Project funded by the EUROPEAN UNION

SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

A Scientific Network for Earthquake, Landslide & Flood Hazard Prevention - Project Workshop
Thesaloniki, May 7-9, 2015

MICROZONATION FOR RAINFALL INDUCED LANDSLIDE

Özyeğin University, Civil Engineering Dep. — Prof.Dr. M. Atilla Ansal
Mef University, Civil Engineering Dep. — Ass.Prof.Dr. Gökçe Tönük
Boğaziçi Uni., Kandilli Observatory and Earthquake Res.Inst. — Dr. Hadi Khanbabazadeh
Özyeğin University, Civil Engineering Dep. . — Okan İlhan, M.Sc

Selected Methods

- **Mora and Vahrson Method (1994):**

  Empirical relationship based on the case studies.

- **Montgomery and Dietrich Method (1994):**

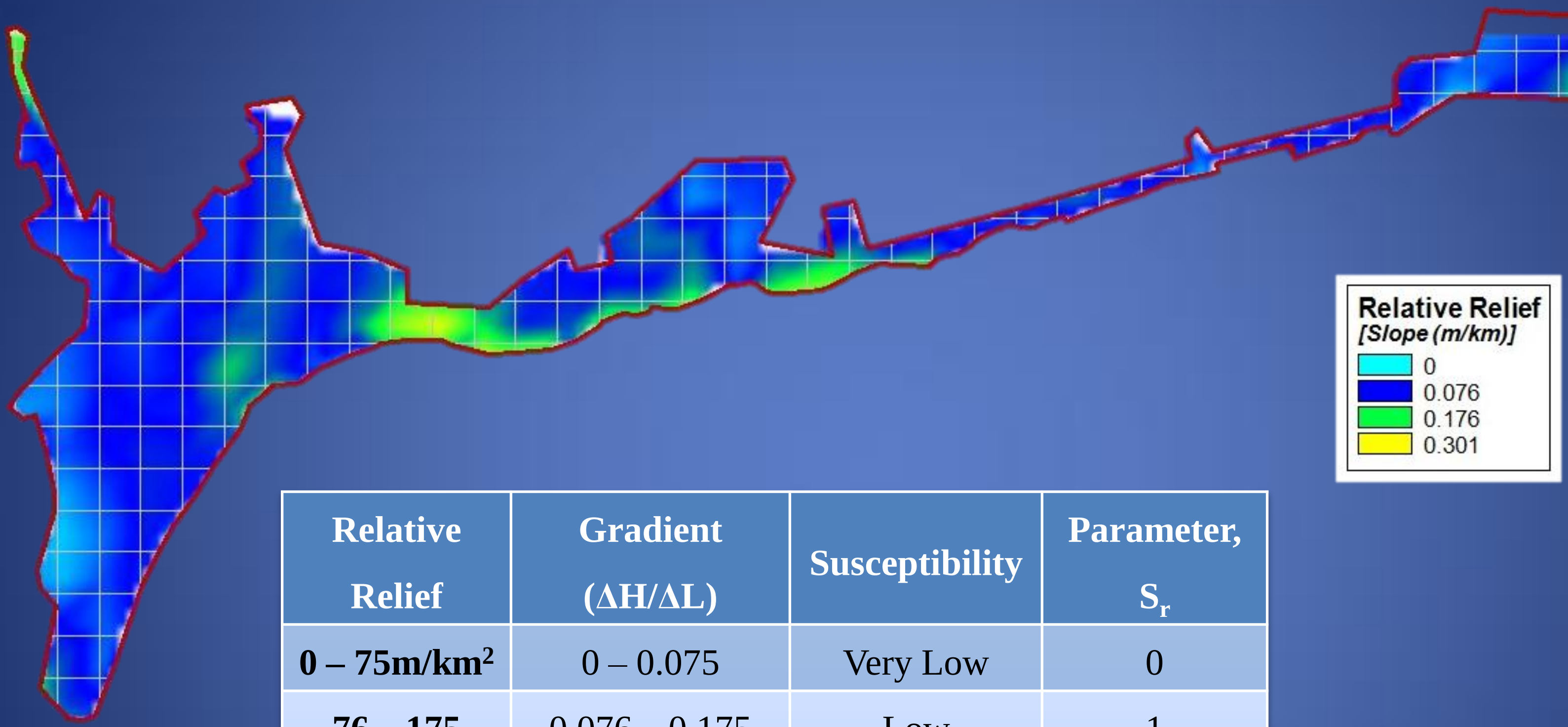
  Topography is the main important factor.

  Proposed Methodology:

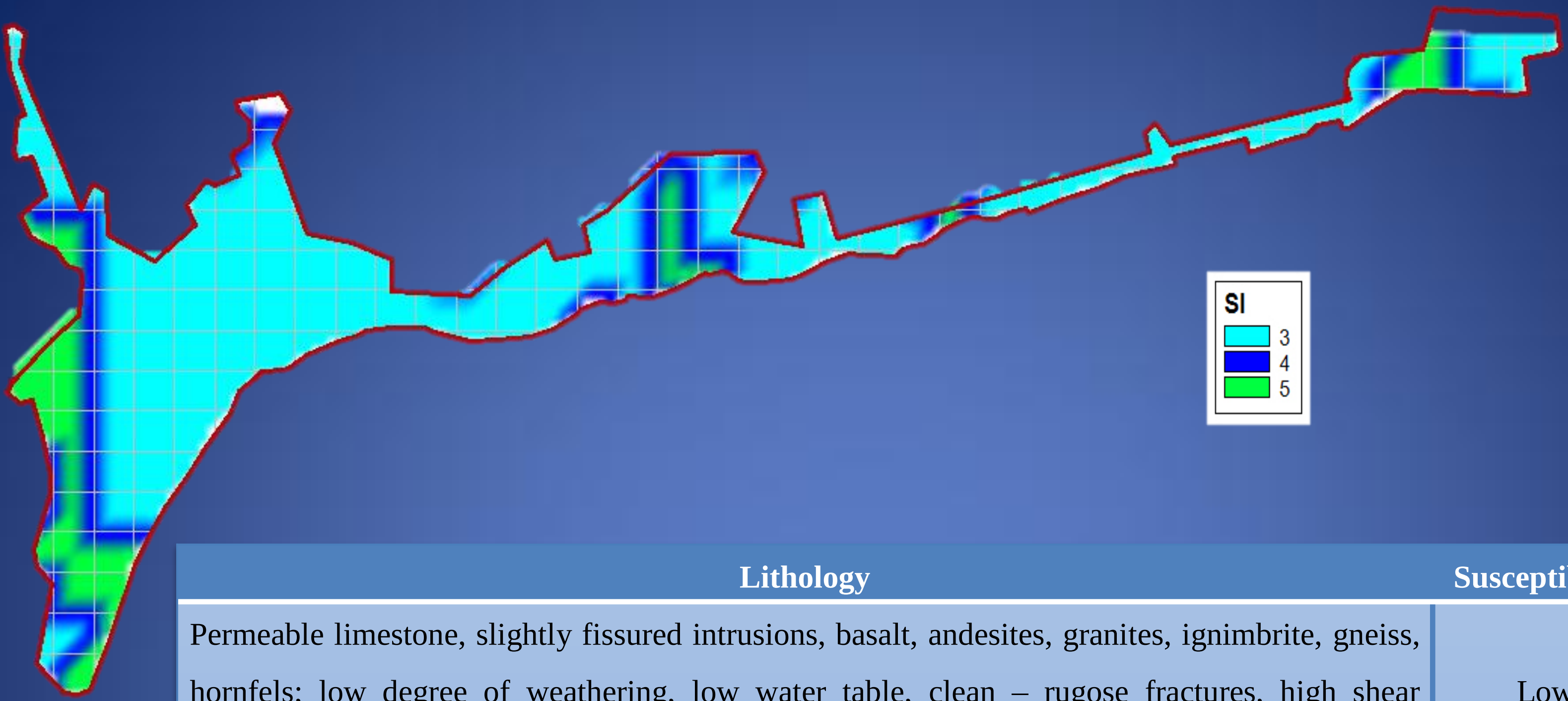
  - Adaptation of water infiltration by Iverson (2000)
  - Time dependent development and drainage of pore pressure and factor of safety calculations.

Mora and Vahrson Method (1994)

$$H_l = |S_r * S_l * S_h| * |T_s + T_p|$$



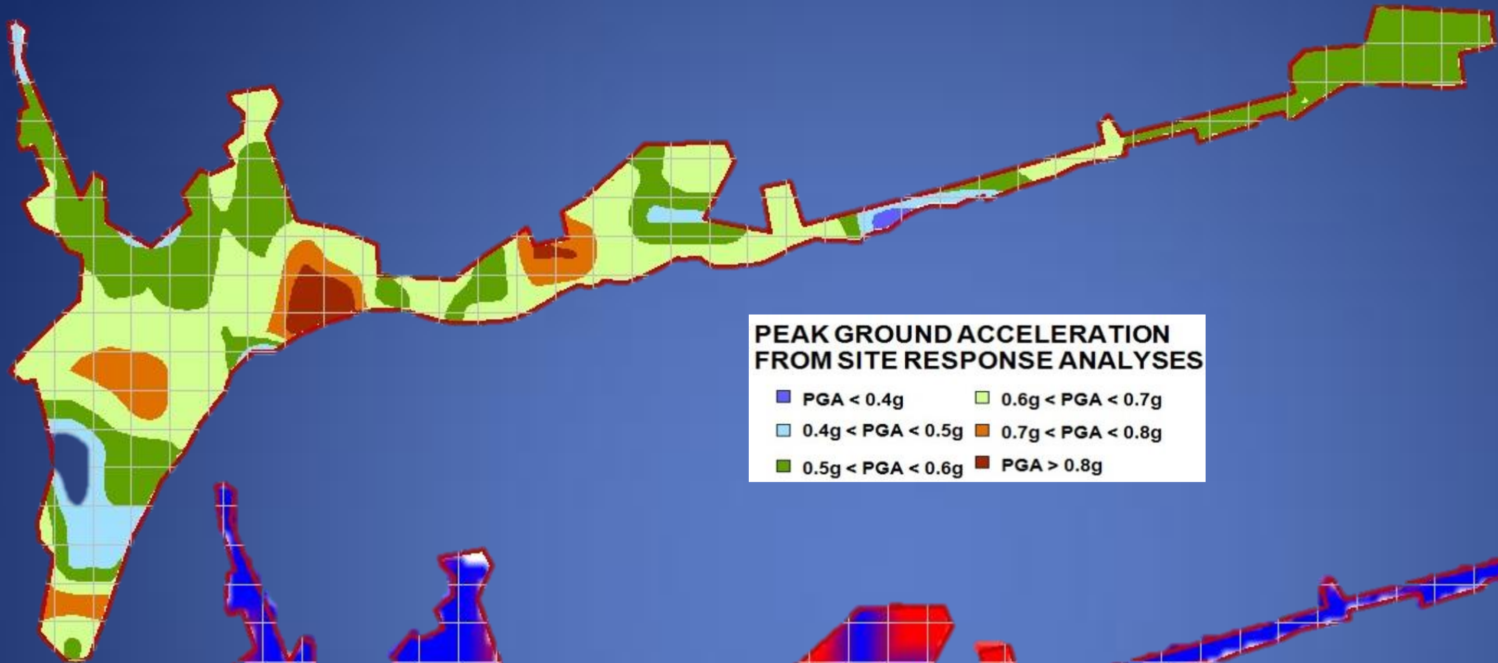
Relative Relief	Gradient ($\Delta H/\Delta L$)	Susceptibility	Parameter, S_r
0 – 75m/km²	0 – 0.075	Very Low	0
76 – 175	0.076 – 0.175	Low	1
176 – 300	0.176 – 0.3	Moderate	2
301 – 500	0.301 – 0.5	Medium	3
501 – 800	0.501 – 0.8	High	4
> 800	> 0.8	Very High	5

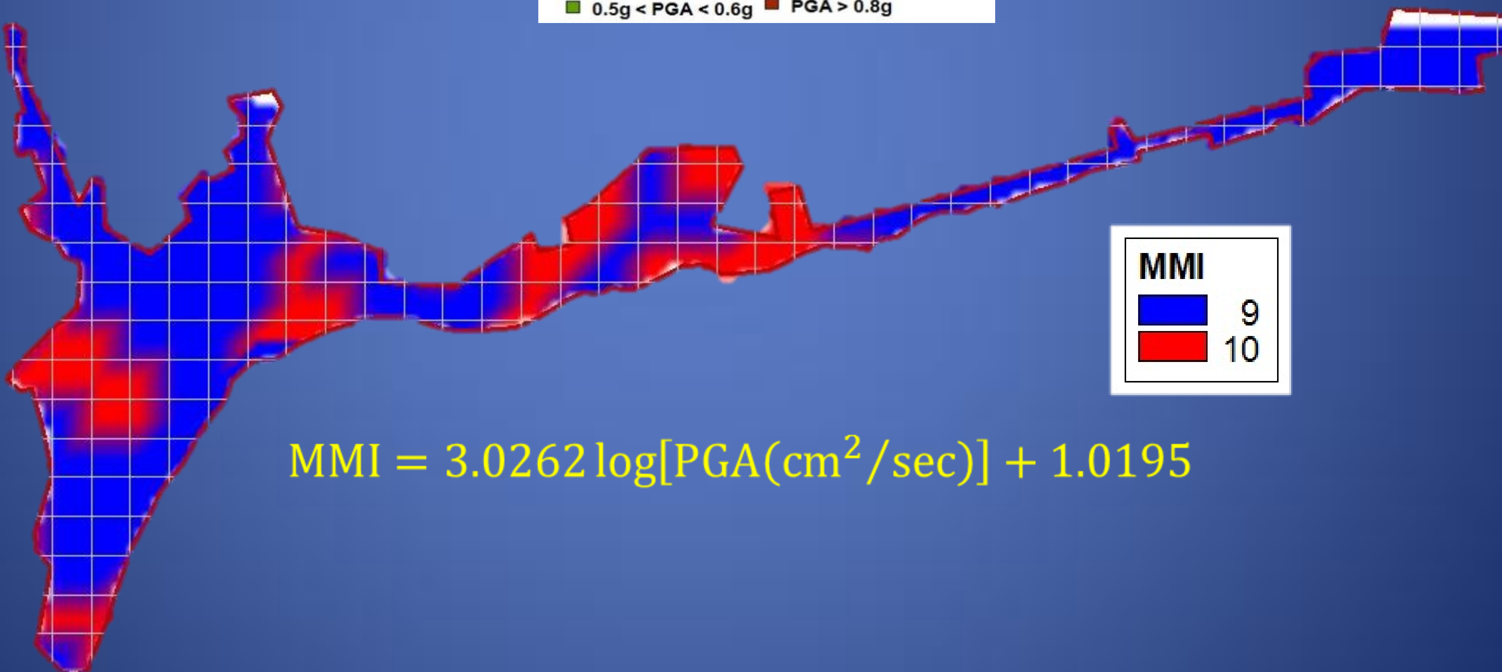


Lithology	Susceptibility	Value, S_l
Permeable limestone, slightly fissured intrusions, basalt, andesites, granites, ignimbrite, gneiss, hornfels; low degree of weathering, low water table, clean – rugose fractures, high shear strength rocks	Low	1
High degree of weathering of above mentioned lithologies and of hard massive clastic sedimentary rocks; low shear strength; shearable structures	Moderate	2
Considerably weathered sedimentary, intrusive, metamorphic, volcanic rocks, compacted sandy regolithic soils, considerable fracturing, fluctuating water tables, compacted colluvium and alluvium	Medium	3
Considerably weathered, hydrothermally altered rocks of any kind, strongly fractures and fissured, clay filled; poorly compacted pyroclastic and fluvio – lacustrine soils, shallow water tables	High	4
Extremely altered rocks, low shear resistance alluvial, colluvial and residual soils, shallow water tables	Very high	5

Mora and Vahrson Method (1994)

Intensities (MM) T_r = 100 years	Susceptibility	Value, T_s
III	Slight	1
IV	Very low	2
V	Low	3
VI	Moderate	4
VII	Medium	5
VIII	Considerable	6
IX	Important	7
X	Strong	8
XI	Very Strong	9
XII	Extremely Strong	10





$$\mathrm{MMI} = 3.0262 \log[\mathrm{PGA}(\mathrm{cm}^2/\mathrm{sec})] + 1.0195$$

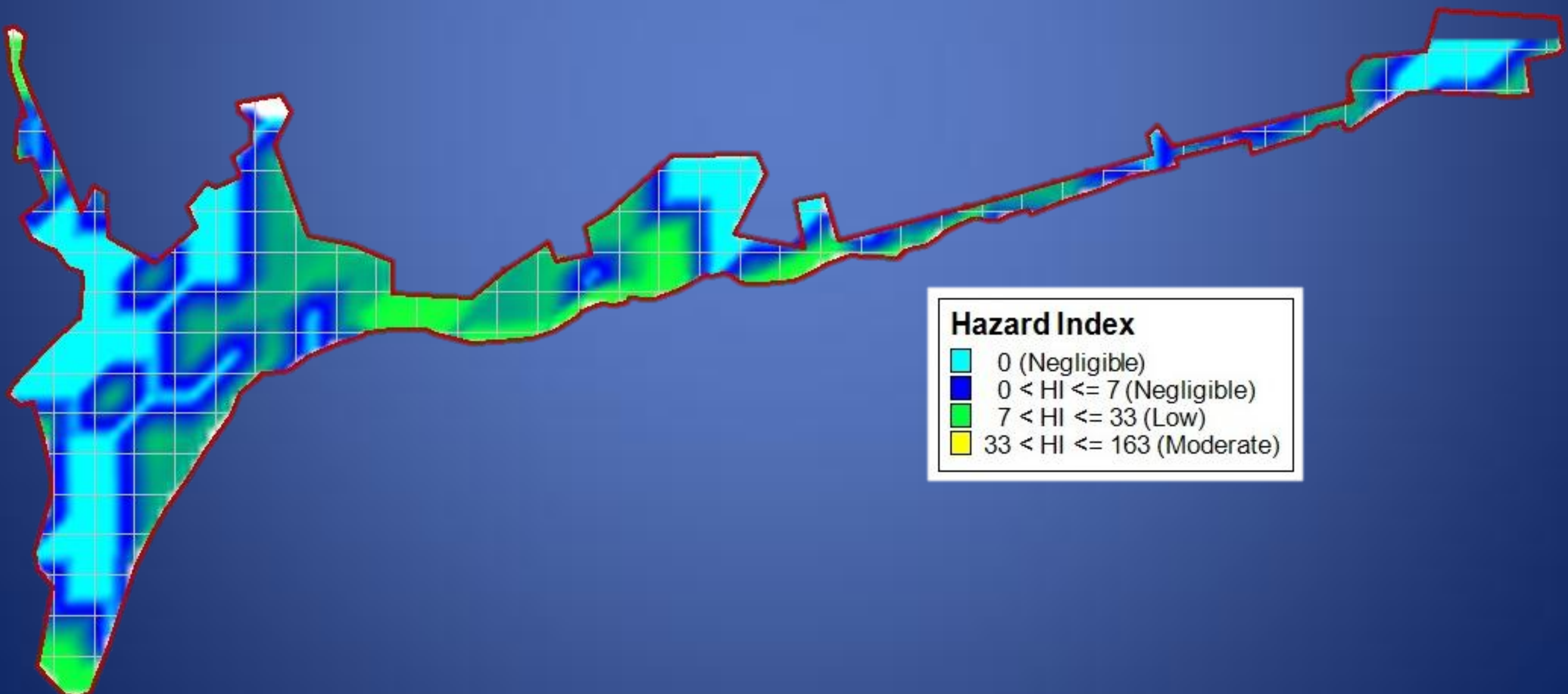
$$H_l = |S_r * S_l * S_h| * |T_s + T_p|$$

Average Monthly Precipitation (mm/month)	**Assigned Value**
< 125	0
125 - 250	1
250 <	2

Summation of Precipitation Averages	**Susceptibility**	**Value, S_h**
0 – 4	Very low	1
5 – 9	Low	2
10 – 14	Medium	3
15 – 19	High	4
20 – 24	Very high	5

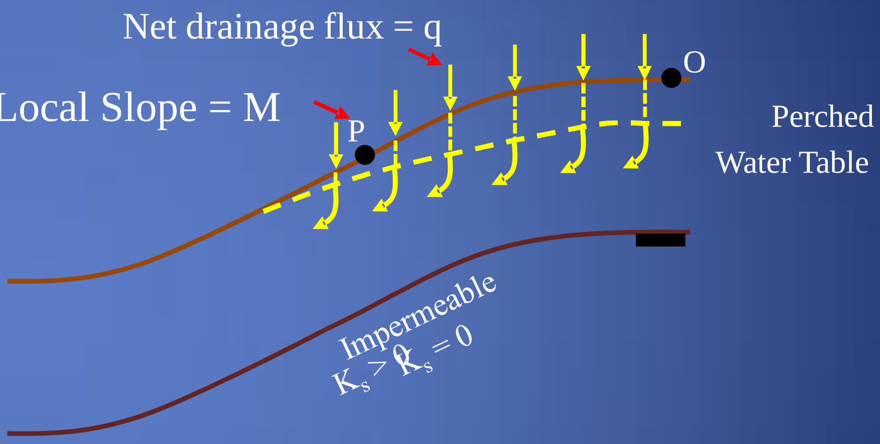
Maximum Rainfall n > 10 years: T_r = 100 years	**Rainfall n<10 years; Average**	**Susceptibility**	**Value, T_p**
< 100 mm	< 50 mm	Very low	1
101 – 200	51 – 90	Low	2
201 – 300	91 – 130	Medium	3
301 – 400	131 – 175	High	4
> 400	> 175	Very High	5

Value from Eq	Class	Susceptibility of Hazard
0 – 6	I	Negligible
7 – 32	II	Low
33 – 162	III	Moderate
163 – 512	IV	Medium
513 – 1250	V	High
> 1250	VI	Very High



Montgomery and Dietrich Methodology (1994):

- Convergent or divergent topographical structures
- Amount of infiltrated rain water
- WETNESS



$$W = \frac{I_z A}{bT\sin\theta}$$

$$FS = \left(\frac{\tan\varphi}{\tan\theta}\right)\left[1 - W\left(\frac{\gamma_w}{\gamma_{sat}}\right)\right]$$

where

I_z = net rainfall rate, **A/b = specific cathment area**,

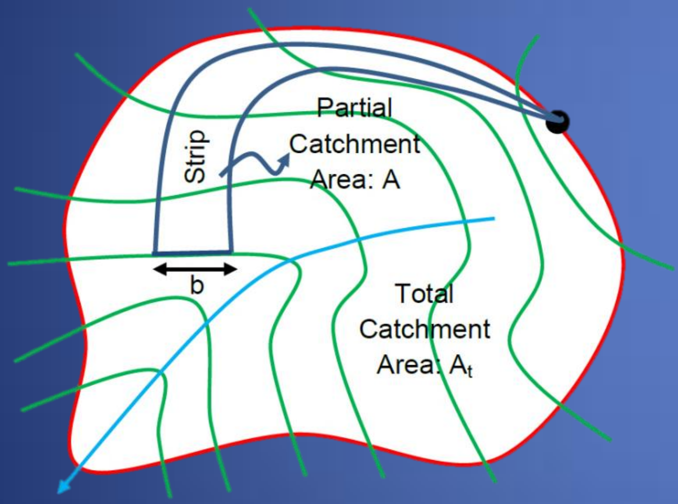
T = the soil transmissivity at saturation,

θ = slope angle, φ = residual shear strength angle,

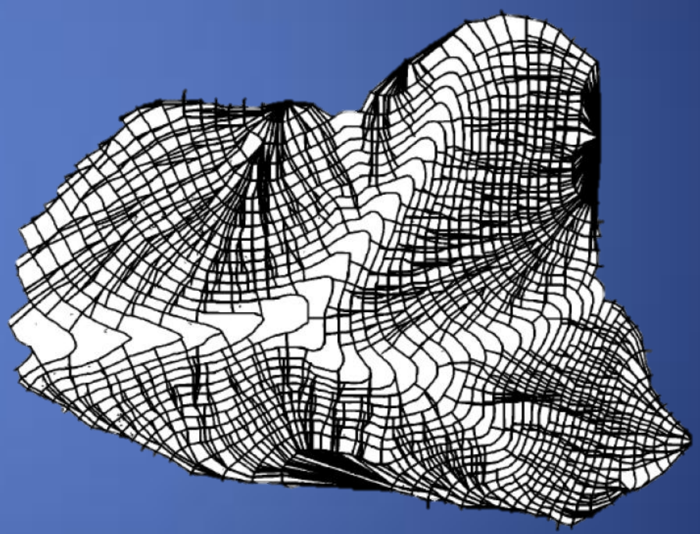
γ_{sat} = the saturated unit weight of soil.

Montgomery and Dietrich Methodology (1994):

- Catchment area is an area of the closed figure formed by the contour portion at the given point of the topographic surface and two flow lines coming from upslope to the ends of the contour portion.



Efflux = Q_0

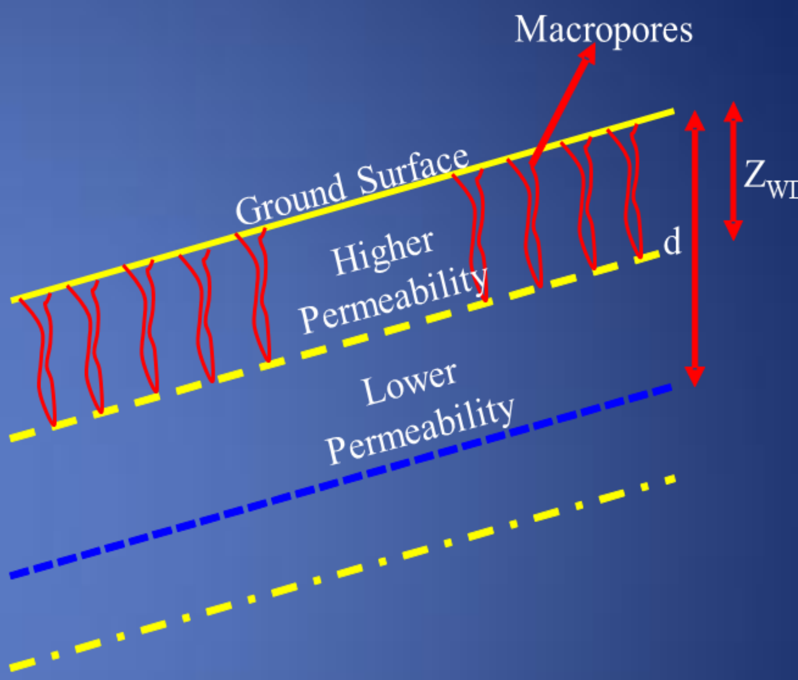


- Tekirdag Region – DEM
- Application of the Papatheodorou and Tzanou (2014) model on Tekirdağ Region using QGIS

Wetting and drying

- Important factor affecting shallow landslides:

Wetting / Drying Process



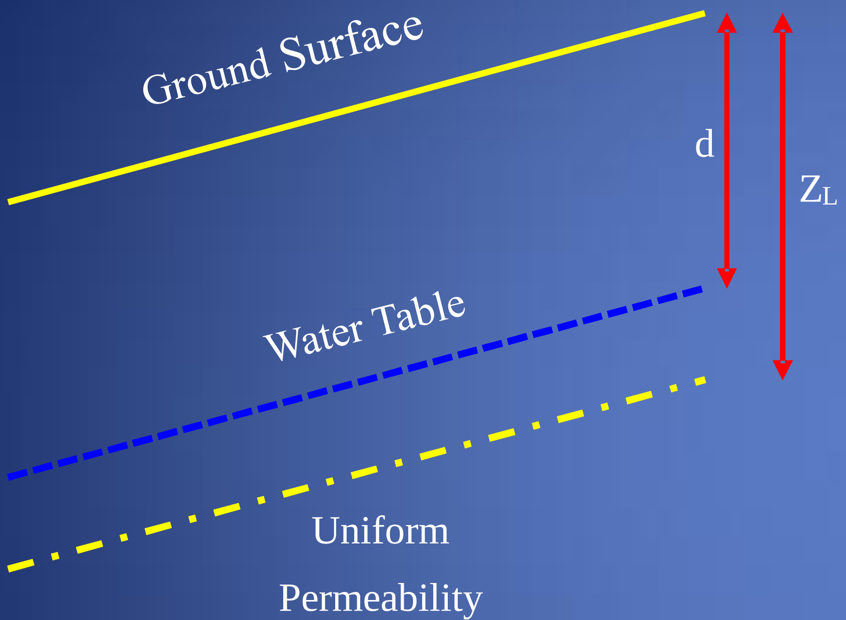
✓ the shallow soil layers are exposed to wetting/drying effects, leading to volume change and thus formation of macropores (Meiers et al. 2011)

✓ the hydraulic conductivity of clay layers increase up to approximately three orders.

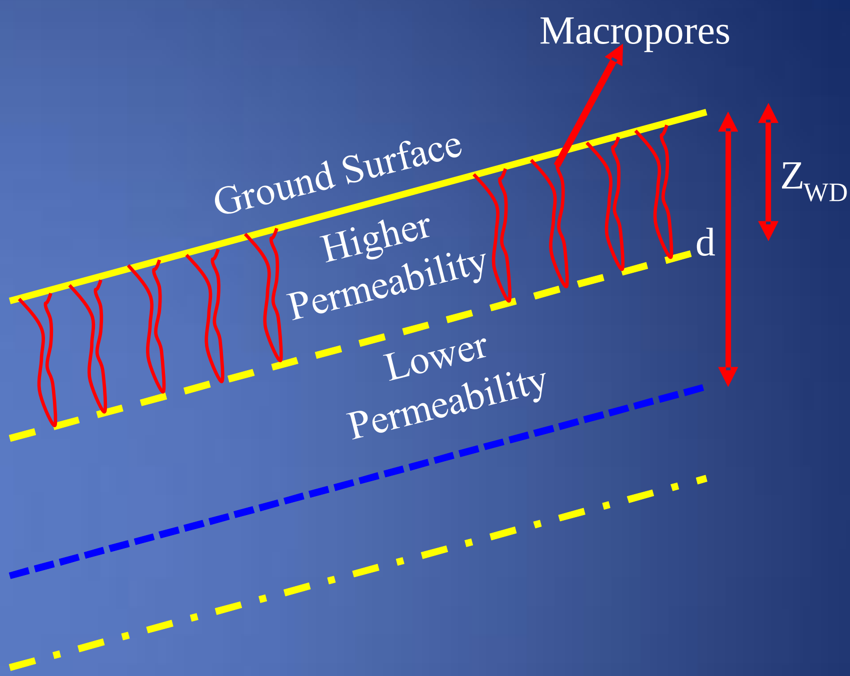
Proposed Methodology

1. Short – Term State (Transient Condition) ($t <= H^2 / D_0$)
   Finite – Depth Boundary Condition: Permeability contrast between the fractured zone and undisturbed beneath soil.
   Infinite – Depth Boundary Condition: No permeability contrast (Uniform permeability through soil layer), (Iverson, 2000)
2. Seepage State ($t >= H / \sqrt{A}$)
   Seepage force introduced in conventional infinite – slope stability equation.

Proposed Methodology



INFINITE – DEPTH
BOUNDARY CONDITION



FINITE – DEPTH
BOUNDARY CONDITION

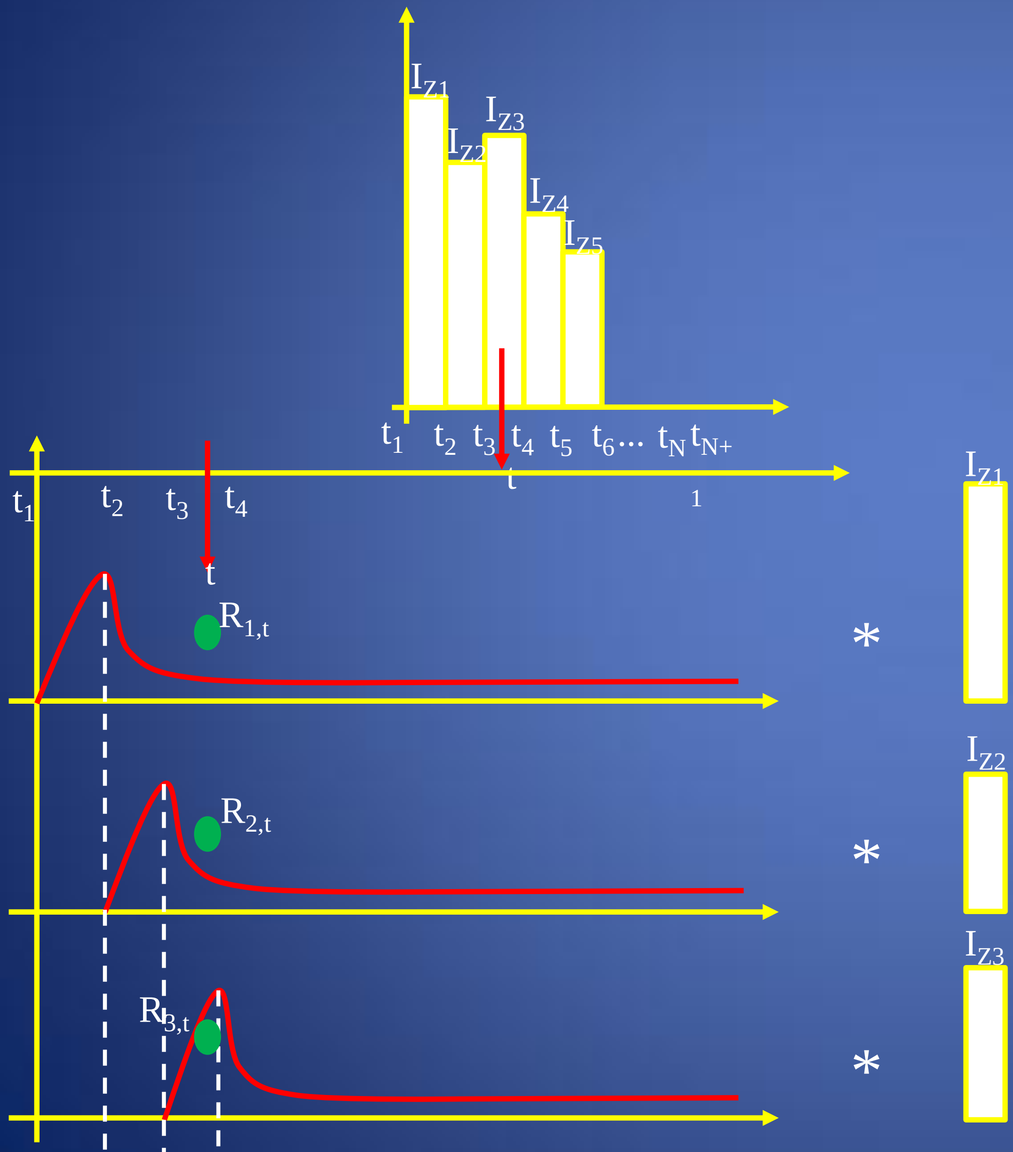
d = Water table depth

Z_L = The last depth the pore pressure calculation is performed in infinite – depth BC.

Z_{WD} = The capillary region depth, where wetting/drying took place

Proposed Methodology

(Solution Method for two different Boundary Conditions)



As a result of dealing with the governing second–order linear partial differential equation, it is required to carry out a solution for each hourly rainfall data in rainfall sequence, thus leading to the superposition of pore pressures generated due to each rainfall data.

Treatment of Rainfall Data Sets

- Two types of rainfall records:
  - ✓ The daily measurements (from 1960 to 2007)
  - ✓ Rainfall records per 10 minutes (from 2007-2014)

- In each Methodology:
  - ✓ Montgomery and Dietrich (1994): *Accumulated daily amount.*
  - ✓ Proposed method: *Hourly pattern of accumulated daily amount.*

Treatment of Rainfall Data Sets

- Rainfall Hazard Approach – I
  - Daily rainfall amount;

    Probability of 1% (1960-2007) = **23 mm/day**

- Rainfall Hazard Approach – II
  - Daily rainfall amount;

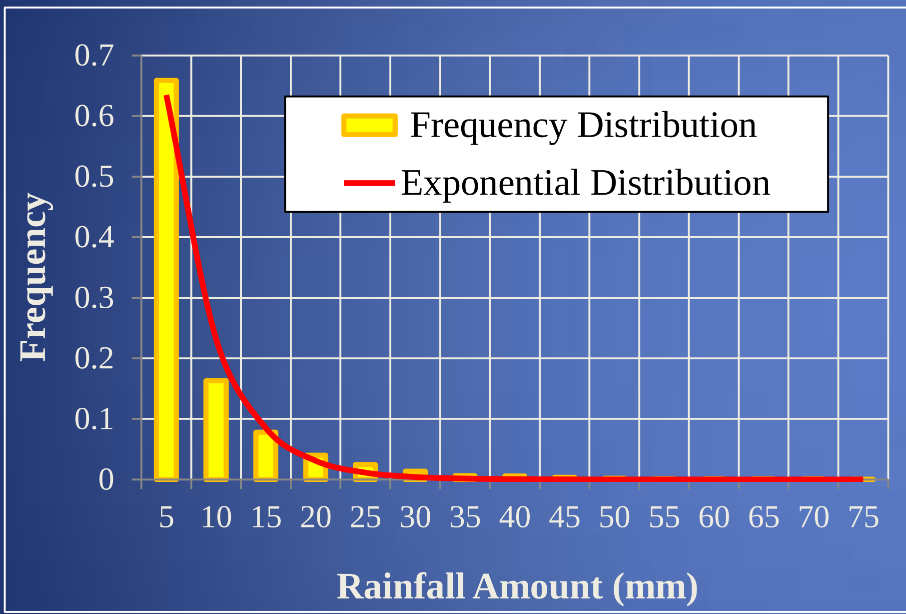
Exceedance Probability of 1% within 1 year (RP = 100 years)

Exceedance probability of 1% within 1 year = **120 mm/day**

Rainfall Hazard Determination (Approach 1)

Rainfall Hazard Criterion → Exceedance of 1% based on available data

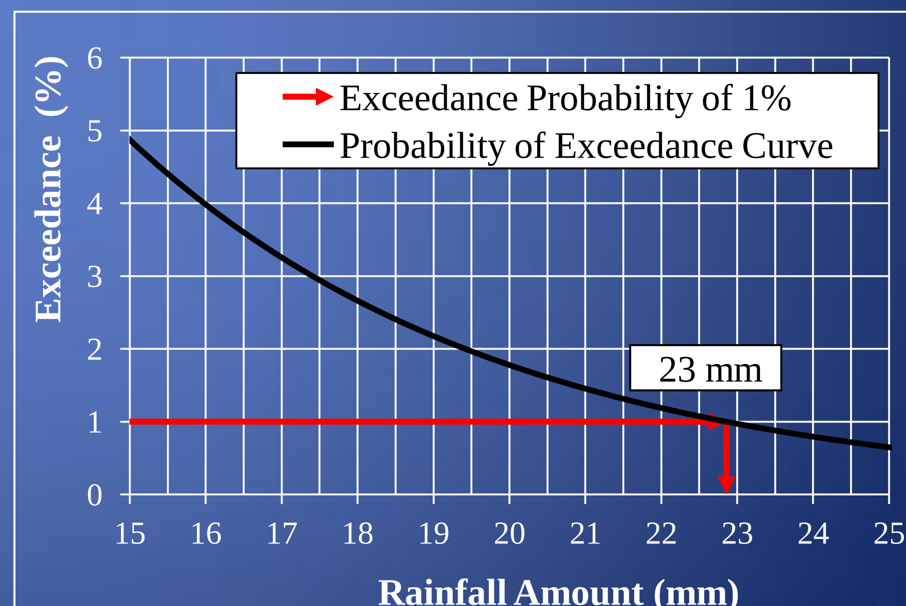
---



1. Daily Rainfall Amount (mm / day)

Data Set:

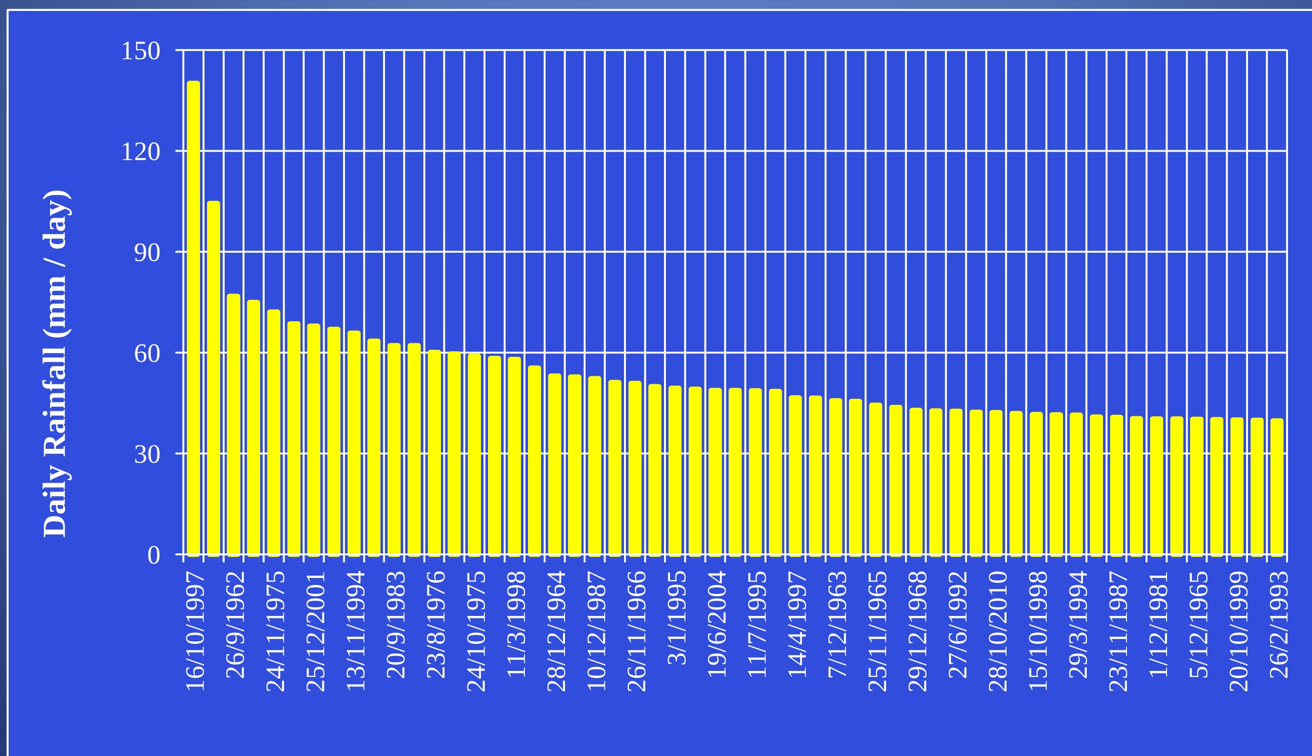
2/1/1960 – 31/8/2014 (19936 Measurements)



Rainfall Hazard Determination (Approach 2)

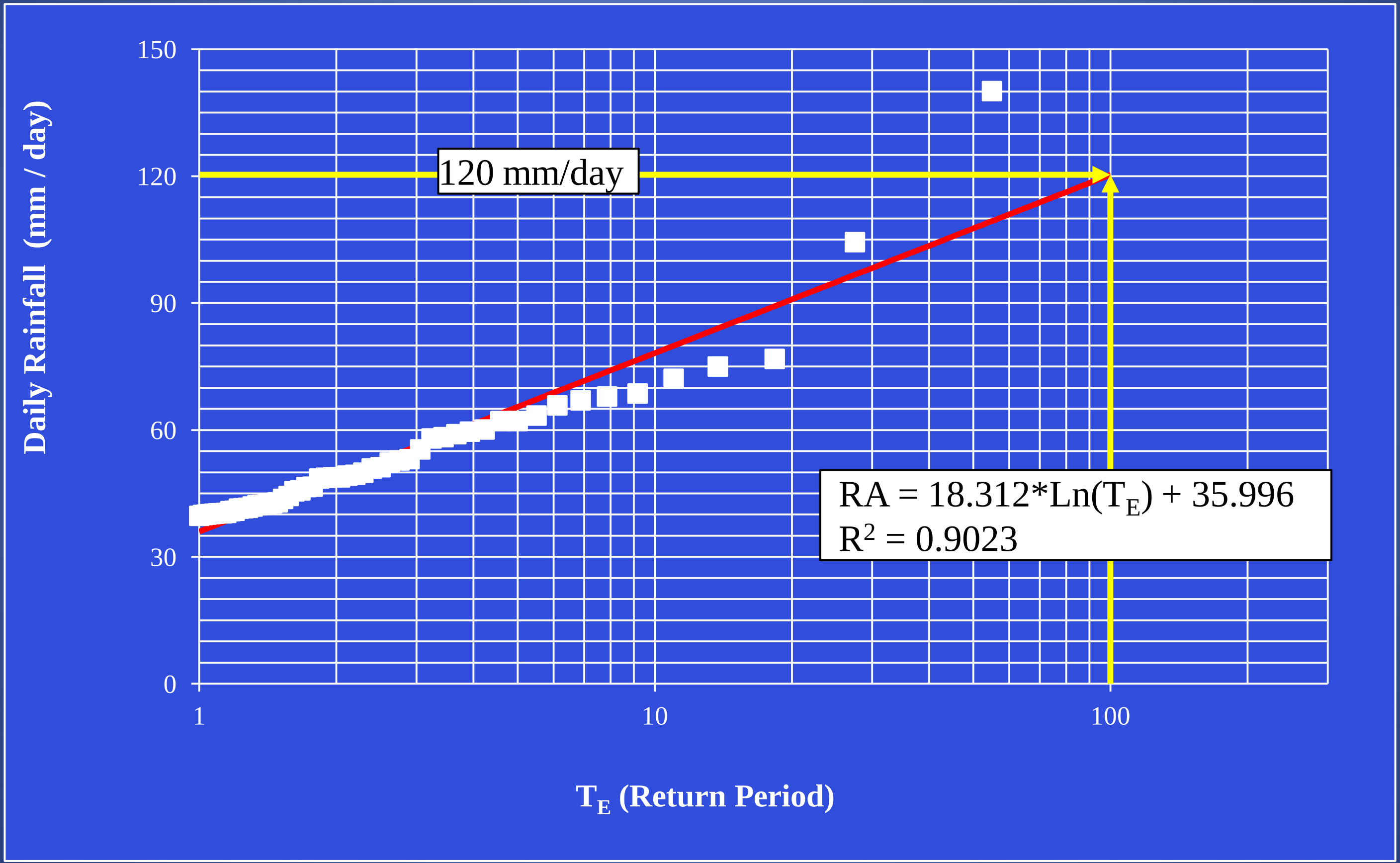
Ven Te Chow (1953) Frequency analysis of hydrologic data with special application to rainfall intensities, University of Illinois Engineering Experiment Station, Bulletin 414

Maximum daily rainfalls considere in rainfall hazard analysis to estimate exceedance probabiities.



Rainfall Hazard Determination (Approach 2)

Annual Exceedance (N Maximum Daily Rainfall)



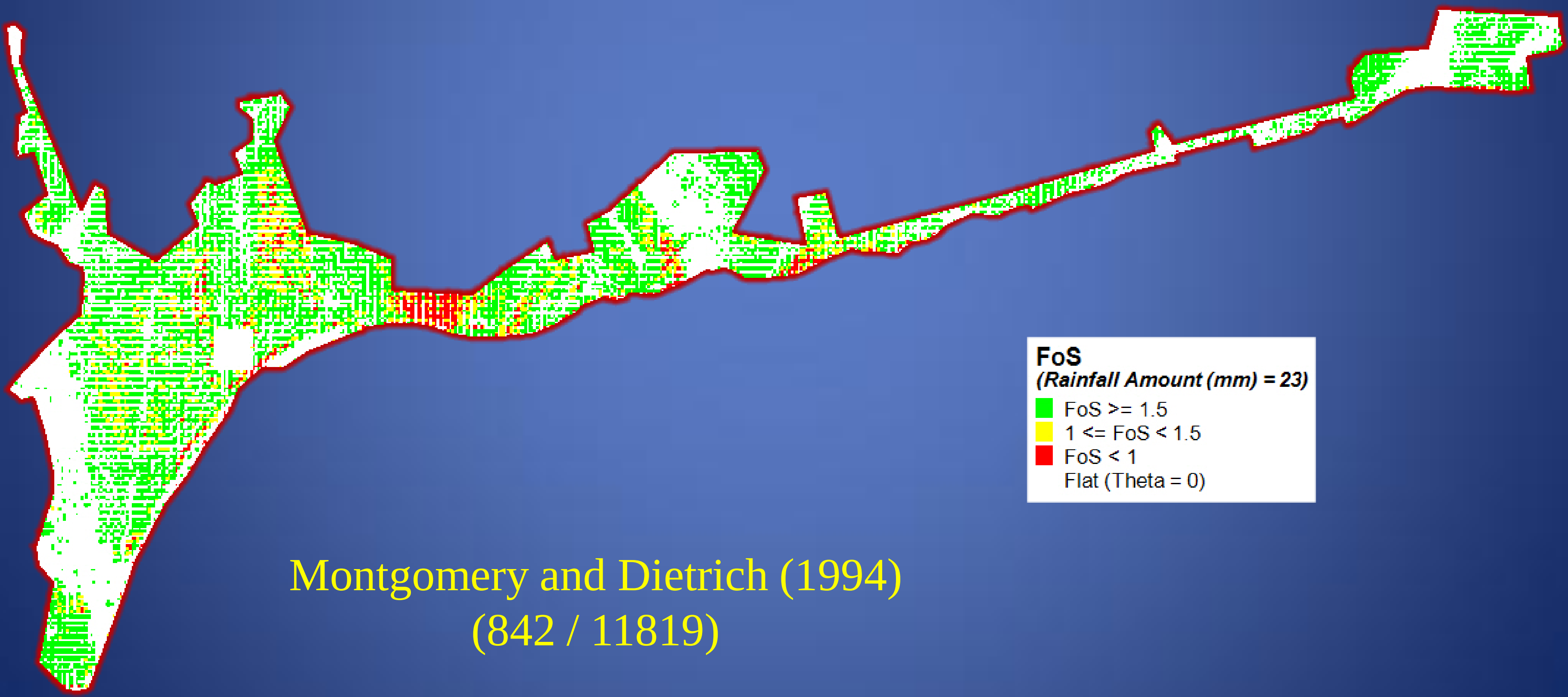
For Tekirdağ Region Case

- Layer depths subjected to wetting/drying are considered equal or slightly higher than the freeze and thaw depth

- Selected depth based borehole data and stratification at the site

Results of Analyses for Tekirdağ Region
(Rainfall Hazard Approach – I)

Rainfall Amount (23 mm):

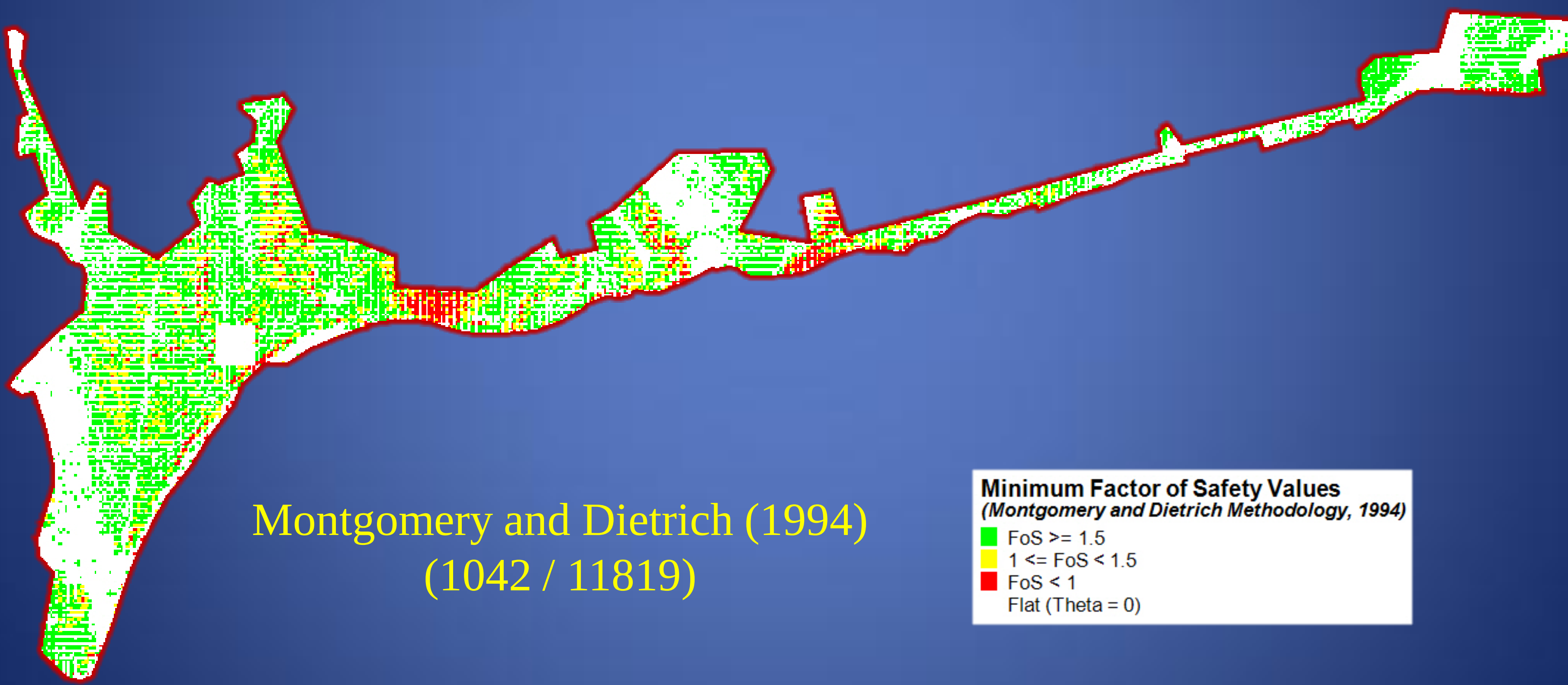


Montgomery and Dietrich (1994)
(842 / 11819)

Proposed Methodology
(1042 / 11819)

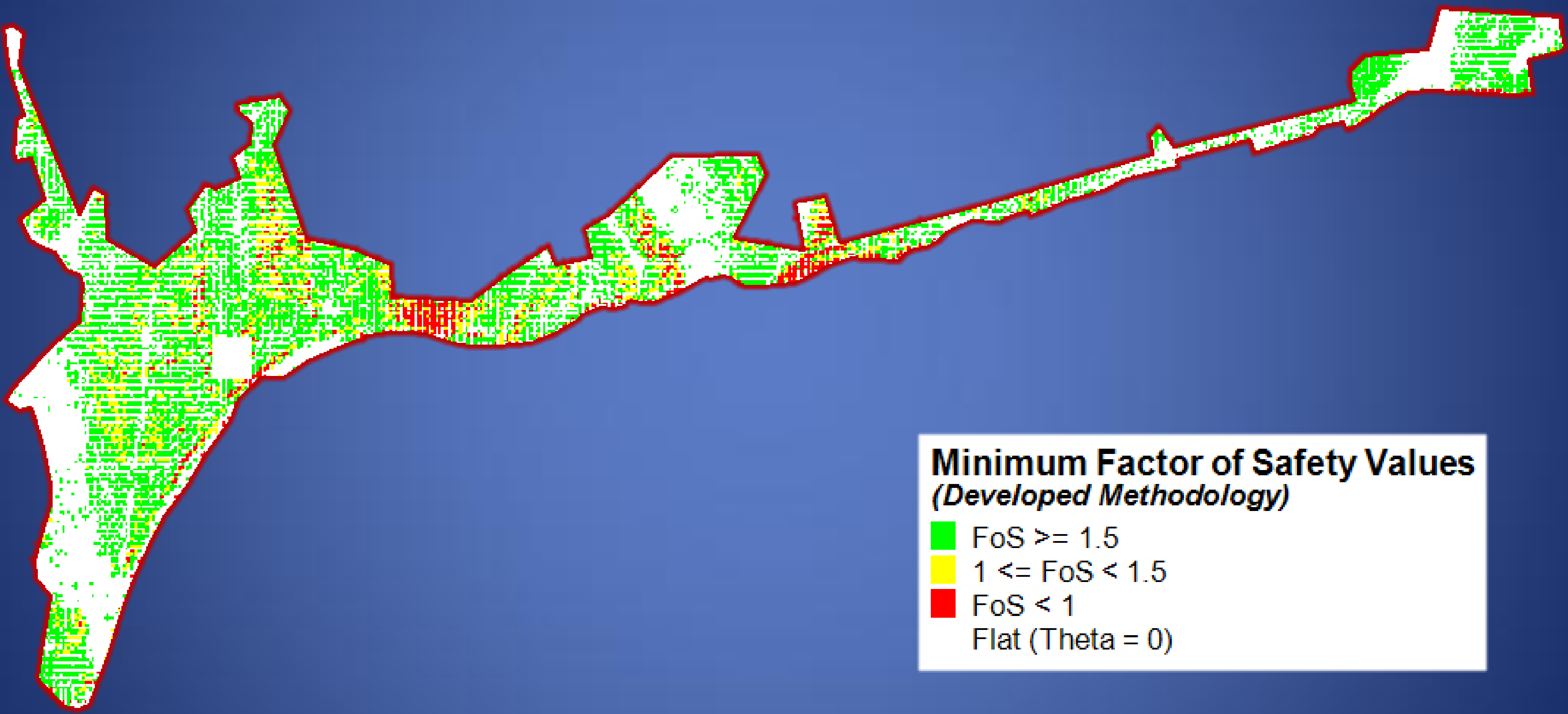
Results of Analyses for Tekirdağ Region
(Rainfall Hazard Approach – II)

Scaled Rainfall Amount (120 mm):



Montgomery and Dietrich (1994)
(1042 / 11819)

Developed Methodology
(1042 / 11819)



Results from Tekirdağ Case Study

- Seepage state, partly not considered in previous studies, may result in an increase in number of cells with low safety factors,
- Variation in rainfall patterns leads to different results in terms of number of cells with low safety factors,
- Probabilistic analysis of rainfall enables to further investigate which amount and pattern of rainfall would lead to the most unfavorable condition (the probabilistic assessment of hourly rainfall intensity)
- The proposed methodology is dependent on the rainfall amount for each cell in comparison to the Montgomery and Dietrich (1994) methodology based on the amount of rainfall for the catchment area.