no trajectories were modelled; it is equal to 1 where the count of modelled trajectories is greater than 0.



Map C - Detail of the landslide susceptibility zonation for debris flows. The map is the result of the combination of the outputs of the "Modified Single Flow Direction" model and "r-randomwalk" based on expert criteria.



Map D - Detail of the landslide inventory and the corresponding susceptibility zonation for deep-seated landslides. Susceptibility derived heuristically adopting geomorphological criteria.



Map E - Detail of the landslide inventory and the corresponding susceptibility zonation for shallow landslides. Susceptibility derived heuristically adopting geomorphological criteria.

The map shows the results of an integrated study to define areas suited for reconstruction following the earthquake sequence that struck central Italy starting from 24<sup>th</sup> August 2016 and caused 303 fatalities and tens of thousands of homeless. In the affected area, peak macroseismic intensity was between IX and XI on the MCS scale (Galli et al., 2017).  
The study defined susceptibility to various landslide types in the territory of the of Castelsantangelo sul Nera Municipality, in the Northern Italian Apennines, Central Italy. Considered landslide types include shallow landslides (SL), deep-seated landslides (DL), debris flows (DF) and rockfalls (RF). The integrated approach resulted in a single map showing the overall propensity of the territory to generate different landslide types.  
All the models were based on information shown on a large scale (1:10,000) geomorphological landslide inventory map (Map A) prepared through the visual interpretation of black & white stereoscopic aerial photographs at 1:33,000 scale (acquired in 1954) and 1:20,000 scale (acquired in 1997). For the interpretation, we used a Galileo SFG 3/B discussion stereoscope with 1x and 4x zoom. Landslides were classified according to their type (namely shallow and deep-seated slides, debris-flows and rockfalls) and relative age, both based on a generational criterion (Santangelo et al., 2014) and according to the date of acquisition of the aerial photographs.  
For the definition of the susceptibility levels we used: (a) the STONE rockfall model (Guzzetti et al., 2004, 2003, 2002) for the kinematic simulation of rockfalls (Map B); (b) the conceptual models "Modified Single Flow Direction" (Huggell et al., 2003) and "r-randomwalk" (Mergili et al., 2015) for the simulation of debris flows (DF); (c) the integrated approach for debris flows (Map C); (d) a heuristic approach to delineate possible evolutionary scenarios (Cardinali et al., 2002) of shallow (SL) and deep-seated (DL) landslides (Map D and Map E). For debris-flow and rockfall (runoff) modelling, we used the TINITALY 10 m x 10 m resolution DEM (Tarquini et al., 2007).  
Each landslide susceptibility model predicts the likelihood of a given pixel of being affected by a landslide of different type. For the single landslide types (Maps B-E), the susceptibility is expressed in each pixel by a Susceptibility Index (SI), shown by one digit. The index adopts the following scheme: (i) SI for rockfalls (RF, Map B) assumes value 0 (absence of modelled trajectories) or 1 (presence of modelled trajectories); (ii) SI for debris-flows (DF, Map C) assumes the values of the combined model (0, 1, 2, 3, 4), where no debris-flow deposits were mapped in the inventory. Inside the deposits mapped in the inventory, SI is equal to 4. The value 0 indicates the absence of modelled or mapped debris flows; (iii) SI for shallow (SL, Map D) and deep-seated landslides (DL, Map E) assume value 0 (absence of landslide scenarios) or 1 (presence of landslide scenarios).  
The four susceptibility maps for single landslide types were then combined into a susceptibility map for multiple landslides types. Such susceptibility map shows, for each pixel, the SIs combined into a four-digits positional index (similarly to what proposed by Cardinali et al., 2002) named the Specific Susceptibility Index (SSI). According to the possible values of each SI, the SSI index can theoretically be composed in 40 different ways. The 40 possible combinations of the SSI (Table 1) describe a specific condition of landslide susceptibility, for multiple landslide types. The SSI is composed by concatenating the values of the Susceptibility Indices, and it expresses, from left to right the susceptibility for rockfalls, debris-flows, deep-seated landslides and shallow landslides. For example, a SSI value "0101" refers to a pixel where, from left to right, no rockfall are expected (0), low debris-flow susceptibility is predicted (1), no deep-seated landslides are expected (0), and shallow landslides are expected (1).  
To perform a zonation of the Specific Susceptibility Index, the 40 values of the SSI were grouped according to expert-defined criteria in a Total Susceptibility Index (TSI, Table 1). The TSI has a total of five classes (Negligible, Low, Medium, High and Very High), which range from 0 to 4 and express, for each pixel, the overall propensity to landslide occurrence. The rationale that guided the zonation of SSI in the TSI is to highlight those situations where fast moving landslides are expected. It was also given more emphasis to rockfalls compared to debris-flows since the former can be triggered also by unpredictable events such as earthquakes, as opposed to debris-flows which are mainly triggered by extreme weather events.  
Additionally, the exposure was defined according to the zonation of the local levels of the Total Susceptibility Index, based on the assumption that any built-up area is exposed to potential damage if located in a susceptible area. Therefore, the exposure shares the TSI levels: the higher the susceptibility, the higher the exposure. The exposure map can be used to read both the exposure to landslides of built-up areas and the exposure of areas that could be built.  
Finally, based on morphological criteria of similarity with already built-up areas, morphologically suitable areas for edification were identified. Areas suitable for post-seismic reconstruction were defined as those which are morphologically suitable and where the exposure to landslides is at maximum high. Areas where the exposure is very high where considered unsuitable.

Table 1 - Composition of the Total Susceptibility Index (TSI). Along the columns, the Susceptibility Indices for RF, DF, DL and SL are shown with colors corresponding to the corresponding maps (Maps B-E). For each combination of the SIs it is shown, along the columns, the Specific Susceptibility Index (SSI) and the TSI, which classes also correspond to the exposure classes. The color scheme of the last two rows corresponds to the color scheme of the main map.

	RF	DF	DL	SL	RF	DF	DL	SL	RF	DF	DL	SL	RF	DF	DL	SL	RF	DF	DL	SL	RF	DF	DL	SL	RF	DF	DL	SL	RF	DF	DL	SL	RF	DF	DL	SL	RF	DF	DL	SL		
Susceptibility Indices (Sis) for single landslide types	RF	DF	DL	SL	RF	DF	DL	SL	RF	DF	DL	SL	RF	DF	DL	SL	RF	DF	DL	SL	RF	DF	DL	SL	RF	DF	DL	SL	RF	DF	DL	SL	RF	DF	DL	SL	RF	DF	DL	SL		
Susceptibility and exposure zonation	SSI	0000	0001	0100	0101	0010	0011	0110	0111	0200	0201	0210	0211	0300	0301	0310	0311	0400	0401	0410	0411	1000	1001	1010	1011	1100	1101	1110	1111	1200	1201	1210	1211	1300	1301	1310	1311	1400	1401	1410	1411	
	TSI	0	1	1	1	1	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4