Theoretical basis.

1.1 Estimating the design rainfall.

Starting from the available rainfall data by a monitoring station, it's possible to perform the needed processing to get the curves which associate the depth of rainfall (h) as a function of their duration (t).
Equation which links these two variables can generally have the following forms:

$$h\ (mm) = a\ t^{n};$$

where a = rainfall depth when t=1 hour;
n = scale factor.

It's called *Intensity, Duration, Frequency curve* (IDF curve).

The pluviometric data are usually available in tabular form, where the maximum annual rainfalls are recorded relative to a specific duration. The rainfall duration lower and higher than one hour are usually reported separately
The reference durations are usually standard, taking in account 10, 15, 30, 45 minutes duration, in the case of brief and heavy rainfall, and 1, 3, 6, 12, 24 hours duration, in the case of hourly rainfall.

N.	t = 10 minutes	t = 15 minutes	t = 30 minutes	t = 45 minutes	year
1	17.0	19.0	22.4	30.4	1985
2	10.6	14.2	21.0	29.6	1986
3	5.4	7.8	15.8	30.2	1987
4	9.2	10.4	23.0	35.8	1988

Table 1 – rainfall duration less than 1 hour.

N.	t = 1 h	t = 3 h	t = 6 h	t = 12 h	t = 24 h	year
1	10.0	20.0	22.0	33.4	43.4	1985
2	37.0	38.0	39.8	39.8	41.0	1986
3	28.0	31.2	31.2	43.8	61.2	1987
4	54.0	68.6	71.2	71.2	71.2	1988

Table 2 – rainfall duration more than 1 h.

A reliable estimation of the IDF curve requires recordings covering at least a 30-35-years period.
These are the steps to follow to get the curves relative to rainfall of duration higher than 1 hour.

- The pluviometric data, for each reference duration, must be organized and numbered in descending order, therefore putting the maximum recorded data, in every temporal interval (1, 3, 6 ,12, 24 hours), on the first row, the minimum ones on the last.
- Through a regression calculation, in correspondence of each row, the parameters a and n of the IDF curve are estimated. The order number of every row gets the return period of the rainfall event. So the first row of a table with N values displays the parameters a and n of the IDF curve having a return period of N years, the last displays the parameters a and n of the IDF curve with a return time of 1 year.

The same procedure must be implemented in the case of rainfall of duration less than 1 hour, when these data are available.
It can note that the parameter *n* tends to remain constant, while the parameter *a* varies as a function of the return time.
Through statistical procedures, the estimates of the parameters a and n can be extrapolated to return time higher than the total number of years for which recorded data are available.
The statistical method by Gumbel is widely used. The procedure is the following.

- Concluded the calculation of the N IDF curves, each for every year of the recorded data, the calculated parameters a must be organized in ascending order, assigning the number 1 to the maximum value and the number N to the minimum value.

- The N ratios:

$$P_i = i / (N + 1);$$

are calculated, where *i* is in the interval 1-N. These ratios express the probability that the specific value of *a* is not reached or passed. The calculated values of P_i allow to define a scale of the return time:

$$T_i = 1 / (1 - P_i).$$

- the N couple of values (T_i, a_i) can be drawn on a semi-logarithmic graph (the return-time values, along the X axis, must be traced in logarithmic scale), interpolating the data in order to trace a straight line: the graph allows to determine the parameter a for every chosen return time.

Obviously, the extrapolation of the parameter *a* must not surpass excessively the number of the years for which the data are available

1.2 Estimating the critical intensity and duration of the rainfall which can cause landslides in detritic layers.

1.2.1 Calculating the critical thickness of the detritic layers.

Landslides which involve a detritic layer, that's the result of the rock weathering, are generally characterized by a wide areal extension in respect to the layer thickness.
Such sort of landslide can be efficiently analyzed by the infinite slope method (Skempton, 1957), supposing a planar surface of sliding, parallel to the topographic profile, and an infinite length.
The detritic layer usually is set in motion due the saturation of the strata after an intense rainfall. The detritic layer usually is set in motion due the saturation of the strata after an intense rainfall. Whereby the Skempton's formula can be used to determine the thickness of the saturated detritic layer to achieve the equilibrium (driving forces= resisting forces). In this condition the safety factor is equal to 1 and the thickness of the layer is called critical thickness.
The critical thickness can be directly calculated through the following expression:

$$h_{crit} = \frac{c}{\gamma} \frac{1}{\left(tg\beta - \frac{\gamma'}{\gamma} tg\varphi \right)} \cos^2 \beta$$

where:
c (t/mq) = drained cohesion of the layer;
φ (°) = angle of shear resistance of the layer;
γ (t/mc) = unit weight of the layer;
γ'(t/mc) = buoyant unit weight of the layer;
β (°) = topographic slope.
Obviously in the case of a soil layer where the cohesion is null, the critical thickness is equal to zero.

1.2.2 Estimating the potential infiltration ratio.

The potential infiltration ratio (f) is the maximum water volume which can be infiltrated into the ground, if such a volume is available. The actual infiltration water volume may be lower if the surface runoff is not sufficient. Anyway it cannot be higher.
The potential infiltration ratio depends on the ground permeability and on the initial saturation ratio. The higher is the permeability, the higher will be the infiltration. The higher is the saturation ratio, the lower will be the infiltration.
Green & Ampt's method is commonly used to estimate the potential infiltration ratio. This procedure involves that the saturation front moves itself downward as a function of the time, dividing distinctly the saturated ground volume, with a water contents equal to the soil porosity (η), by the deeper one, not yet reached by the saturation front, having a water contents equal to the initial one (θ).
At time t, after beginning of the infiltration process, the cumulative infiltration F, that is the water volume which is infiltrated till that moment, can be express by the following formula:

$$F(t)(mm) = Kt + \Delta\theta(h_0 + \psi)\ln\left(1 + \frac{F(t)}{\Delta\theta(h_0 + \psi)}\right)$$

where:

K(m/h)	= vertical permeability of the ground, usually sets equal to the 50% of the horizontal one;
t(h)	= calculation time;
ψ(mm)	= capillary rise;
h_0(mm)	= hydraulic depth, in respect to the ground.
Δθ	= η-θ;

Since the parameter F appears in both the members of the equation, the solution has to be found through an iterative process, imposing a first value inside the second member, solving the equation and then substituting the new calculated value in the second member. Calculation has to be repeated until the difference between two consecutive values of F will be lower than a prefix limit (for example 0.001).

The value of the capillary rise may be chosen, selecting it by the following table:

Soil type	ψ(m)
Gravel	0.05-0.30
Coarse sand	0.30-0.80
Medium sand	0.12-2.40
Fine sand	0.30-3.50
Silt	1.5-12
Clay	>10

Known the cumulative infiltration, the potential infiltration ratio can be calculated by the following expression:

$$f(t)(mm/h) = K\frac{F(t) + \Delta\theta\left(h_0 + \psi\right)}{F(t)}$$

1.2.3 Estimating the intensity and duration of the critical rainfall.

The model, conceived by Wallace (1977) and by Pradel and Raad (1993), envisages the following set of events.

- An infinite slope, after the Skempton's definition, gets involved in a rainfall having an intensity higher than the soil permeability. The upstream water inflow along the topographic surface and the evapotranspiration are considered negligible, supposing the two phenomenons compensate themselves for each other.
- The surface layer starts to saturate and the saturation line tends to deepen itself as a function of time.
- When the thickness of the saturated layer is equal to the critical thickness, calculated through the verify of the slope stability, the landslide starts to move.

If the rainfall duration is less than the time necessary to saturate the critical thickness, the landslide cannot be activated.
Using the model by Green and Ampt, it can be identified the minimum duration of the rainfall which can cause the landslide:

$$t_{\min} = \frac{\Delta\theta}{k}\left[D - P_{ris}\ln\left(\frac{P_{ris} + D}{P_{ris}}\right)\right]$$

where:

$\Delta\theta$	= residual effective porosity, given by (1-s) θ, where s is the initial degree of saturation of the soil and θ is the effective porosity;
k (mm/h)	= soil permeability;
D (mm)	= critical thicknes;
P_{ris} (mm)	= matric pressure at the wetting front.

Consequently, to have the activation of the landslide must be $t_{prec} \geq t_{min}$ (t_{prec} =rainfall duration).

If the rainfall intensity is less than the soil permeability, it cannot form a moving front of saturation.

To a specific rainfall duration value, it can estimate the minimum rainfall intensity to form a moving front of saturation.:

$$I_{\min}(mm/h) = \frac{\Delta\theta}{t}\left[D - P_{ris}\ln\left(\frac{P_{ris}+D}{P_{ris}}\right)\right]\frac{D+P_{ris}}{D}$$

Varying the duration, starting from a minimum value equal to (tmin), a bi-logarithmic curve which gives the minimum rainfall intensity, associated to a specific duration, to have the landslide activation.
From a practical point of view, all the rainfall with a duration longer than t_{min} and an intensity above the curve can originate a landslide.
To envisage the frequency of the rainfall events, which can trigger a landslide in a specific slope, the calculated curve must be compared to the IDF curve.
In the following graph, the blue curve is the calculated curve and the black one is the IDF curve. The red zone assembles all the values of duration and intensity which can activate a landslide having a return time equal to the IDF curve. If the reference event falls inside the red area, the landslide will be probably activated. If the reference event lies above or below the IDF curve, the chosen return period is wrong and must be modified.

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