

# Robust Areal Landslide Prediction (RALP)

version 1.04

Dr. Enok Cheon (3DTSP and GUI), Dr. Emir A. Oguz (3DPLS)  
Dept. of Natural Hazards, NGI, Sandakerveien 140, 0484 Oslo

# Content

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3. 3DTS example
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5. License

# 1. Installation and Setup

## RALP software versions

- If want access to code for quick implementation or running in Linux or MacOS, use “RALP\_v1\_04”
- If user is using Windows PC for the software and do not want to install new Python version, use “RALP\_v1\_04\_window” or install in local computer using “RALP\_v1\_04\_window\_setup.exe”

## Folder Contents – for all platforms (Windows, MacOS, Linux)

 test_case_3DPLS	Example case to run 3DPLS analysis
 test_case_3DTSP	Example case to run 3DTSP analysis
 Functions_3DPLS_v1_1.py	Function python file for 3DPLS
 input_3DPLS.yaml	Template and description of YAML input files for 3DPLS
 input_3DTSP_v20250813_template_and_explanation.yaml	Template and description of YAML input files for 3DTSP
 license.txt	States the license agreement
 Main_3DPLS_v1_1.yaml.py	Main python file used to perform 3DPLS model
 main_3DTSP_v20250813.py	Main python file used to perform 3DTSP model
 NGI_logo_cropped.ico	NGI logo icon
 NGI_logo_cropped.png	NGI logo image
 Python Install and Setup - linux.sh	File to run to set up python and their libraries in Linux
 Python Install and Setup - Mac.sh	File to run to set up python and their libraries in MacOS
 Python Install and Setup - windows.bat	File to run to set up python and their libraries in Windows
 RALP_v1_00.py	RALP GUI python file
 requirements.txt	Python library version requirements
 Robust Areal Landslide Prediction (RALP) - GUI v1.00 - User Manual.pdf	User Manual
 start_GUI_linux_mac.sh	File to start the GUI/software in Linux and MacOS
 start_GUI_windows.bat	File to start the GUI/software in Windows

## For Installing Python and Libraries

### Option 1 – If Python is not installed on the machine (especially MacOS or Windows)

- Run the “Python Install and Setup – Mac.sh” or “Python Install and Setup – windows.bat”
- After installing Python, it will automatically install the required libraries

### Option 2 – If Python is already installed on the machine (especially Linux)

- Make sure these versions of the Python libraries are installed

Or use the pip install commands (on command prompt/PowerShell in Windows and on terminal in MacOS or Linux)

- The version does not necessarily need to match, but it has been tested to work well in this version

Library	Version	Pip install command (Windows)	Pip install command (Mac/Linux)
pyyaml	6.0.1	python -m pip install pyyaml==6.0.1	pip3 install pyyaml==6.0.1
numpy	1.26.4	python -m pip install numpy==1.26.4	pip3 install numpy==1.26.4
pandas	2.2.2	python -m pip install pandas==2.2.2	pip3 install pandas==2.2.2
scipy	1.13.0	python -m pip install scipy==1.13.0	pip3 install scipy==1.13.0
plotly	5.22.0	python -m pip install plotly==5.22.0	pip3 install plotly==5.22.0
laspy	2.5.3	python -m pip install laspy==2.5.3	pip3 install laspy==2.5.3
pykrige	1.7.1	python -m pip install pykrige==1.7.1	pip3 install pykrige==1.7.1
scikit-learn	1.4.2	python -m pip install scikit-learn==1.4.2	pip3 install scikit-learn==1.4.2

# For Opening the Graphical User Interface (GUI)

## Windows

double-click the "start\_GUI\_windows. bat" file in the "RALP\_v1\_04" folder

## MacOS or Linux

follow these steps:

(a) open the terminal

(b) navigate to your terminal into the "RALP\_v1\_04" folder by typing the following command:

*cd <filepath of the folder containing the "RALP\_v1\_04" folder>/RALP\_v1\_04*

(c) copy and type the following command to start the GUI:

*sh start\_GUI\_linux\_mac.sh*

## Folder Contents – for windows only

 help	User manual and template for input YAML file
 python-3.10.11-embed-amd64	Local Python to run RALP
 script	Python and batch scripts for running RALP
 test_case_3DPLS	Example case to run 3DPLS analysis
 test_case_3DTSP	Example case to run 3DTSP analysis
 license.txt	License text
 NGI_logo_cropped.ico	NGI logo icon
 NGI_logo_cropped.png	NGI logo image
 RALP_v1_00_windows.exe	RALP software executable
 RALP_v1_00_windows.pyc	RALP GUI script
 requirements.txt	Python libraries and versions required for RALP

# 2. RALP software interface manual

# User Interface

Robust Areal Landslide Prediction (RALP) v1.00

**Robust Areal Landslide Prediction (RALP)**

Dr. Enok Cheon (3DTSP & GUI) and Dr. Emir A. Oguz (3DPLS) - ver 1.00

**Restart JSON** Select File

**Project Name** Project\_number\_000

**Input Directory** Select Folder

**Results Directory** Select Folder

**Topography and GIS Input**

**DEM** Select GIS

**Soil Depth** Probabilistically Vary Depth  Uniform Depth Assign

**Groundwater** Thickness Above Bedrock Assign

**RiZero** Uniform Assign

**Surface Dip** Open GIS (optional)

**Surface Aspect** Open GIS (optional)

**Bedrock Dip** Open GIS (optional)

**Bedrock Aspect** Open GIS (optional)

**Local Cell Size (Slopes from DEM)** 1

**Slope Stability Analysis**

**Slope Model** 3D Translational Slide (3DTS)

**3DTS Slip Surface** Min Cell 3 Max Cell 6

Superellipse Power 1.0, 2.0, 10.0

Superellipse Eccentricity Ratio 1.0, 1.3333, 1.5, 2.0

**3DTS Resistances** Side  Root van Zadelhoff et al. (2021)

**Type** Drained

**Ellipsoidal Slip Surface** a (m) 100.0 b (m) 20.0  
c (m) 2.5 z (m) 1.0  
Ellipsoidal  $\alpha$  Comp   $\alpha$  ( $^{\circ}$ ) 0.0  
Minimum Soil Column Number 200

**Critical FS** 1.0

**Debris-Flow Criteria**  Upload Files network UCA Criteria

**Hydraulic Analysis**

**Rainfall History** Uniform Assign

Intensity Unit mm/hr Time Subdivision 1

**Infiltration Model** Green-Ampt SWCC Model van Genutchen (1980)

**Y\_W** 9.81 Surface Dip for Green-Ampt

**Probabilistic Analysis**

Monte Carlo Iterations 1000

Random Field Method SCMD Save Correlation Matrix

**Material Properties Assignment**

Material Assign Uniform Material Number 1 Assign

**Post-Analysis (3DPLS)**

Landslide Source Select GIS (optional)

Investigation Zone Full Extent

min row 0 min col 0 max row 0 max col 0

Investigation Time Final Time  hr

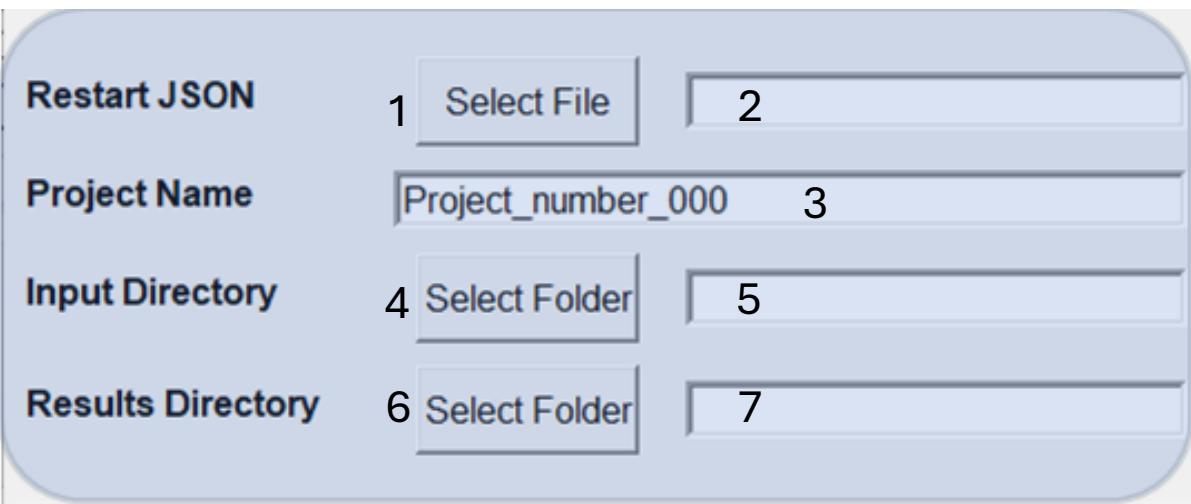
**Result Format** asc Soil dZ 0.25

**Generate Plots**  Multi CPU  maxCPU 16

Rain Template Rain CSV Material Template Material CSV

Help Open Folders Setup Run

## User Interface – Project name and Directory



- 1. Select Overall JSON input (for 3DTSP)**
  - Navigate and search for the overall JSON input file which contains all the information needed to restart the simulation
- 2. Overall JSON input file name**
  - Name of the Overall JSON input of 3DTSP analysis
- 3. Project Name**
  - Name of the simulation run
  - Used to generate the output files
  - Default name assigned
  - Delete the text to fill in the project name that the user wants
- 4. Select Input Directory**
  - Navigate and search for the folder directory where all analysis files are stored
- 5. Input Directory**
  - Text showing the input directory
  - Can manually change the input directory with this text box
- 6. Select Results Directory**
  - Navigate and search for the folder directory where all simulation results are saved
- 7. Results Directory**
  - Text showing the results directory
  - Can manually change the results directory with this text box

# User Interface – Topography and GIS Input

Topography and GIS Input

DEM	1 Select GIS	2
Soil Depth	Probabilistically Vary Depth	3 <input type="checkbox"/>
	4 Uniform Depth	5 Assign
Groundwater	6 Thickness Above Bedrock	7 Assign
RiZero	8 Uniform	9 Assign
Surface Dip	10 Open GIS	(optional) 11
Surface Aspect	12 Open GIS	(optional) 13
Bedrock Dip	14 Open GIS	(optional) 15
Bedrock Aspect	16 Open GIS	(optional) 17
Local Cell Size (Slopes from DEM)	1	18

1. **Select digital elevation model (DEM) file**
  - Navigate and select the DEM file
2. **DEM file name**
  - Text showing the file name of DEM file
  - Can manually change the DEM file name with this text box
3. **Option to perform probabilistic soil depth**
  - Uses the standard normal distribution and varies the soil depth using coefficient of variation (CoV):  
 $\min \leq \text{soil depth} [= \text{mean} * (1 + \text{CoV} * \text{normal}(0, 1))] \leq \max$
4. **Options for modelling soil depth (mean value)**
  - *Uniform Depth* – assign uniform soil depth value
  - *GIS file* – use GIS data
  - *Holm (2012) & Edvarson (2013)* – use correlation by Holm (2012) & Edvarson (2013):  
$$\text{depth} = -2.578 * \tan(\text{surface\_dip}) + 2.612$$
  - *Linear Multiregression* – use multilinear regression:  
$$\text{depth} = b_0 + p_1 * b_1 + \dots + p_n * b_n$$
  - *Power Multiregression* – use multilinear regression:  
$$\text{depth} = b_0 * p_1^{b_1} * \dots * p_n^{b_n}$$
5. **Soil Depth Data Assign**
  - Opens a new window to assign soil depth data or requires GIS files to be uploaded (for *GIS file* option)

## User Interface – Topography and GIS Input

### Probabilistically Vary Depth and Soil Depth Option: Uniform Depth

NGL Uniform Soil Depth

**Uniform Soil Depth**

Mean Soil Depth (m) 0.0

Min Soil Depth (m) 0.0

Max Soil Depth (m) 0.0

CoV 0.0

Assign

Assign uniform soil depth

### Probabilistically Vary Depth and Soil Depth Option: Uniform Depth

NGL Uniform Soil Depth

**Uniform Soil Depth**

Mean Soil Depth (m) 0.0

Min Soil Depth (m) 0.0

Max Soil Depth (m) 0.0

CoV 0.0

Assign

Assign uniform mean soil depth.

For probabilistic soil depth, the minimum, maximum, and coefficient of variation (CoV) can be assigned.

$$\text{min soil depth} \leq \text{uniform depth} * (1 + \text{CoV} * \text{normal}(0, 1)) \leq \text{max soil depth}$$

## User Interface – Topography and GIS Input

### Probabilistically Vary Depth and Soil Depth Option: *Holm (2012) & Edvarson (2013)*

NCI Holm (2012) &... - X

**Dip-Based Soil Depth Range**

Min Soil Depth (m) 0.0

Max Soil Depth (m) 0.0

CoV 0.0

Assign

Assign minimum and maximum soil depth range,  
Such that the following equation does not compute negative values:  
$$\text{depth} = -2.578 \cdot \tan(\text{surface\_dip}) + 2.612$$

### Probabilistically Vary Depth and Soil Depth Option: *Holm (2012) & Edvarson (2013)*

NCI Holm (2012) &... - X

**Dip-Based Soil Depth Range**

Min Soil Depth (m) 0.0

Max Soil Depth (m) 0.0

CoV 0.0

Assign

Assign minimum and maximum soil depth range,  
Such that the following computed mean depth does not compute negative values:  
$$\text{mean depth} = -2.578 \cdot \tan(\text{surface\_dip}) + 2.612$$

Coefficient of variation (CoV) can be assigned for:  
$$\text{min soil depth} \leq \text{mean depth} * (1 + \text{CoV} * \text{normal}(0, 1)) \leq \text{max soil depth}$$

## User Interface – Topography and GIS Input

### Probabilistically Vary Depth and Soil Depth Option: Power Multiregression or Linear Multiregression

Soil Depth Multiregression

Regression Soil Depth

Number of Parameters	Coefficient	File Name
1	10	4
2	0.0	5
3	0.0	
CoV	0.0	
Intercept	0.0	
Parameter 1	0.0	6 Select
Parameter 2	0.0	Select
Parameter 3	0.0	Select
Parameter 4	0.0	Select
Parameter 5	0.0	Select
Parameter 6	0.0	Select
Parameter 7	0.0	Select
Parameter 8	0.0	Select
Parameter 9	0.0	Select
Parameter 10	0.0	Select

Assign 7

1. Number of independent variables (1 – 10)
2. Minimum soil depth
3. Maximum soil depth
4. Corresponding  $b_n$  factors (max assigned based on “number of parameters”)
  - *Linear Multiregression:* soil depth =  $(b_0 + p_1 \cdot b_1 + \dots + p_n \cdot b_n)$
  - *Power Multiregression:* soil depth =  $(b_0 \cdot p_1^{b_1} \cdot \dots \cdot p_n^{b_n})$
5. File name of the selected GIS file containing the independent factors ( $p_n$ )
6. Open the GIS file that contains the corresponding factor ( $p_n$ )
7. Confirm the data specified

## User Interface – Topography and GIS Input

### Probabilistically Vary Depth and Soil Depth Option: Power Multiregression or Linear Multiregression

NRI Soil Depth Multiregression

Regression Soil Depth

Number of Parameters	1	5
Min Depth (m)	2	0.0
Max Depth (m)	3	10.0
CoV	4	0.0

Coefficient 5 File Name 6

Intercept	0.0	
Parameter 1	0.0	7 Select
Parameter 2	0.0	Select
Parameter 3	0.0	Select
Parameter 4	0.0	Select
Parameter 5	0.0	Select
Parameter 6	0.0	Select
Parameter 7	0.0	Select
Parameter 8	0.0	Select
Parameter 9	0.0	Select
Parameter 10	0.0	Select

Assign 8

1. Number of independent variables (1 – 10)
2. Minimum soil depth
3. Maximum soil depth
4. Coefficient of variation (CoV)
5. Corresponding  $b_n$  factors (max assigned based on “number of parameters”)
  - *Linear Multiregression:* mean soil depth =  $(b_0 + p_1 \cdot b_1 + \dots + p_n \cdot b_n)$
  - *Power Multiregression:* mean soil depth =  $(b_0 \cdot p_1^{b_1} \cdot \dots \cdot p_n^{b_n})$   
min soil depth  $\leq$  mean depth  $\cdot (1 + \text{CoV} \cdot \text{normal}(0, 1)) \leq$  max soil depth
6. File name of the selected GIS file containing the independent factors ( $p_n$ )
7. Open the GIS file that contains the corresponding factor ( $p_n$ )
8. Confirm the data specified

## User Interface – Topography and GIS Input

**Topography and GIS Input**

DEM	1 Select GIS	2
Soil Depth	Probabilistically Vary Depth	3 <input type="checkbox"/>
	4 Uniform Depth	5 Assign
Groundwater	6 Thickness Above Bedrock	7 Assign
RiZero	8 Uniform	9 Assign
Surface Dip	10 Open GIS	(optional) 11
Surface Aspect	12 Open GIS	(optional) 13
Bedrock Dip	14 Open GIS	(optional) 15
Bedrock Aspect	16 Open GIS	(optional) 17
Local Cell Size (Slopes from DEM)	1	18

## 6. Options for Modelling Groundwater Table

- *Thickness Above Bedrock* – assign the groundwater table (henceforth, GWT) to be a vertical distance above the bedrock level  
GWT = min{ground surface, bedrock surface + thickness}
- *Depth From Surface* – assign the GWT to be a vertical distance below the ground surface level  
GWT = max{bedrock surface, ground surface - thickness}
- *% of Soil Thickness Above Bedrock* – assign the GWT to be a fraction of the soil thickness above the bedrock level
  - 0 = GWT on bedrock
  - >0 and <1 -> GWT = bedrock surface + (percentage/100)\*soil thickness
  - 1 = GWT on surface
- *% of Soil Thickness From Surface* - assign the GWT to be a fraction of the soil thickness below the ground surface
  - 0 = GWT on surface
  - >0 and <1 -> GWT = ground surface - (percentage/100)\*soil thickness
  - 1 = GWT on bedrock
- *GWT elevation GIS* – groundwater table in elevation Z

## 7. Groundwater Table Data Assign

- Opens a new window to assign soil depth data or requires GIS files to be uploaded (for *G/S file* option)

# User Interface – Topography and GIS Input

## Groundwater Option: *Thickness Above Bedrock*

This dialog box allows users to assign groundwater thickness above bedrock. It includes fields for Type of Data (number or GIS), Value (numerical input), and GIS filename (text input). A 'Select' button is provided for GIS files, and an 'Assign' button is used to confirm the settings.

Type of Data	Value	GIS filename	Action
number	1	0.0	3
	2		4 Select
			5 Assign

## Groundwater Option: *% of Soil Thickness Above Bedrock*

This dialog box allows users to assign groundwater as a percentage of soil thickness above bedrock. It includes fields for Type of Data (number or GIS), Value (numerical input), and GIS filename (text input). A 'Select' button is provided for GIS files, and an 'Assign' button is used to confirm the settings.

Type of Data	Value	GIS filename	Action
number	1	0.0	3
	2		4 Select
			5 Assign

## Groundwater Option: *Depth From Surface*

This dialog box allows users to assign groundwater depth from the surface. It includes fields for Type of Data (GIS or number), Value (numerical input), and GIS filename (text input). A 'Select' button is provided for GIS files, and an 'Assign' button is used to confirm the settings.

Type of Data	Value	GIS filename	Action
GIS	1	0.0	3
	2		4 Select
			5 Assign

## Groundwater Option: *% of Soil Thickness From Surface*

This dialog box allows users to assign groundwater as a percentage of soil thickness from the surface. It includes fields for Type of Data (number or GIS), Value (numerical input), and GIS filename (text input). A 'Select' button is provided for GIS files, and an 'Assign' button is used to confirm the settings.

Type of Data	Value	GIS filename	Action
number	1	0.0	3
	2		4 Select
			5 Assign

1. Data type option
  - *number* – assign this value uniformly everywhere
  - *GIS* – use a GIS file to specify a spatially varying value
2. Numerical value – use decimal for % values
3. File name of the selected GIS file containing the spatially varying value
4. Open the GIS file
5. Confirm the data specified

## User Interface – Topography and GIS Input

Topography and GIS Input

DEM	1 Select GIS	2
Soil Depth	Probabilistically Vary Depth	3 <input type="checkbox"/>
	4 Uniform Depth	5 Assign
Groundwater	6 Thickness Above Bedrock	7 Assign
RiZero	8 Uniform	9 Assign
Surface Dip	10 Open GIS	(optional) 11
Surface Aspect	12 Open GIS	(optional) 13
Bedrock Dip	14 Open GIS	(optional) 15
Bedrock Aspect	16 Open GIS	(optional) 17
Local Cell Size (Slopes from DEM)	1	18

### 8. Options for RiZero (for Iverson infiltration)

- Uniform - assign single value to all regions
- GIS file – assign GIS file containing information

### 9. RiZero Data Assign (for Iverson infiltration)

- Opens a new window to assign RiZero value or requires GIS files to be uploaded (for GIS file option)

### 10. Select Surface dip file (optional)

- Navigate and select the GIS file containing the ground surface dip value

### 11. Surface dip GIS file name (optional)

- If assigned, it shows the file name of the ground surface dip GIS file, which can manually be changed with this text box
- If unassigned, computed from DEM and soil depth

### 12. Select Surface Aspect file (optional)

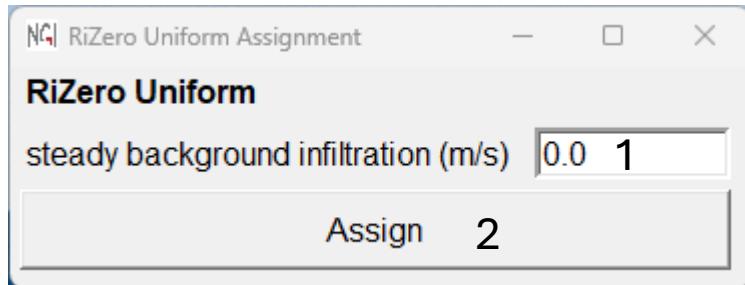
- Navigate and select the GIS file containing the ground surface aspect value

### 13. Surface Aspect GIS file name (optional)

- If assigned, it shows the file name of the ground surface aspect GIS file, which can manually be changed with this text box
- If unassigned, computed from DEM and soil depth

## User Interface – Topography and GIS Input

### RiZero Option: Uniform



1. Assign steady background infiltration for Iverson (2000)
2. Confirm the data specified

## User Interface – Topography and GIS Input

Topography and GIS Input

DEM	1 Select GIS	2
Soil Depth	Probabilistically Vary Depth	3 <input type="checkbox"/>
	4 Uniform Depth	5 Assign
Groundwater	6 Thickness Above Bedrock	7 Assign
RiZero	8 Uniform	9 Assign
Surface Dip	10 Open GIS	(optional) 11
Surface Aspect	12 Open GIS	(optional) 13
Bedrock Dip	14 Open GIS	(optional) 15
Bedrock Aspect	16 Open GIS	(optional) 17
Local Cell Size (Slopes from DEM)	1	18

### 14. Select bedrock dip file (optional)

- Navigate and select the GIS file containing the bedrock surface dip value

### 15. Bedrock dip GIS file name (optional)

- If assigned, it shows the file name of the bedrock surface dip GIS file, which can manually be changed with this text box
- If unassigned, computed from DEM and soil depth

### 16. Select Bedrock Aspect file (optional)

- Navigate and select the GIS file containing the bedrock surface aspect value

### 17. Bedrock Aspect GIS file name (optional)

- If assigned, it shows the file name of the bedrock surface aspect GIS file, which can manually be changed with this text box
- If unassigned, computed from DEM and soil depth

### 18. Local cell size

- Integer number indicating the size of DEM cell used to perform bilinear interpolation to compute the dip and aspect data
- Default = 1

# User Interface – Slope Stability Analysis Input

Slope Stability Analysis

Slope Model	3D Translational Slide (3DTS) 1					
3DTS Slip Surface	Min Cell	3	2	Max Cell	6	3
Superellipse Power	1.0, 2.0, 10.0			4		
Superellipse Eccentricity Ratio	1.0, 1.3333, 1.5, 2.0			5		
3DTS Resistances	Side	6	<input checked="" type="checkbox"/>	Root	7	van Zadelhoff et al. (2021)
Type	Drained			8		
Ellipsoidal Slip Surface	a (m)	100.0	9	b (m)	20.0	10
	c (m)	2.5	11	z (m)	1.0	12
	Ellipsoidal $\alpha$ Comp	13	<input checked="" type="checkbox"/>	$\alpha$ ( $^{\circ}$ )	0.0	14
	Minimum Soil Column Number			200	15	
Critical FS	1.0	16				
Debris-Flow Criteria	<input type="checkbox"/> 17	Upload Files	network	UCA	Criteria	
	18	19	20			

## 1. Select slope stability analysis model

- (Opt. 1) *Skip (only perform infiltration)* – no slope stability analysis is performed – only perform Green-Ampt rainfall infiltration
- (Opt. 2) *Infinite Slope*
- (Opt. 3) *3D Translational Slide (3DTS)* – assign model parameters from 2 to 7
- (Opt. 4) *3D Normal* – perform 3DPLS model – assign model parameters from 8 to 14
- (Opt. 5) *3D Bishop* – perform 3DPLS model – assign model parameters from 8 to 14
- (Opt. 6) *3D Janbu* – perform 3DPLS model – assign model parameters from 8 to 14

# User Interface – Slope Stability Analysis Input

**Slope Stability Analysis**

Slope Model	3D Translational Slide (3DTS) 1					
3DTS Slip Surface	Min Cell	3 2	Max Cell	6 3		
Superellipse Power	1.0, 2.0, 10.0		4			
Superellipse Eccentricity Ratio	1.0, 1.3333, 1.5, 2.0		5			
3DTS Resistances	Side	6	<input checked="" type="checkbox"/>	Root	7	van Zadelhoff et al. (2021)
Type	Drained		8			
Ellipsoidal Slip Surface	a (m)	100.0	9	b (m)	20.0	10
	c (m)	2.5	11	z (m)	1.0	12
	Ellipsoidal $\alpha$ Comp	13	<input checked="" type="checkbox"/>	$\alpha$ ( $^{\circ}$ )	0.0	14
	Minimum Soil Column Number		200	15		
Critical FS	1.0	16				
Debris-Flow Criteria	<input type="checkbox"/> 17	Upload Files		network	UCA	Criteria
	18	19	20			

## 2. Minimum DEM cell size for 3DTS slip surface

- Integer number indicating the smallest 3DTS slip surface based on the number of DEM cell

## 3. Maximum DEM cell size for 3DTS slip surface

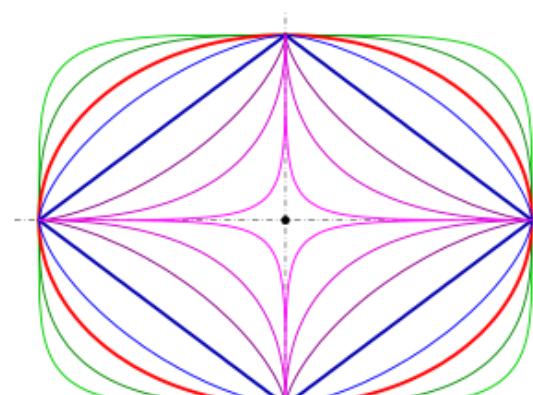
- Integer number indicating the largest 3DTS slip surface based on the number of DEM cell
- If value equal to value as “Min Cell”, single size used

## 4. Superellipse Power for 3DTS slip surface

- Power coefficient (n) used to determine the shape of the 3DTS slip surface
- If multiple, separate them using comma (,)

## 5. Superellipse Eccentricity Ratio for 3DTS slip surface

- 3DTS slip surface eccentricity ratio used to change the size of shapes
- If multiple, separate them using comma (,)



n = 5, 3, 2, 1.5, 1, 0.7, 0.5, 0.3

## Superellipse Equation

$$\left| \frac{x}{a} \right|^n + \left| \frac{y}{b} \right|^n = 1$$

n = Superellipse Power

a/b = b/a = Superellipse Eccentricity Ratio

a = size in x-direction

b = size in y-direction

# User Interface – Slope Stability Analysis Input

Slope Stability Analysis							
Slope Model	3D Translational Slide (3DTS) 1						
3DTS Slip Surface	Min Cell	3	2	Max Cell	6	3	
Superellipse Power	1.0, 2.0, 10.0			4			
Superellipse Eccentricity Ratio	1.0, 1.3333, 1.5, 2.0			5			
3DTS Resistances	Side	6	<input checked="" type="checkbox"/>	Root	7	van Zadelhoff et al. (2021)	

## 6. Side resistance consideration for 3DTS

- Checkbox. If checked (the check mark is visible), the side resistance will be considered in 3DTS

## 7. Root reinforcement model for 3DTS

- (Opt. 1) *None* – root reinforcement not considered
- (Opt. 2) *Constant with Depth*
- (Opt. 3) *van Zadelhoff et al. (2022)*

### (Opt. 2) Constant with Depth

$$Q_{root,base} = \begin{cases} c_{root,b} A_b & , z \geq z_r \\ 0 & , z < z_r \end{cases}$$

$$Q_{root,side} = c_{root,s} A_s = c_{root,s} \cdot (length \cdot \min\{z, z_r\})$$

As = side area; Ab = base area;

z = depth of slide surface; z<sub>r</sub> = depth of root present

### (Opt. 3) van Zadelhoff et al. (2022)

$$\Gamma_{\text{PDF}}(x|\alpha, \beta) = \frac{x^{\alpha-1} e^{-\beta x}}{\beta^{-\alpha} \Gamma(\alpha)}, \quad (x, \alpha, \beta > 0).$$

$$RR_{\max} = (c \cdot DBH) \cdot \Gamma_{\text{PDF}}\left(\frac{D_{\text{trees}}}{DBH \cdot 18.5} \middle| \alpha_1, \beta_1\right).$$

$$R_{\text{lat}} = RR_{\max} \cdot \int_0^{H_{\text{soil}}} \Gamma_{\text{PDF}}\left(H \middle| \alpha_2, \beta_2\right) dH.$$

$$R_{\text{bas}} = RR_{\max} \cdot \Gamma_{\text{PDF}}(H_{\text{soil}}|\alpha_2, \beta_2),$$

# User Interface – Slope Stability Analysis Input

Slope Stability Analysis	
Slope Model	3D Translational Slide (3DTS) 1
3DTS Slip Surface	Min Cell 3 2 Max Cell 6 3
Superellipse Power	1.0, 2.0, 10.0 4
Superellipse Eccentricity Ratio	1.0, 1.3333, 1.5, 2.0 5
3DTS Resistances	Side 6 <input checked="" type="checkbox"/> Root 7 van Zadelhoff et al. (2021)
Type	Drained 8
Ellipsoidal Slip Surface	a (m) 100.0 9 b (m) 20.0 10 c (m) 2.5 11 z (m) 1.0 12 Ellipsoidal $\alpha$ Comp 13 <input checked="" type="checkbox"/> $\alpha$ ( $^{\circ}$ ) 0.0 14 Minimum Soil Column Number 200 15
Critical FS	1.0 16
Debris-Flow Criteria	<input type="checkbox"/> 17 Upload Files network 18 UCA 19 Criteria 20

## 8. 3DPLS model soil condition type

- (Opt. 1) Drained
- (Opt. 2) Undrained

## 9 ~ 14. Ellipsoidal slip surface parameter for 3DPLS model

- Parameter a, b, c, z, and  $\alpha$  defined in figure below

## 13. Direction angle $\alpha$ auto-compute option

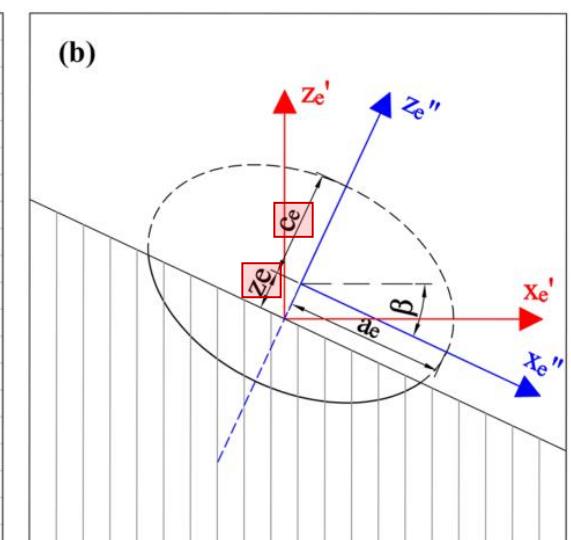
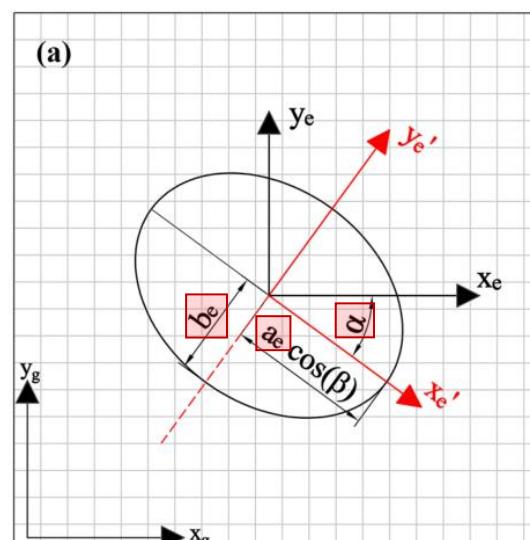
- If checked, the direction angle  $\alpha$  is computed from the average aspect direction

## 14. Direction angle $\alpha$ assign

- If the auto-compute option (13.) is unchecked, the direction angle  $\alpha$  can directly assigned

## 15. Minimum soil column required for ellipsoidal surface

- The 3DPLS model will generate soil columns that would exceed the specified minimum value



# User Interface – Slope Stability Analysis Input

Slope Stability Analysis	
Slope Model	3D Translational Slide (3DTS) 1
3DTS Slip Surface	Min Cell 3 2 Max Cell 6 3
Superellipse Power	1.0, 2.0, 10.0 4
Superellipse Eccentricity Ratio	1.0, 1.3333, 1.5, 2.0 5
3DTS Resistances	Side 6 <input checked="" type="checkbox"/> Root 7 van Zadelhoff et al. (2021)
Type	Drained 8
Ellipsoidal Slip Surface	a (m) 100.0 9 b (m) 20.0 10 c (m) 2.5 11 z (m) 1.0 12 Ellipsoidal $\alpha$ Comp 13 <input checked="" type="checkbox"/> $\alpha$ ( $^{\circ}$ ) 0.0 14 Minimum Soil Column Number 200 15
Critical FS	1.0 16
Debris-Flow Criteria	<input type="checkbox"/> 17 Upload Files
	network 18 UCA 19 Criteria 20

## 16. Critical factor of safety (FS)

- FS threshold at which any DEM cell with computed  $FS < \text{critical FS}$  will be considered to have failed
- For probabilistic analysis, it will be used to compute the frequency of incidents where  $FS < \text{critical FS}$

## 17. Apply debris-flow criteria (Kang et al., 2017)

- Checkbox. If checked, the debris-flow criteria will be considered in 3DTS model to determine whether the location will transition into debris flow (large movement) or remain as slide (small movement)

## 18. Upload DEM network (optional)

- Navigate and search for the DEM network file used for debris-flow criteria

## 19. Upload UCA GIS file (optional)

- Navigate and search for the GIS file containing upslope contribution area (UCA) data used for debris-flow criteria

## 20. Upload determined Criteria (optional)

- Navigate and search for the GIS file containing the Criteria data (0 = remain as slide or 1 = transition into debris-flow) used for debris-flow criteria

## User Interface – Topography and GIS Input

### Debris-flow criteria (Kang et al., 2017)

If a landslide occurs ( $FS < \text{critical } FS$ ) and satisfies these two criteria, the shallow landslide will transition to debris flow.

If a landslide occurs ( $FS < \text{critical } FS$ ) but does not satisfy these two criteria, the shallow landslide will not develop into debris flow.

Criteria 1:  $UCA \geq 500 \text{ m}^2$

Criteria 2: slope  $\geq 34 \exp(-0.003 * UCA) + 14.32^\circ$

# User Interface – Hydraulic Analysis

Hydraulic Analysis

Rainfall History	Uniform	1	2 Assign		
Intensity Unit	mm/hr	3	Time Subdivision	1	4
Infiltration Model	Green-Ampt	5	SWCC Model	6	van Genutchen (1980)
$\gamma_w$	9.81	7	Surface Dip for Green-Ampt	8	<input type="checkbox"/>

## 1. Spatial variability for rainfall event

- *Uniform* – assign a uniform rainfall intensity everywhere
- *GIS file* – use GIS data specifying rainfall intensity
- *Deterministic Rainfall Gauge* – using rainfall gauge points to assign rainfall intensity value from the closest measured location
- *Probabilistic Rainfall Gauge* – using rainfall gauge points and probabilistic spatial distribution

## 2. Rainfall History Data Assign

- Opens a new window to assign rainfall data or requires GIS files to be uploaded (for *GIS file* option)

## 3. Intensity unit

- Unit used for rainfall intensity (<length>/<time>) and rainfall duration (<time>)
- Options for <length> = mm, cm, m
- Options for <time> = s, min (minute), hr (hour)

## 4. Time Subdivision (for 3DTS – Green-Ampt)

- Positive integer showing the subdivision of analysis per each rainfall history
- e.g.) if “Time Subdivision” = 2, it will generate results at time = 0, time = 0.5hr, and time = 1hr for rainfall simulation between time 0 to 1hr

# User Interface – Hydraulic Analysis

## Rainfall History Option: Uniform

Uniform Rainfall			
Time Step	1 Start Time	2 End Time	3 Intensity
1	0.0	0.0	0.0
2	0.0	0.0	0.0
3	0.0	0.0	0.0
4	0.0	0.0	0.0
5	0.0	0.0	0.0
6	0.0	0.0	0.0
7	0.0	0.0	0.0
8	0.0	0.0	0.0
9	0.0	0.0	0.0
10	0.0	0.0	0.0
11	0.0	0.0	0.0
12	0.0	0.0	0.0
13	0.0	0.0	0.0
14	0.0	0.0	0.0
15	0.0	0.0	0.0
16	0.0	0.0	0.0
17	0.0	0.0	0.0
18	0.0	0.0	0.0
19	0.0	0.0	0.0
20	0.0	0.0	0.0

1. Start time
  - starting time of given rainfall intensity
  - always exclusive, except when time = 0
2. End Time
  - ending time of given rainfall intensity
  - always inclusive
3. Intensity
  - Rainfall intensity between the start time and the end time
  - The rainfall intensity can be non-uniform
4. Confirm the data specified

# User Interface – Hydraulic Analysis

## Rainfall History Option: GIS file

NGL Rainfall History

**GIS-based Rainfall**

Time Step	Start Time	End Time	GIS
1	0.0	1	0.0
2	0.0	0.0	
3	0.0	0.0	
4	0.0	0.0	
5	0.0	0.0	
6	0.0	0.0	
7	0.0	0.0	
8	0.0	0.0	
9	0.0	0.0	
10	0.0	0.0	
11	0.0	0.0	
12	0.0	0.0	
13	0.0	0.0	

5 Assign  
4 Select

1. Start time
  - starting time of given rainfall intensity
  - always exclusive, except when time = 0
2. End Time
  - ending time of given rainfall intensity
  - always inclusive
3. Geospatial Intensity GIS file name
  - Rainfall intensity between the start time and the end time
4. Open the GIS file
5. Confirm the data specified

# User Interface – Hydraulic Analysis

## Rainfall History Option: Deterministic Rainfall Gauge

Rainfall History						
Deterministic Rain Gauge						
Time Step	Start Time	End Time	1: X (m)	1: Y (m)	1: I	2: X (m)
1	0.0	1	0.0	2	0.0	3
2	0.0		0.0		0.0	
3	0.0		0.0		0.0	
4	0.0		0.0		0.0	
5	0.0		0.0		0.0	
6	0.0		0.0		0.0	
7	0.0		0.0		0.0	
8	0.0		0.0		0.0	
9	0.0		0.0		0.0	
10	0.0		0.0		0.0	
11	0.0		0.0		0.0	
12	0.0		0.0		0.0	
13	0.0		0.0		0.0	
14	0.0		0.0		0.0	
15	0.0		0.0		0.0	
16	0.0		0.0		0.0	
17	0.0		0.0		0.0	
18	0.0		0.0		0.0	
19	0.0		0.0		0.0	
20	0.0		0.0		0.0	
21	0.0		0.0		0.0	

1. Start time
  - starting time of the given rainfall intensity
  - always exclusive, except when time = 0
2. End Time
  - ending time of the given rainfall intensity
  - always inclusive
3. Rain gauge location X
4. Rain gauge location Y
5. Rain gauge recorded rainfall intensity
6. Confirm the data specified

### Note

- Up to 5 rain gauges can be assigned
- Each rain gauges are assigned by a number (1 – 5)

# User Interface – Hydraulic Analysis

## Rainfall History Option: Deterministic Rainfall Gauge

Rainfall History												
Probabilistic Rain Gauge												
Time Step	Start Time	End Time	1: X (m)	1: Y (m)	1: mean I	1: CoV	1: P. Dist.	1: CorLenX	1: CorLenY	1: Min	1: Max	2: X
1	0.0	1	0.0	2	0.0	3	0.0	4	0.0	5	0.0	6
2	0.0		0.0		0.0		N	7	8	9	0.0	10
3	0.0		0.0		0.0		N			0.0		0.0
4	0.0		0.0		0.0		N			0.0		0.0
5	0.0		0.0		0.0		N			0.0		0.0
6	0.0		0.0		0.0		N			0.0		0.0
7	0.0		0.0		0.0		N			0.0		0.0
8	0.0		0.0		0.0		N			0.0		0.0
9	0.0		0.0		0.0		N			0.0		0.0
10	0.0		0.0		0.0		N			0.0		0.0
11	0.0		0.0		0.0		N			0.0		0.0
12	0.0		0.0		0.0		N			0.0		0.0
13	0.0		0.0		0.0		N			0.0		0.0
14	0.0		0.0		0.0		N			0.0		0.0
15	0.0		0.0		0.0		N			0.0		0.0
16	0.0		0.0		0.0		N			0.0		0.0
17	0.0		0.0		0.0		N			0.0		0.0
18	0.0		0.0		0.0		N			0.0		0.0
19	0.0		0.0		0.0		N			0.0		0.0
20	0.0		0.0		0.0		N			0.0		0.0
21	0.0		0.0		0.0		N			0.0		0.0

### Note

- Up to 5 rain gauges can be assigned
- Each rain gauges are assigned by a number (1 – 5)

### 1. Start time

- starting time of the given rainfall intensity
- always exclusive, except when time = 0

### 2. End Time

- ending time of the given rainfall intensity
- always inclusive

### 3. Rain gauge location X

### 4. Rain gauge location Y

### 5. Rain gauge recorded mean rainfall intensity

### 6. Rain gauge coefficient of variation (CoV) of rainfall intensity

### 7. Rain gauge probabilistic distribution of rainfall intensity (“N” = normal, “LN” = log-normal)

### 8. Rain gauge rainfall intensity correlation length in the x-direction (“inf” if uniform required)

### 9. Rain gauge rainfall intensity correlation length in the y-direction (“inf” if uniform required)

### 10. Rain gauge recorded min rainfall intensity

### 11. Rain gauge recorded max rainfall intensity

### 12. Confirm the data specified

# User Interface – Hydraulic Analysis

Hydraulic Analysis

Rainfall History	Uniform	1	2 Assign
Intensity Unit	mm/hr	3	Time Subdivision 1 4
Infiltration Model	Green-Ampt	5	SWCC Model 6 van Genuchten (1980)
$\gamma_w$	9.81	7	Surface Dip for Green-Ampt 8 <input type="checkbox"/>

## 5. Rainfall infiltration model

Note that the infiltration model is set based on the selected “slope model”

- *Green-Ampt* – for 3DTS model - select SWCC at 6.
- *Iverson* – for 3DPLS – not yet

## 6. Soil-water characteristic curve (SWCC) model for the Green-Ampt model

- *van Genuchten (1980)*
- *Fredlund and Xing (1994)*

## 7. Unit weight of water (unit: kN/m<sup>3</sup>)

- Default: 9.81 kN/m<sup>3</sup>
- For *Iverson* infiltration, fixed to 10.0 kN/m<sup>3</sup>

## 8. Consider Surface Dip for Green-Ampt model

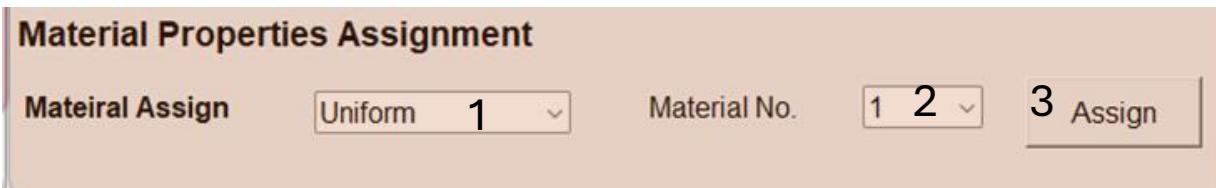
- Checkbox. If checked (the check mark is visible), the rainfall infiltration rate is reduced based on the surface dip

## User Interface – Probabilistic Analysis



- 1. Maximum iteration number of Monte Carlo Simulation**
  - If the value is one (1), deterministic analysis is performed
- 2. Random field generation method**
  - (Opt. 1) CMD – covariance matrix decomposition (Fenton and Griffiths 2008) – correlation length in X- and Y-directions considered both
  - (Opt. 2) SCMD – separated covariance matrix decomposition (Li et al. 2019) – correlation length in X- and Y-directions considered separately and later combined
- 3. Save correlation matrix (for 3DPLS)**
  - Save the correlation matrix for later usage

# User Interface – Material Properties Assignment



- 1. Method for assigning material properties**
  - *Uniform* – all DEM region has the same material properties
  - *Zone-Based* – geospatially varying material properties are assigned based on soil grouping
  - *GIS files* – geospatially varying material properties are assigned based on GIS files
- 2. Number of material numbers**
  - Number from 1 to 10
- 3. Rainfall History Data Assign**
  - Opens a new window to assign rainfall data or requires GIS files to be uploaded (for *GIS file* option)

# User Interface – Material Properties Assignment

## Material Option: Uniform and Zone-based [Deterministic]

Material

Zone-Based Deterministic Material Properties: 3 soil zones

Material Zones	Open GIS 1	2	3	K <sub>s</sub> (m/s)	ψ <sub>i</sub>	SWCC_model	a (kPa)	n	m	θ <sub>s</sub>	θ <sub>r</sub>	m <sub>v</sub>	S <sub>max</sub> (m)	D (m <sup>2</sup> /s)	γ <sub>s</sub> (kN/m <sup>3</sup> )	ϕ' (°)
1	0.0	0.0	van Genuchten	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	van Genuchten	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	van Genuchten	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	van Genuchten	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	van Genuchten	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	van Genuchten	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	van Genuchten	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	van Genuchten	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	van Genuchten	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	van Genuchten	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Assign 4

1. Open a GIS file containing the material ID at each cell  
(not required if only 1 soil zone or *Uniform*)
2. Material zone GIS file name
3. Parameters (refer to Slides 28, 29, and 30 for details)
4. Confirm the data specified

# User Interface – Material Properties Assignment

## Material Option: Uniform and Zone-based [Probabilistic]

Material

Uniform Probabilistic Material Properties: 1 soil zones

Material Zones	Open GIS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500	501	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	544	545	546	547	548	549	550	551	552	553	554	555	556	557	558	559	560	561	562	563	564	565	566	567	568	569	570	571	572	573	574	575	576	577	578	579	580	581	582	583	584	585	586	587	588	589	590	591	592	593	594	595	596	597	598	599	600	601	602	603	604	605	606	607	608	609	610	611	612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627	628	629	630	631	632	633	634	635	636	637	638	639	640	641	642	643	644	645	646	647	648	649	650	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	667	668	669	670	671	672	673	674	675	676	677	678	679	680	681	682	683	684	685	686	687	688	689	690	691	692	693	694	695	696	697	698	699	700	701	702	703	704	705	706	707	708	709	710	711	712	713	714	715	716	717	718	719	720	721	722	723	724	725	726	727	728	729	730	731	732	733	734	735	736	737	738	739	740	741	742	743	744	745	746	747	748	749	750	751	752	753	754	755	756	757	758	759	760	761	762	763	764	765	766	767	768	769	770	771	772	773	774	775	776	777	778	779	780	781	782	783	784	785	786	787	788	789	790	791	792	793	794	795	796	797	798	799	800	801	802	803	804	805	806	807	808	809	810	811	812	813	814	815	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831	832	833	834	835	836	837	838	839	840	841	842	843	844	845	846	847	848	849	850	851	852	853	854	855	856	857	858	859	860	861	862	863	864	865	866	867	868	869	870	871	872	873	874	875	876	877	878	879	880	881	882	883	884	885	886	887	888	889	890	891	892	893	894	895	896	897	898	899	900	901	902	903	904	905	906	907	908	909	910	911	912	913	914	915	916	917	918	919	920	921	922	923	924	925	926	927	928	929	930	931	932	933	934	935	936	937	938	939	940	941	942	943	944	945	946	947	948	949	950	951	952	953	954	955	956	957	958	959	960	961	962	963	964	965	966	967	968	969	970	971	972	973	974	975	976	977	978	979	980	981	982	983	984	985	986	987	988	989	990	991	992	993	994	995	996	997	998	999	1000	1001	1002	1003	1004	1005	1006	1007	1008	1009	10010	10011	10012	10013	10014	10015	10016	10017	10018	10019	10020	10021	10022	10023	10024	10025	10026	10027	10028	10029	10030	10031	10032	10033	10034	10035	10036	10037	10038	10039	10040	10041	10042	10043	10044	10045	10046	10047	10048	10049	10050	10051	10052	10053	10054	10055	10056	10057	10058	10059	10060	10061	10062	10063	10064	10065	10066	10067	10068	10069	10070	10071	10072	10073	10074	10075	10076	10077	10078	10079	10080	10081	10082	10083	10084	10085	10086	10087	10088	10089	10090	10091	10092	10093	10094	10095	10096	10097	10098	10099	100100	100101	100102	100103	100104	100105	100106	100107	100108	100109	100110	100111	100112	100113	100114	100115	100116	100117	100118	100119	100120	100121	100122	100123	100124	100125	100126	100127	100128	100129	100130	100131	100132	100133	100134	100135	100136	100137	100138	100139	100140	100141	100142	100143	100144	100145	100146	100147	100148	100149	100150	100151	100152	100153	100154	100155	100156	100157	100158	100159	100160	100161	100162	100163	100164	100165	100166	100167	100168	100169	100170	100171	100172	100173	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# User Interface – Material Properties Assignment

## Material Option: GIS file

Material

GIS-based Material Properties

Properties 1 File or Value

K<sub>s</sub> (m/s) 2 3 Select 4 Assign Select GIS

Ψ<sub>i</sub> Select

SWCC\_model van Genuchten (1980)

a (kPa) Select

n Select

m Select

θ<sub>s</sub> Select

θ<sub>r</sub> Select

m<sub>v</sub> Select

S\_max (m) Select

γ<sub>s</sub> (kN/m<sup>3</sup>) Select

ϕ' (°) Select

...

1. Parameters (refer to Slides 28, 29, and 30 for details)
2. GIS file names containing the corresponding properties
3. Open a GIS file containing the material properties
4. Confirm the data specified

## Material properties

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- These hydraulic and soil properties must be provided under the heading in the Material properties

Category	Column [symbol] (unit)	Descriptions
Hydraulics	<b>MatID</b>	ID number of soil group (i.e., MatID)
	<b>k_sat [Ks] (m/s)</b>	Saturated permeability rate
	<b>initial_suction [<math>\Psi</math>] (kPa)</b>	Initial suction pressure
	<b>SWCC_a [a] (kPa)</b>	Soil-water characteristic curve (SWCC) - a parameter
	<b>SWCC_n [n]</b>	Soil-water characteristic curve (SWCC) - n parameter
	<b>SWCC_m [m]</b>	Soil-water characteristic curve (SWCC) - m parameter
	<b>theta_sat [<math>\theta_s</math>]</b>	Saturated volumetric water content
	<b>theta_residual [<math>\theta_r</math>]</b>	Residual volumetric water content
	<b>soil_m_v [m<sub>v</sub>]</b>	Soil mass compressibility index
	<b>max_surface_storage [S_max] (m)</b>	Maximum water height possible on surface ponding
Soil	<b>Diffusivity [D] (m<sup>2</sup>/s)</b>	Diffusivity for Iverson (2000) infiltration
	<b>soil unit weight [<math>\gamma_s</math>] (kN/m<sup>3</sup>)</b>	Soil unit weight
	<b>phi [<math>\phi'</math>] (deg)</b>	Mohr-Coulomb effective soil friction angle
	<b>phi_b [<math>\phi_b</math>] (deg)</b>	Unsaturated pore-water pressure friction angle
	<b>c/Su [<math>c'</math>] (kPa)</b>	Mohr-Coulomb effective soil cohesion or undrained strength

## Material properties

- These hydraulic and soil properties must be provided under the heading in the Material properties

root reinforcement model	Column [symbol] (unit)	Descriptions
<b>None</b>		<i>No additional data needs to be provided</i>
<b>Constant with Depth</b>	<b>veg areal weight [<math>\gamma_v</math>] (kN/m<sup>2</sup>)</b>	Areal unit weight for tree
	<b>root c_base (kPa)</b>	Constant base cohesion from root reinforcement
	<b>root c_side (kPa)</b>	Constant side cohesion from root reinforcement
	<b>root depth (m)</b>	Depth from the ground surface where root is present
<b>van Zadelhoff et al. (2022)</b>	<b>veg areal weight [<math>\gamma_v</math>] (kN/m<sup>2</sup>)</b>	Areal unit weight for tree
	<b>root alpha2 [<math>\alpha</math>]</b>	Fitting parameter (shape)
	<b>root beta2 [<math>\beta</math>]</b>	Fitting parameter (rate = 1/scale)
	<b>root RR_max [RR_max] (kN/m)</b>	Maximum root reinforcement strength

## Material properties - Probabilistic

- These hydraulic and soil properties must be provided under the heading in the Material properties

Probabilistic Heading	Descriptions
$\mu$ (or mean)	Mean value
CoV	Coefficient of variation
Prob. Dist.	Probabilistic distribution (“N” = normal, “LN” = log-normal)
CorL X (m)	Correlation length in the x-direction (“inf” if uniform required)
CorL Y (m)	Correlation length in the y-direction (“inf” if uniform required)
Min	Min value
Max	Max value

### Note

- Probabilistic data are noted in the following format: {parameter}: {probabilistic input}

## User Interface – Post-Analysis (currently only for 3DPLS)

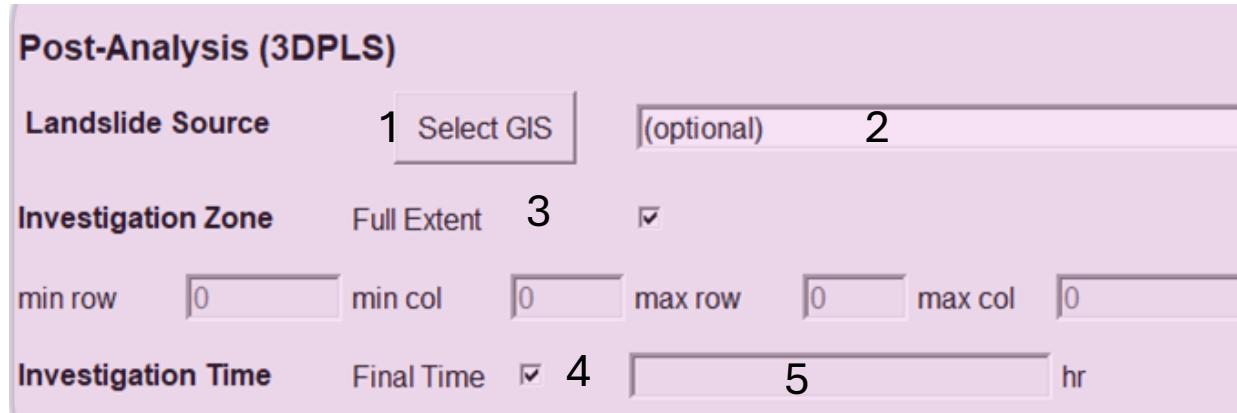
Post-Analysis (3DPLS)

Landslide Source      1 Select GIS      (optional) 2

Investigation Zone      Full Extent 3     

min row 0 min col 0 max row 0 max col 0

Investigation Time      Final Time 4      5 hr



### 1. Select landslide source file (optional)

- Navigate and select the GIS file identifying landslide source locations. At each cell, 0 = no landslide and 1 = landslide occurrence locations
- Optional to whether analyze performance or not

### 2. Landslide source file name

- Text showing the file name of landslide source file
- Can manually change the landslide source file name with this text box

### 3. Option for auto-compute investigation zone

- If checked the 3DPLS model will use all regions for analyzing landslide geohazard risk
- If unchecked, the user must provide the 2 grid corner points [(min row, min col) and (max row, max col)]. The regions inside the box generated between the 2 points will be analyzed for landslide geohazard risk

## User Interface – Post-Analysis (currently only for 3DPLS)

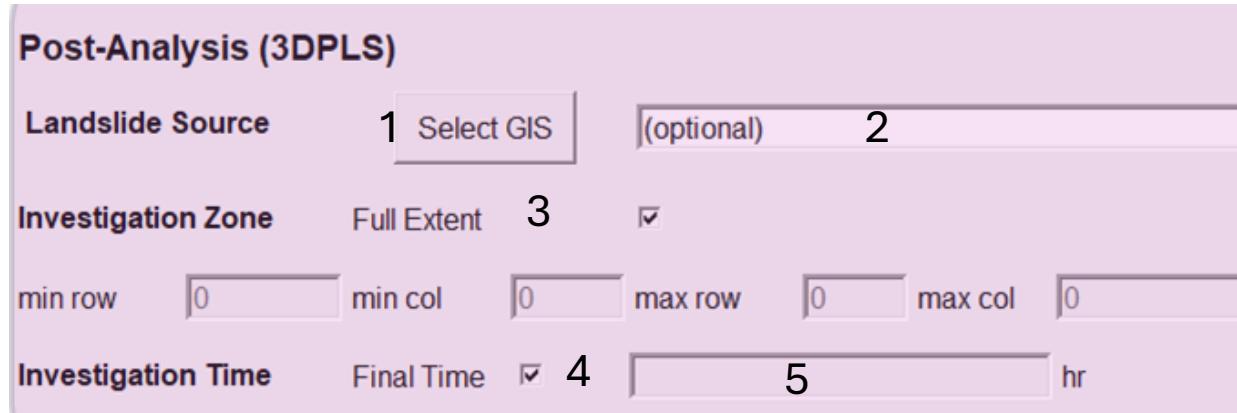
Post-Analysis (3DPLS)

Landslide Source      1 Select GIS      (optional)      2

Investigation Zone      Full Extent      3     

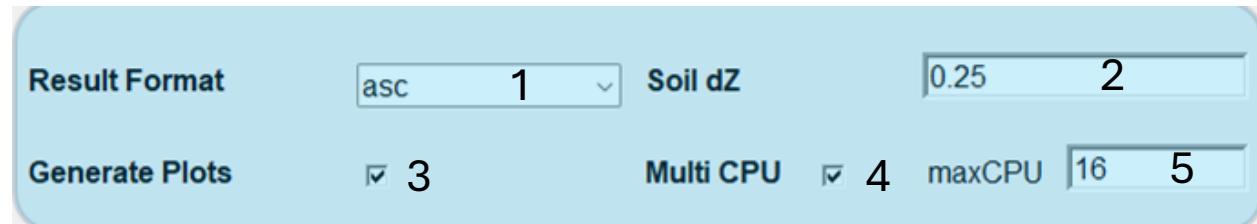
min row      0      min col      0      max row      0      max col      0

Investigation Time      Final Time      4      5      hr



4. **Option for auto-compute investigation time**
  - If checked the 3DPLS model will use the final simulation time for analyzing landslide geohazard risk
  - If unchecked, the user must provide the simulation times to investigate
5. **Option for auto-compute investigation time**
  - Times at which the landslide geohazard risk is analyzed in 3DPLS
  - The time unit changes depending on the selected “intensity unit” in the **Hydraulic Analysis**
  - If multiple, separate them using comma (,)

## User Interface – Options



### 1. File format of computed results stored in GIS

- (Opt. 1) asc – Esri ASCII raster
- (Opt. 2) csv – comma-delimited values
- (Opt. 3) grd – Surfer 6 Text Grid

### 2. Soil depth vertical spacing

- The soil is subdivided with regular spacing with the assigned value. The 3DTS model will use these values to find the critical failure depth.
- Critical failure depth is the lowest depth at which  $FS < \text{critical FS}$
- e.g.) if 0.25m, a 1m thick soil layer is subdivided into 0.25, 0.5, 0.75, and 1m. Then FS is computed at each depth (0.25, 0.5, 0.75, 1.0).

### 3. Option for generating plots

- Checkbox. If checked (the check mark is visible), interactive HTML plots are generated

### 4. CPU multiprocessing Option

- Check whether CPU multiprocessing is utilized

### 5. Option for selecting the number of CPU multiprocessing logical cores

- Number of CPU logical cores to use for parallelization (faster computation)

## User Interface – Functions



### General Advice

- Please select all the necessary options in the other section, then generate CSV template (“Rain Template” and “Material Template”) to assign
- When the number of rainfall and material properties is large, the software can become slow depending on the computer. In such cases, uploading the CSV file will be advised

#### 1. Generate rainfall history template

- Create and save a template CSV file to assign rainfall history

#### 2. Select the rainfall history CSV file

- Navigate and search for the CSV file containing the rainfall history

#### 3. Generate material template

- Create and save a template CSV file to assign material properties

#### 4. Select the material CSV file

- Navigate and search for the CSV file containing the material

## Rainfall history CSV

start time	end time	intensity
0	1	0.5
1	3	5.0
3	4	rainfall_GIS_hr_3_to_4.asc

### Interpretation of the above example

- Uniform rainfall intensity of 0.5 ( $\langle \text{length} \rangle / \langle \text{time} \rangle$ ) between 0 ( $\langle \text{time} \rangle$ ) [including] and 1 ( $\langle \text{time} \rangle$ ) [including]
- Uniform rainfall intensity of 5.0 ( $\langle \text{length} \rangle / \langle \text{time} \rangle$ ) between 1 ( $\langle \text{time} \rangle$ ) [excluding] and 3 ( $\langle \text{time} \rangle$ ) [including]
- Geospatially varying rainfall intensity provided by “rainfall\_GIS\_hr\_3\_to\_4.asc” with unit of ( $\langle \text{length} \rangle / \langle \text{time} \rangle$ ) between 3 ( $\langle \text{time} \rangle$ ) [excluding] and 4 ( $\langle \text{time} \rangle$ ) [including]

### Start Time

- starting time of given rainfall intensity
- always exclusive, except when time = 0

### End Time

- ending time of given rainfall intensity
- always inclusive

### Intensity

- Rainfall intensity between the start time and the end time
- The rainfall intensity can be non-uniform
- If rainfall intensity is to be applied uniformly across the entire DEM region, assign a numerical value
- If geospatial variation of rainfall intensity is available, assign the file name of the rainfall GIS file. The GIS file must always include the extension (.csv, .asc, or .grd)

## Material properties CSV

Based on the selected method for assigning material properties:

### Uniform

- Assign all the material properties in 2<sup>nd</sup> row with numbers
- Assign integer number one (1) to ID

ID	k_sat (m/s)	initial_suction (kPa)	SWCC_a (kPa)	...
1	1.00E-06	0	33.33	...

### Zone-Based

- Assign all the material properties in 2<sup>nd</sup> row and below with numbers
- Start assigning material ID from integer number one (1)
- Each row of material properties will correspond to the assigned number at ID

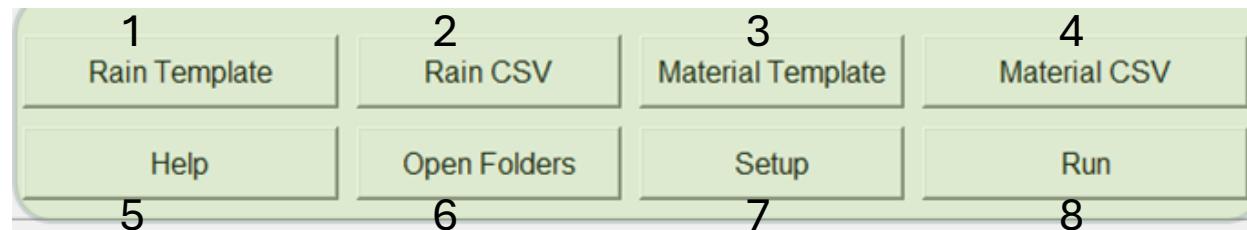
ID	k_sat (m/s)	initial_suction (kPa)	SWCC_a (kPa)	...
1	1.00E-06	0	33.33	...
2	1.50E-06	10	20.0	...
:	:	:	:	:

### GIS files

- Assign all the material properties in 2<sup>nd</sup> row with numbers or GIS file names
- If a GIS file name is assigned, the values from the GIS file will be imported to apply geospatially varying properties
- Assign integer number one (1) to ID

ID	k_sat (m/s)	initial_suction (kPa)	SWCC_a (kPa)	...
1	K_sat.grd	Ini_psi.asc	SWCC_a.csv	...

# User Interface – Functions



## Tip

If you want to run the simulations on the high-performance computers (HPC) instead of local computer:

- Use the **Setup** to generate the necessary files
- Copy and paste the whole **input folder** into the HPC
- Run the produced bash “.sh” script for Linux/MacOS or batch “.bat” scripts for Windows OS
- The results will be saved in a subfolder (named “<project name> \_results” or “04 Results”) inside the copied input folder

## 5. Help

- Opens this manual

## 6. Open Input and results folders

- The input and results directories are opened in the file explorer (or equivalent) for easier access to input files and generated results

## 7. Setup

- Generates necessary files and folders at the input directory:
  - YAML file – contains all input data
  - Bash “.sh” script – script allows users to run this analysis on MacOS and Linux
  - Batch “.bat” script – a script allows users to run this analysis on Windows

## 8. Run

- Generate the YAML file (contains all input data) and run the analysis on the local machine

## Abbreviation for output files – 3DTS

Abbreviation	Explanation
bedrock surface	GIS showing elevation of bedrock surface
change in theta	Volumetric water content deficient
crit_FS_z	Failure depth based on critical factor of safety (FS)
debris-flow-source	Identify landslide failure that develops into debris-flow (0 = not source, 1 = source)
DEM	Digital elevation model (DEM)
DEM_debris_flow_initiation	Debris-flow Criteria data in GIS file
DEM_initial_suction	Assigned initial suction pressure material properties
DEM_k_sat	Assigned saturated permeability material properties
DEM_root_alpha2	Assigned "van Zadelhoff et al. (2022)" parameter alpha2
DEM_root_beta2	Assigned "van Zadelhoff et al. (2022)" parameter beta2
DEM_root_c_base	Assigned "Constant with Depth" root reinforcement model base cohesion
DEM_root_c_side	Assigned "Constant with Depth" root reinforcement model side cohesion
DEM_root_depth	Assigned "Constant with Depth" root reinforcement model root depth
DEM_root_model	Assigned root reinforcement model (0 = "Constant with Depth", 1 = "van Zadelhoff et al. (2022)")
DEM_root_RR_max	Assigned "van Zadelhoff et al. (2022)" parameter RRmax

## Abbreviation for output files – 3DTS

Abbreviation	Explanation
DEM_veg_areal_weight	Assigned vegetation areal weight
DEM_S_max	Assigned maximum surface ponding depth
DEM_soil_c	Assigned soil Mohr-Coulomb cohesion strength
DEM_soil_m_v	Assigned soil compression index
DEM_soil_phi	Assigned soil Mohr-Coulomb frictional angle strength
DEM_soil_phi_b	Assigned soil unsaturated pore-water pressure friction angle strength
DEM_soil_unit_weight	Assigned soil unit weight
DEM_SWCC_a	Assigned soil water characteristic curve (SWCC) parameter a
DEM_SWCC_m	Assigned soil water characteristic curve (SWCC) parameter m
DEM_SWCC_model	Assigned soil water characteristic curve (SWCC) model (0 = "van Genutchen (1980)", 1 = "Fredlund and Xing (1994)")
DEM_SWCC_n	Assigned soil water characteristic curve (SWCC) parameter n
DEM_theta_residual	Assigned saturated volumetric water content
DEM_theta_sat	Assigned residual volumetric water content
dip_base_deg	Dip angle on bedrock surface in degrees (0 – 90°)
aspect_base_deg	Aspect of the bedrock surface in degrees (0 – 360°). -1 for flat slope

## Abbreviation for output files – 3DTS

Abbreviation	Explanation
aspect_surf_deg	Aspect of the ground surface in degrees (0 – 360°). -1 for flat slope
dip_surf_deg	Dip angle on ground surface in degrees (0 – 90°)
F_cumul	Cumulative amount of infiltration
f_rate	Current infiltration rate
gwt_dz	Depth of groundwater table (gwt) from ground surface (negative = ponding, positive = below ground surface)
gwt_z	Elevation of groundwater table (gwt)
initial theta	Initial volumetric water content based on assigned initial suction pressure
initial_suction	Assigned initial suction pressure
min_FS	Smallest FS computed at given cell
P	Cumulative amount of precipitation
ponding - cumul F_p	Green-Ampt ponding cumulative infiltration
ponding - time T_p	Green-Ampt ponding time
ponding - time T_pp	Green-Ampt ponding time2
ponding - wetting front z_p	Green-Ampt ponding wetting front elevation
rain_I	Current rainfall intensity

## Abbreviation for output files – 3DTS

Abbreviation	Explanation
soil thickness	Soil thickness
t(number)	simulation time step (number)
wet_z	Elevation of wetting front
z_w	Depth of wetting front from ground surface

## Abbreviation for output files – 3DPLS

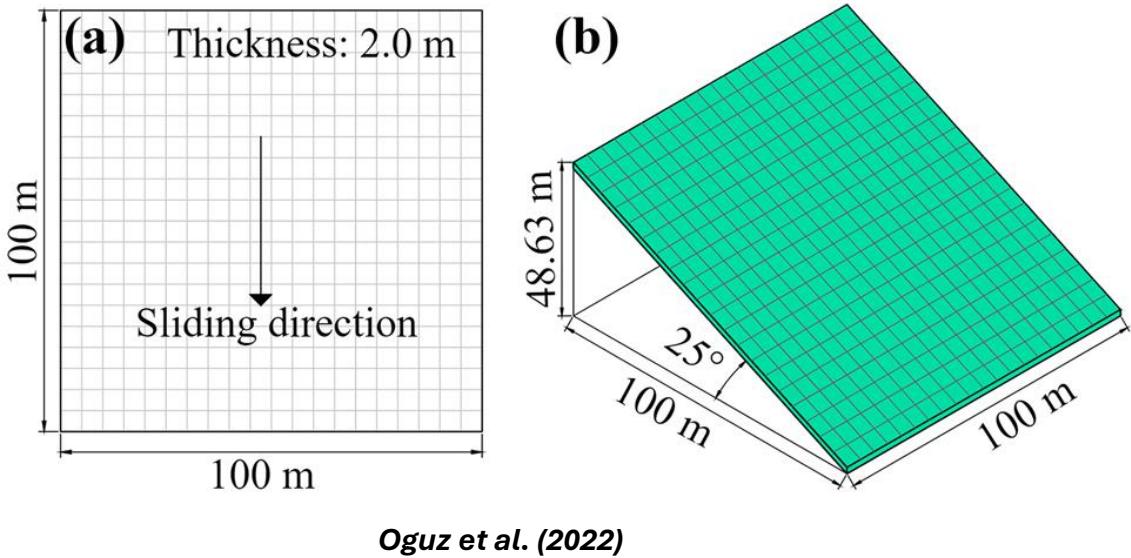
Abbreviation	Explanation
aspect.asc	In the GIS folder. Aspect of the ground surface in degrees (0 – 360°). -1 for flat slope
dem.asc	In the GIS folder. Digital Elevation Model (DEM) of terrain
depthwt.asc	In the GIS folder. Depth of initial groundwater table
dir.asc	In the GIS folder. Direction of groundwater flow (optional)
rizer0.asc	In the GIS folder. Steady background infiltration in m/s
slope.asc	In the GIS folder. Slope angle in degrees
source.asc	In the GIS folder. Initiation zones for comparing with observed landslide event (optional)
zmax.asc	In the GIS folder. Depth to bedrock in meters (soil thickness)
zones.asc	In the GIS folder. Geological units as integer IDs for zone-based material properties
MC_xxxx_FS_Values.npy	In the 04-Results folder. It stores the computed factor of safety (FS) at each DEM cell. The xxxx number marks the Monte Carlo iteration number
MeanFSMap.png	In the 04-Results folder. Displays mean FS
PfMap.png	In the 04-Results folder. Displays the probability of $FS \leq$ critical FS at each DEM cell

# 3. 3DTS example

Example for double-checking whether  
3DTS model performs on the installed computer

# Problem definition

## Slope Geometry



## Non-uniform Rainfall History

start time [hr]	end time [hr]	Intensity [mm/hr]
0	1	5.0
1	2	3.0

A planar slope with shallow soil depth (2 m) and inclination of 25° is presented. The region spans 100 m x 100 m with a digital elevation model (DEM) in a resolution of 5 m x 5 m. Due to shallow soil depth, the 3DTS is suitable for analysing shallow translational slope failures.

The groundwater table is located 1m below the ground surface. The soil above the groundwater table is unsaturated, while the soil below the groundwater table is fully saturated.

A short rainfall with non-uniform intensity occurs in this region. It is assumed that the rainfall intensity is not spatially varying.

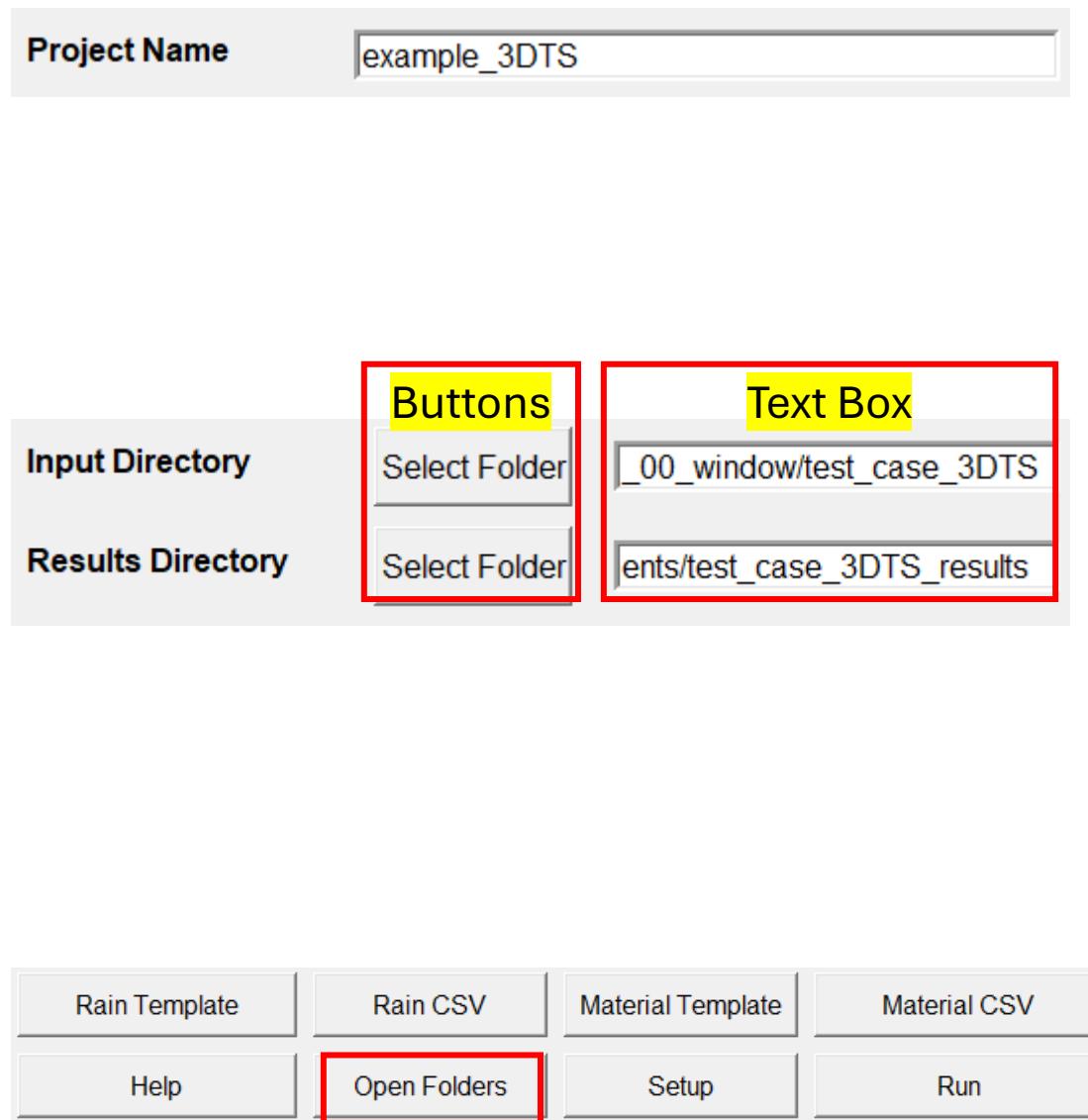
The entire region is the same soil unit. A deterministic and probabilistic analysis will be performed in this example. For the probabilistic analysis, the min and max values are always assigned such that ( $\text{min} < \text{mean} < \text{max}$ ) is established.

# Material properties

For deterministic analysis, assign the mean values

Category	Column Headings (unit)	mean	CoV	Prob. Dist.	CorL X (m)	CorL Y (m)	Min	Max
Hydraulics	k_sat (m/s)	10 <sup>-6</sup>	0.1	Normal	50	50	0	1
	initial_suction (kPa)	10	0	Normal	inf	inf	0	20
	SWCC model type	van Genuchten (1980)						
	SWCC_a (kPa)	33.33	0	Normal	inf	inf	0	40
	SWCC_n	2	0	Normal	inf	inf	0	5
	SWCC_m	0.5	0	Normal	inf	inf	0	1
	theta_sat	0.3831	0	Normal	inf	inf	0	1
	theta_residual	0.0462	0	Normal	inf	inf	0	1
	soil_m_v	0	0	Normal	inf	inf	0	1
Soil	max_surface_storage (m)	0	0	Normal	inf	inf	0	1
	soil unit weight (kN/m <sup>3</sup> )	20	0.05	Lognormal	100	100	15	25
	phi (deg)	40	0.05	Lognormal	100	100	20	45
	phi_b (deg)	10	0	Normal	inf	inf	0	20
Root van Zadelhoff et al. (2022)	c/Su (kPa)	6	0.1	Lognormal	100	100	0	50
	veg areal weight (kN/m <sup>2</sup> )	0.98	0	Normal	inf	inf	0	10
	root alpha2	1.284	0	Normal	inf	inf	0	2
	root beta2	3.688	0	Normal	inf	inf	0	5
	root RR_max (kN/m)	2.0	0.05	Lognormal	20	20	0	5

## 3DTSP example – step-by-step



### 1. Assign project name

- The project name will be used throughout the analysis for generating output files
- Please name them anything. In our case, we are going to use “example\_3DTS”
- Please note that white spacing is allowed, but replacing them with underscore (“\_”) or minus (“-”) is advised

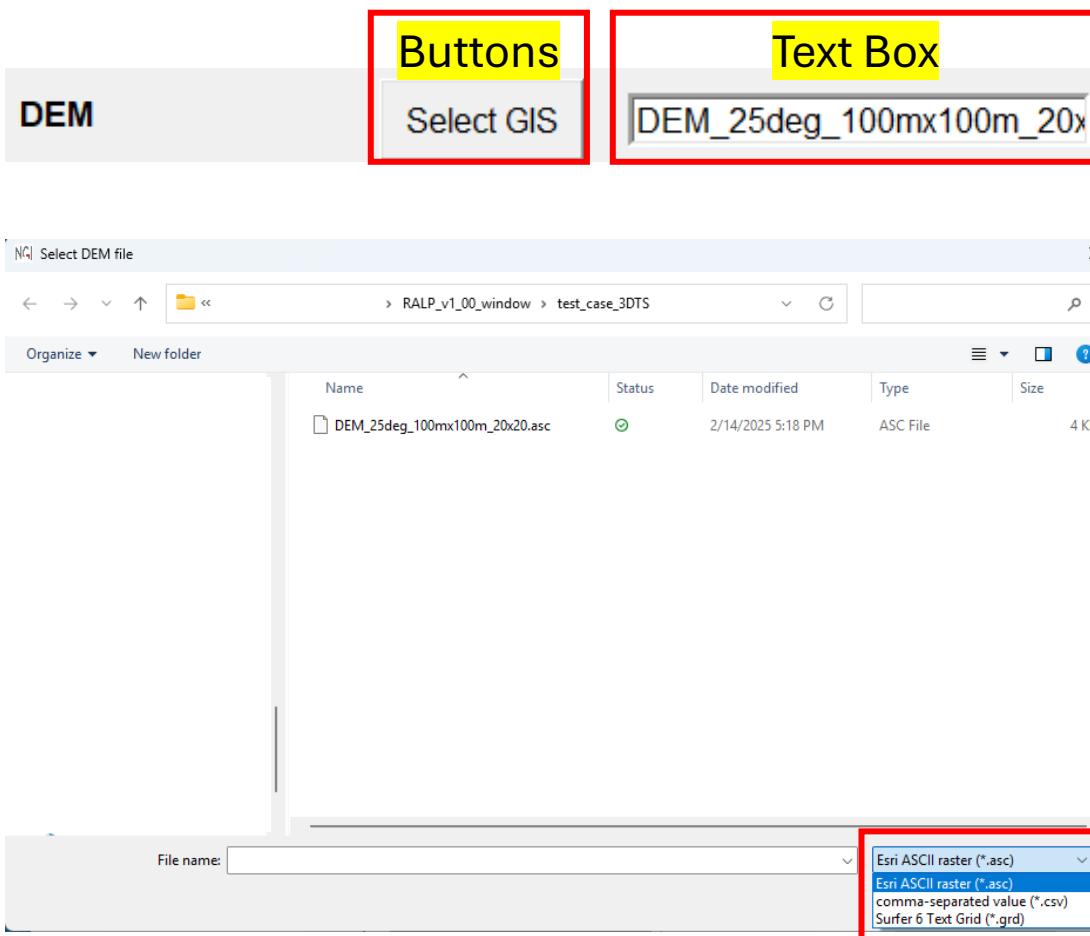
### 2. Input and output directory

- The input directory should be the folder containing all the necessary GIS and CSV files required for the 3DTS analysis
- The 3DTS example should be located at “C:\Program Files\RALP\_window\test\_case\_3DTS” (for Windows version) or in the directory the user has saved the files.
- Assign a directory in the **Results Directory** where the user wants to save the analysis results. For this example, it was saved in the “Documents/test\_case\_3DTS\_results” folder
- To assign the directories, either press the corresponding **Select Folder button** and navigate to the folder, or directly copy and paste the directory to the **text box**

### 3. Open Folders

- Press the **Open Folders button (highlighted with a red box)** to check that the directories assigned are correct. You will have two file explorers (or equivalent) opened. One is for the input directory and the other is for the results directory

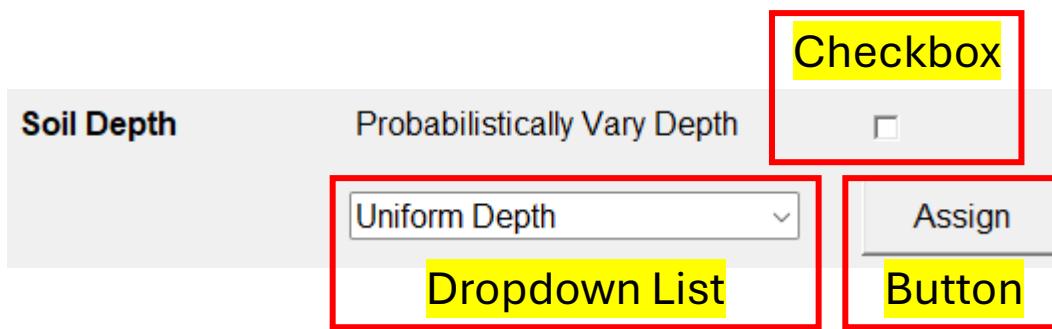
## 3DTSP example – step-by-step



### 4. Assign digital elevation model (DEM)

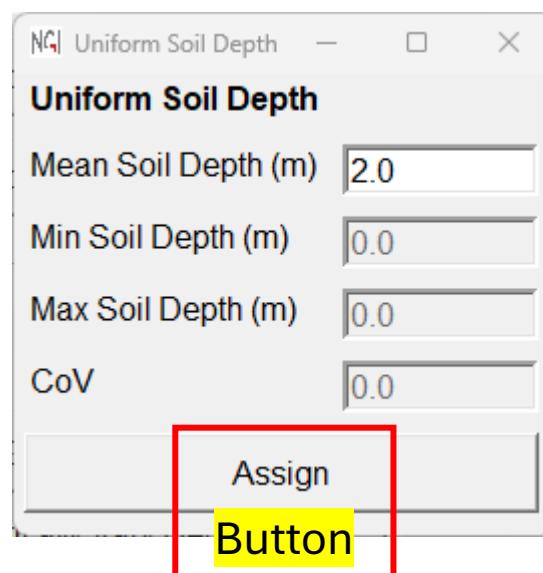
- Press **Select GIS button** and select the either "DEM\_25deg\_100mx100m\_20x20.asc" or "DEM\_25deg\_100mx100m\_20x20.csv"
- Since the software can accept three different types of DEM, please use one of these file formats for future use. To change the type of files you want to select, please change the in this drop-down list (highlighted with red box)
- As typical, if the user knows exactly the name of the DEM file, the user can copy and paste the DEM file name into the textbox

## 3DTSP example – step-by-step



### 5. Assign soil depth

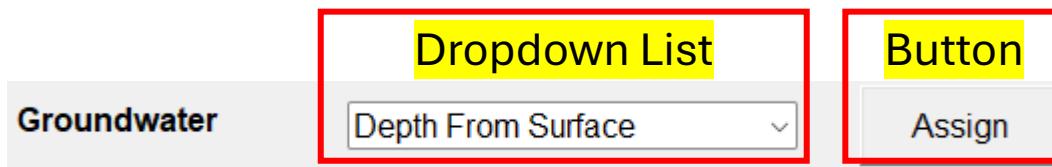
- Since we are performing deterministic soil depth in the example, make sure the checkbox next to the **Probabilistically Vary Depth** is unchecked
- In the dropdown list, make sure the *Uniform Depth* is selected
- Press the **Assign** button



### 6. Assign uniform soil depth

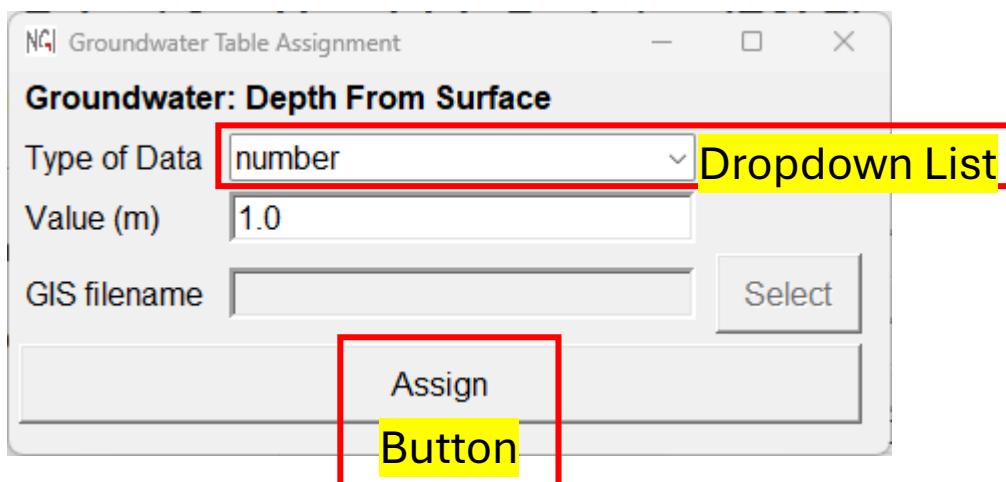
- The slope geometry shows uniform 2 m thickness, so assign 2 m to the **Mean Soil Depth (m)**
- Press the **Assign** button

## 3DTSP example – step-by-step



### 7. Select groundwater table assign method

- As previously mentioned, the groundwater table is located 1m depth below the ground surface
- The user can take any method to assign the groundwater table. In our example, we took the most convenient method with *Depth From Surface* approach
- Press the **Assign** button



### 8. Assign groundwater table

- Since the uniform soil depth is assigned, the groundwater table location will be uniformly 1 m below the ground surface
- Select the number option in the **Type of Data** dropdown list and assign 1.0 m to the **Value (m)**
- Press the **Assign** button

## 3DTSP example – step-by-step

Slope Model	3D Translational Slide (3DTS)			
3DTS Slip Surface	Min Cell	7	Max Cell	7
Superellipse Power	10.0			
Superellipse Eccentricity Ratio	1.0			
3DTS Resistances	Side	<input checked="" type="checkbox"/>	Root	van Zadelhoff et al. (2021)

### 9. Select slope model

- This example will perform 3DTS model
- For the 3DTS slip surface, we will test a slip surface of square shape of 7 cells per side. Hence, the parameters requires should match the image above

### 10. Assign side and root resistance

- The example is testing effect of side resistance and root reinforcement.
- For the root reinforcement, we will use the *van Zadelhoff et al. (2021)* model

Critical FS	1.3		
Debris-Flow Criteria	<input type="checkbox"/>		
Checkbox			
Upload Files	network	UCA	Criteria

### 11. Critical slope factor of safety (Critical FS)

- This example will assume any slope with factor of safety (FS) < 1.3 will be considered to have failed

### 12. Debris-Flow Criteria

- No debris-flow criteria will be applied in this example; therefore, leave the checkbox unchecked

## 3DTSP example – step-by-step

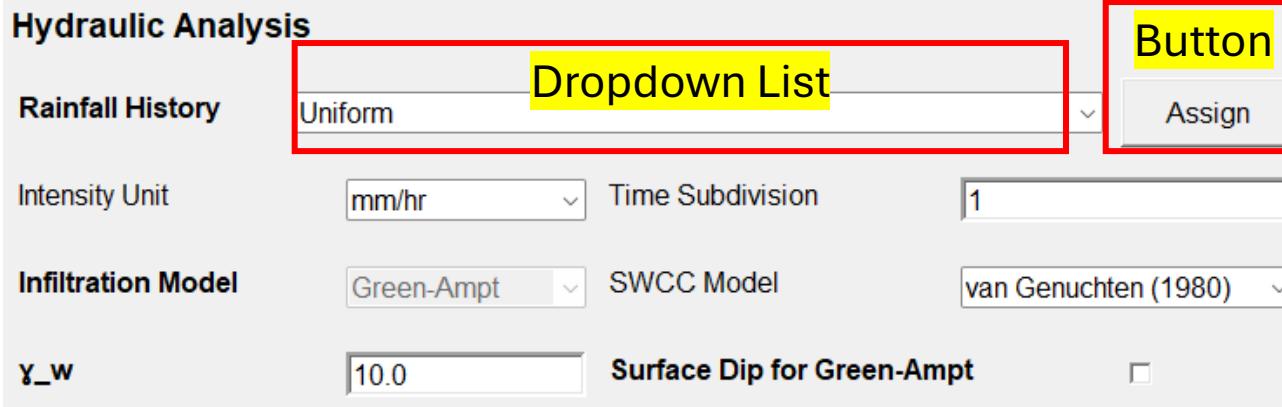
Hydraulic Analysis

Rainfall History **Dropdown List** **Button**

Intensity Unit mm/hr Time Subdivision 1

Infiltration Model Green-Ampt SWCC Model van Genuchten (1980)

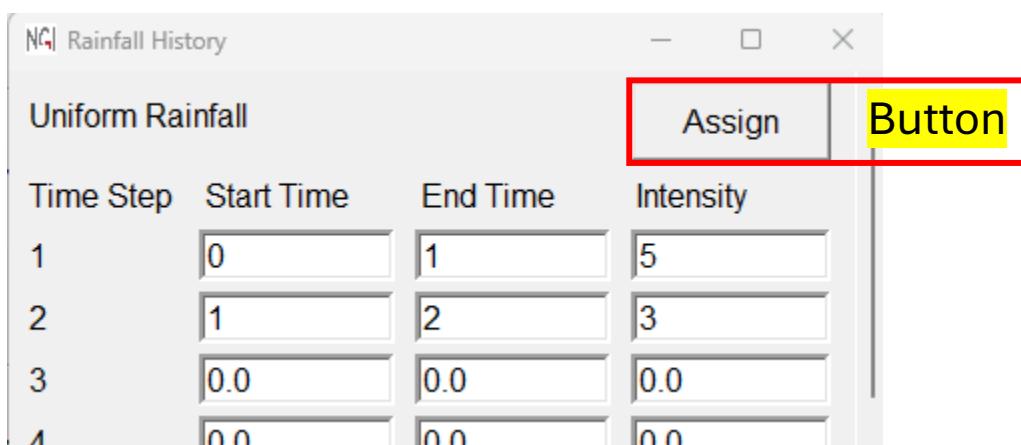
$\gamma_w$  10.0 Surface Dip for Green-Ampt



### 13. Select rainfall spatial variability option

- Since this example will perform the 3DTS model, the Green-Ampt method is selected
- In the **Rainfall History dropdown list**, *Uniform* option is selected to assign the same rainfall intensity over the entire slope
- Since the rainfall intensity used is “mm/hr”, ensure that the **Intensity Unit** is consistent
- Since we want results at every hour and the rainfall history is specified in hourly intervals, keep the **Time Subdivision** as one (1)
- Press the **Assign button** to assign rainfall history

Rainfall History			
Uniform Rainfall			
Time Step	Start Time	End Time	Intensity
1	0	1	5
2	1	2	3
3	0.0	0.0	0.0
4	0.0	0.0	0.0



### 14. Select infiltration model options

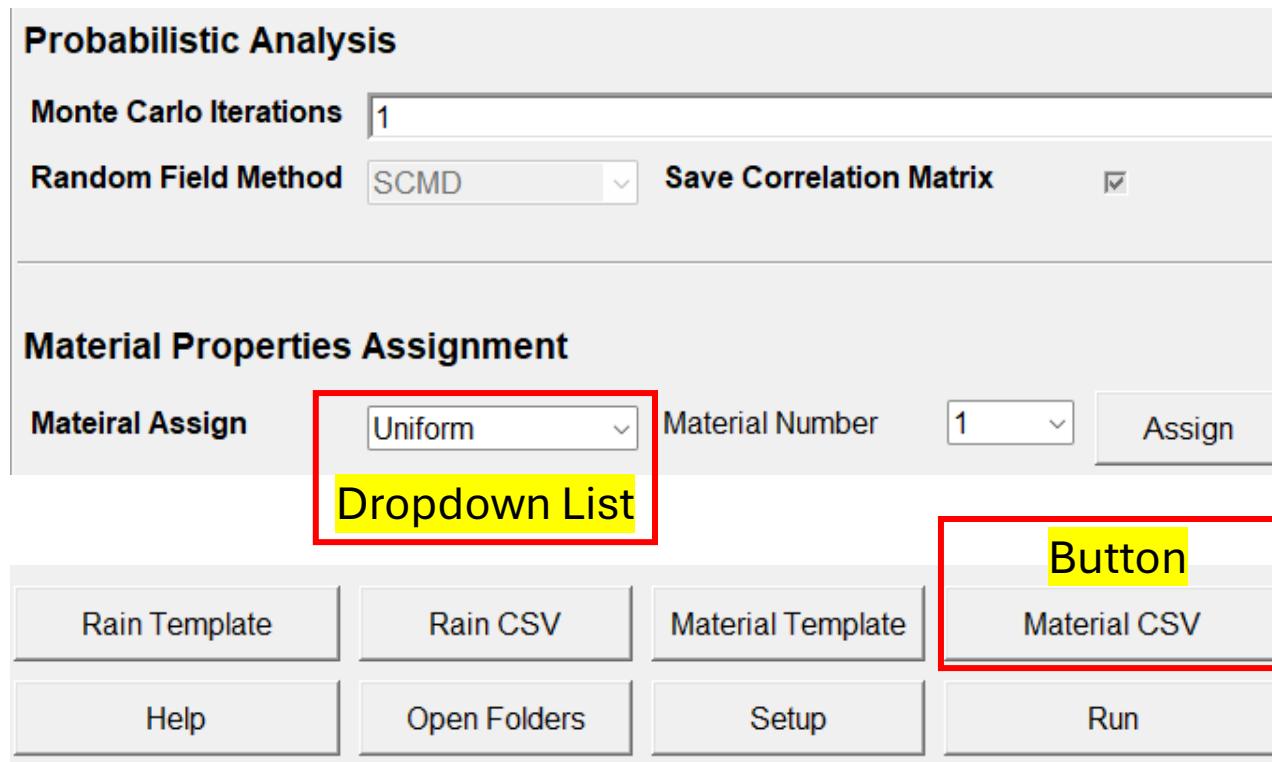
- Select the *van Genuchten (1980)* as the soil-water characteristic curve (SWCC) model
- Assign the unit weight of water ( $\gamma_w$ ) as 10.0 kN/m<sup>3</sup>

### 15. Assign rainfall history

- Assign the non-uniform rainfall history as shown in the image on the left.
- Press the **Assign button** to confirm the rainfall history

# 3DTSP example – step-by-step

## Deterministic Analysis Version



Uniform Deterministic Material Properties: 1 soil zones						
Material Zones	Open GIS					
Mat ID	K <sub>s</sub> (m/s)	Ψ <sub>i</sub>	SWCC_model	a (kPa)	n	m
1	1e-6	10	van Genuchten	33.33	2	0.5
2	0.0	0.0	van Genuchten	0.0	0.0	0.0

### 16-1. Assign the number of iterations

- To perform deterministic analysis, assign integer one (1) to the **Monte Carlo Iterations**

### 16-2. Material properties assign method

- Since the entire slope has the same soil, select *Uniform* soil properties from the **Material Assign** dropdown list

### 16-3. Assign material properties with CSV

- The soil properties are already prepared in a CSV file
- Press the **Material CSV** button to read the material properties.
- In the directory specified in the **Input Directory** from Step 2, select the CSV file named "material\_deterministic\_with\_root\_example.csv"
- To double-check the material properties, press the **Assign** button next to the **Material Number**. Changes to the material properties can be made in the new window titled **Uniform Deterministic Material Properties: 1 soil zones**. To confirm, the user can either select the **Assign button** or close the window

## Probabilistic Analysis Version

**Probabilistic Analysis**

Monte Carlo Iterations	100
Random Field Method	SCMD
Save Correlation Matrix <input checked="" type="checkbox"/>	

**Material Properties Assignment**

Material Assign	Uniform	Material Number	1	Assign
-----------------	---------	-----------------	---	--------

Rain Template	Rain CSV	Material Template	<b>Material CSV</b>
Help	Open Folders	Setup	Run

**Material**

Uniform Probabilistic Material Properties: 1 soil zones

Material Zones	Open GIS						
Mat ID	$K_s$ (m/s): $\mu$	$K_s$ (m/s): CoV	$K_s$ (m/s): Prob. Dist.	$K_s$ (m/s): CorL X (m)	$K_s$ (m/s): CorL Y (m)	$K_s$ (m/s): Min	$K_s$ (m/s): Max
1	1e-6	0.1	Normal	50	50	0	1
2	0.0	0.0				0.0	0.0

### 17-1. Assign the number of iterations

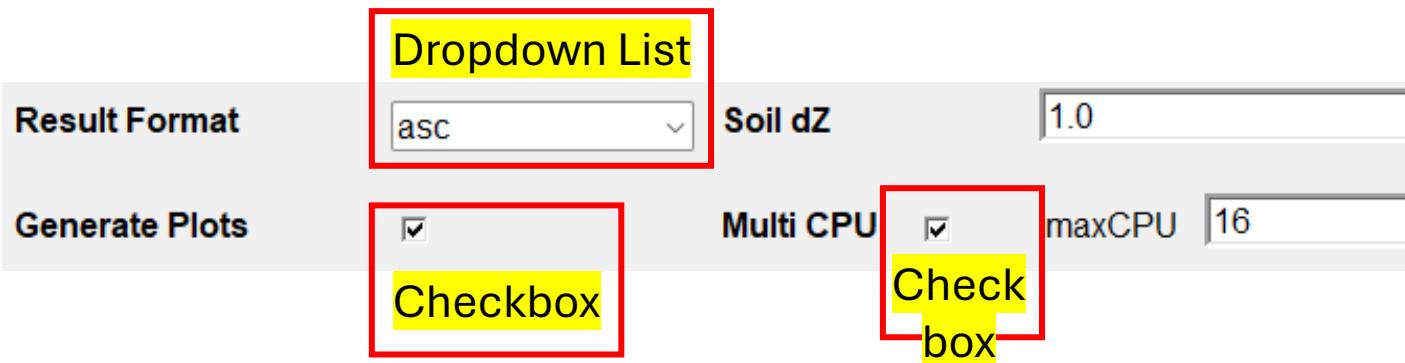
- To perform deterministic analysis, assign an integer 100 to the **Monte Carlo Iterations**
- The Random Field Method by default uses the separated covariance matrix decomposition (SCMD) by Li et al. (2019)

### 17-2. Material properties assign method

- Since the entire slope has the same soil, select *Uniform* soil properties from the **Material Assign** dropdown list

### 17-3. Assign material properties with CSV

- The soil properties are already prepared in a CSV file
- Press the **Material CSV** button to read the material properties.
- In the directory specified in the **Input Directory** from Step 2, select the CSV file named “material\_probabilistic\_with\_root\_example.csv”
- To double-check the material properties, press the **Assign** button next to the **Material Number**. Changes to the material properties can be made in the new window titled **Uniform Probabilistic Material Properties: 1 soil zones**. To confirm, the user can either select the **Assign button** or close the window



#### 18. Generated output files

- To allow the simulation outputs to be opened in GIS software (e.g. QGIS or ArcGIS), assign asc from the **Result Format dropdown list**. For opening in Paraview visualization software, selecting csv from the **Result Format dropdown list** is recommended
- The 3DTS model can be chosen to generate interactive plots. To allow, select the **Generate Plots checkbox**

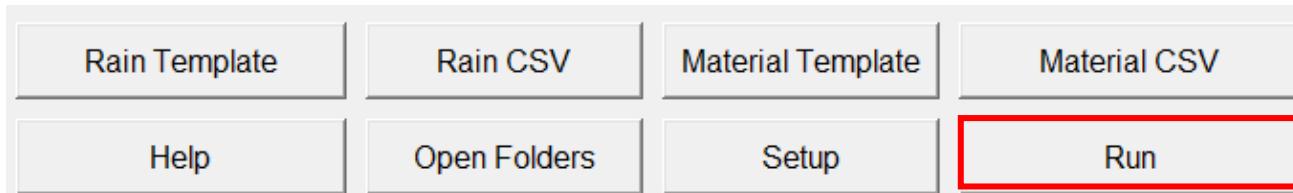
#### 19. Soil vertical axis resolution (for 3DTS model)

- In this example, 1 m is described to **Soil dZ**
- The value specified for **Soil dZ** has three purposes:
  - Each DEM cells are subdivided in the vertical direction using the **Soil dZ** value, where the pore-water pressure/matric suction is computed.
  - The 3DTS slip surface will use the **Soil dZ** value to increase the thickness of the slip surface
  - The **Soil dZ** value specifies the minimum soil thickness considered for analysis

#### 20. CPU Multiprocessing

- To allow faster computation, CPU multiprocessing is utilized to perform analysis in parallel
- Check the **Multi CPU checkbox** and assign the maximum number of CPU threads utilized by assigning 16 to **maxCPU**
- Even if the specified **maxCPU** number exceeds the CPU hardware capability, the software will automatically assign the maximum number of CPUs capable in the local computer

## 3DTSP example – step-by-step



### 21. Start 3DTS analysis on the local computer

- Press the **Run button** to initiate the 3DTS analysis
- A new command prompt, powershell, or terminal window will open and start the 3DTS analysis
- All input and results files are saved in the **Results Directory**

```
#####
# 3D Translational Slope Probabilistic (3DTSP) Model
# by Dr. Enok Cheon
#
#####
#
# Author:      Enok Cheon
# Date:       Aug 13, 2025
# Purpose:    Physically-based Rainfall-Induced Landslide Susceptibility through 3D Translational Slope Probabilistic (3DTSP) Model
# Language:   Python3
# License:

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in the Software without restriction, including without limitation the rights
to use, copy, modify, merge, publish, distribute, sublicense, and/or sell
copies of the Software, and to permit persons to whom the Software is
furnished to do so, subject to the following conditions:

The above copyright notice and this permission notice shall be included in all
copies or substantial portions of the Software.

THE SOFTWARE IS PROVIDED "AS IS", WITHOUT WARRANTY OF ANY KIND, EXPRESS OR
IMPLIED, INCLUDING BUT NOT LIMITED TO THE WARRANTIES OF MERCHANTABILITY,
FITNESS FOR A PARTICULAR PURPOSE AND NONINFRINGEMENT. IN NO EVENT SHALL THE
AUTHORS OR COPYRIGHT HOLDERS BE LIABLE FOR ANY CLAIM, DAMAGES OR OTHER
LIABILITY, WHETHER IN AN ACTION OF CONTRACT, TORT OR OTHERWISE, ARISING
FROM, OUT OF OR IN CONNECTION WITH THE SOFTWARE OR THE USE OR OTHER DEALINGS
IN THE SOFTWARE.

#####
#
The programming is importing python libraries for analysis ...

The programming is reading the input JSON file for analysis ...

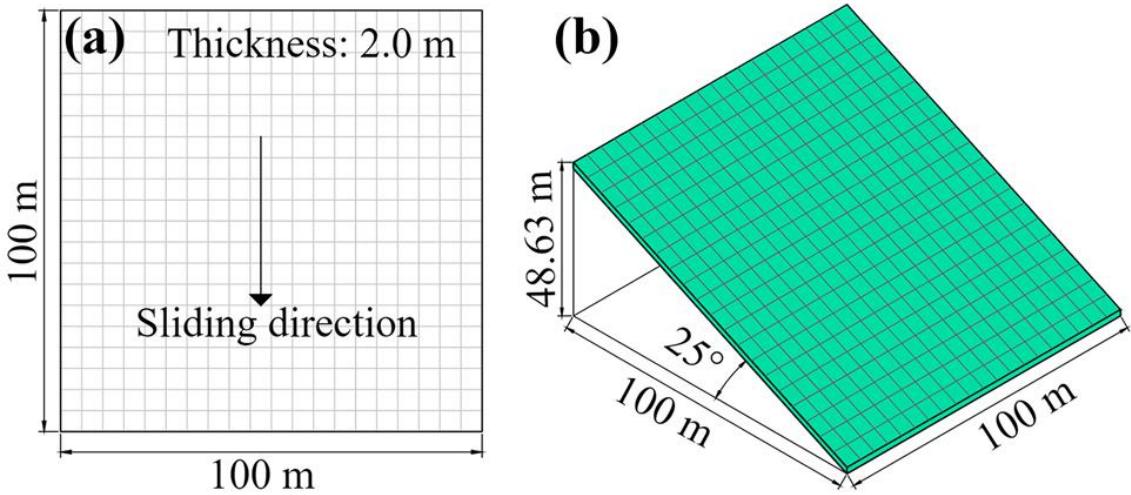
Importing the input JSON file completed!
```

# 4. 3DPLS example

Example for double-checking whether  
3DPLS model performs in the installed computer

# Problem definition

## Slope Geometry



Oguz et al. (2022)

## Uniform Rainfall History

start time [hr]	end time [hr]	Intensity [mm/hr]
0	2	4.0

A planar slope with shallow soil depth (2 m) and inclination of 25° is presented. The region spans 100 m x 100 m with a digital elevation model (DEM) in a resolution of 5 m x 5 m. Due to shallow soil depth, the 3DTS is suitable for analysing shallow translational slope failures.

The groundwater table is located 1m below the ground surface. The soil above the groundwater table is unsaturated, while the soil below the groundwater table is fully saturated.

A short rainfall with uniform intensity occurs in this region. It is assumed that the rainfall intensity is not spatially varying.

The entire region is the same soil unit. A deterministic and probabilistic analysis will be performed in this example. For the probabilistic analysis, the min and max values are always assigned such that ( $\text{min} < \text{mean} < \text{max}$ ) is established.

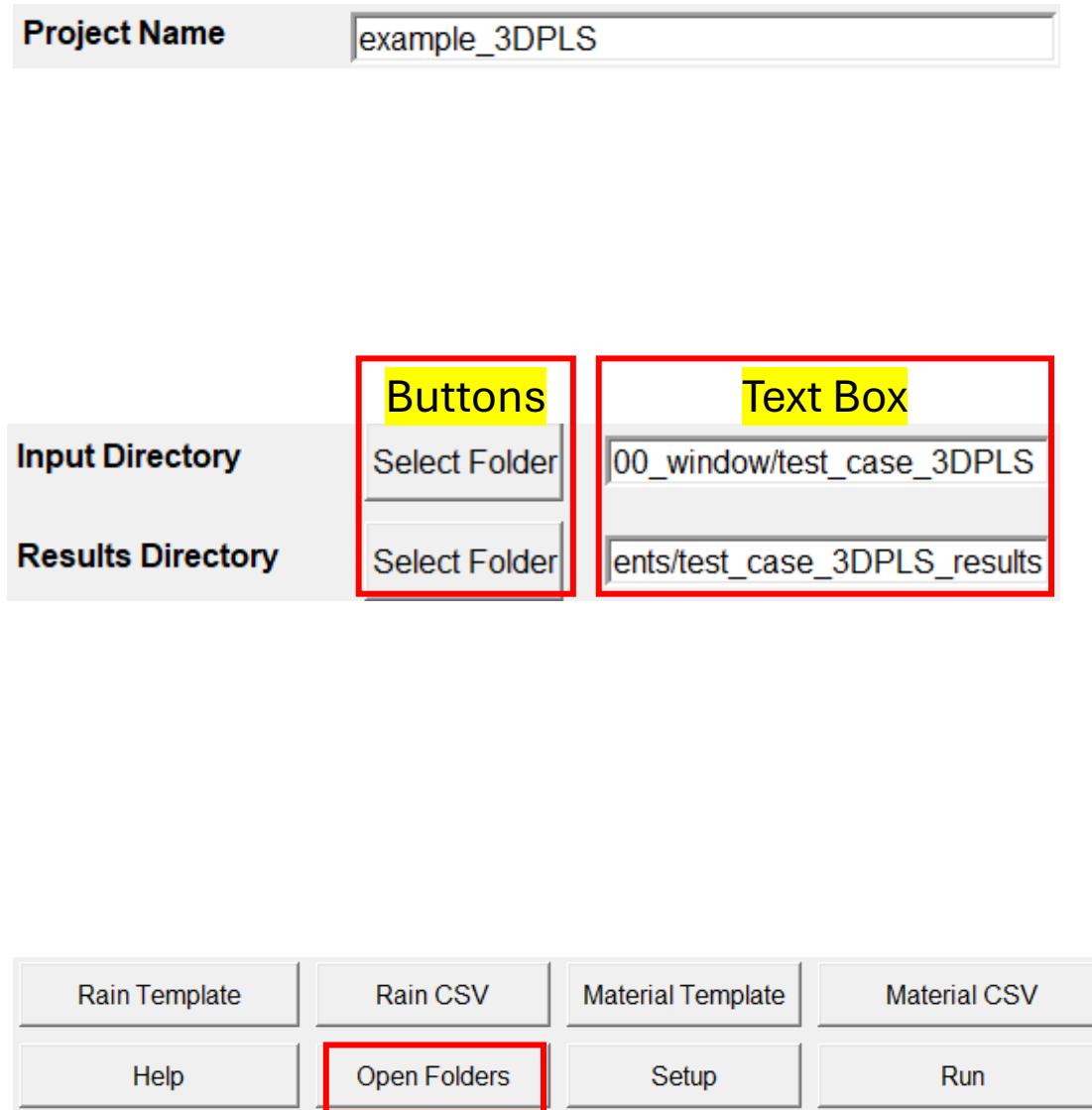
## Material properties

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For deterministic analysis, assign the mean values

Category	Column Headings (unit)	mean	CoV	Prob. Dist.	CorL X (m)	CorL Y (m)
Hydraulics	k_sat (m/s)	$10^{-6}$	0.1	Normal	50	50
	diffusivity (m <sup>2</sup> /s)	$10^{-6}$	0.1	Normal	50	50
Soil	soil unit weight (kN/m <sup>3</sup> )	20	0.05	Lognormal	100	100
	phi (deg)	40	0.05	Lognormal	100	100
	c/Su (kPa)	6	0.1	Lognormal	100	100

## 3DPLS example – step-by-step



### 1. Assign project name

- The project name will be used throughout the analysis for generating output files
- Please name them anything. In our case, we are going to use “example\_3DPLS”
- Please note that white spacing is allowed, but replacing them with underscore (“\_”) or minus (“-”) is advised

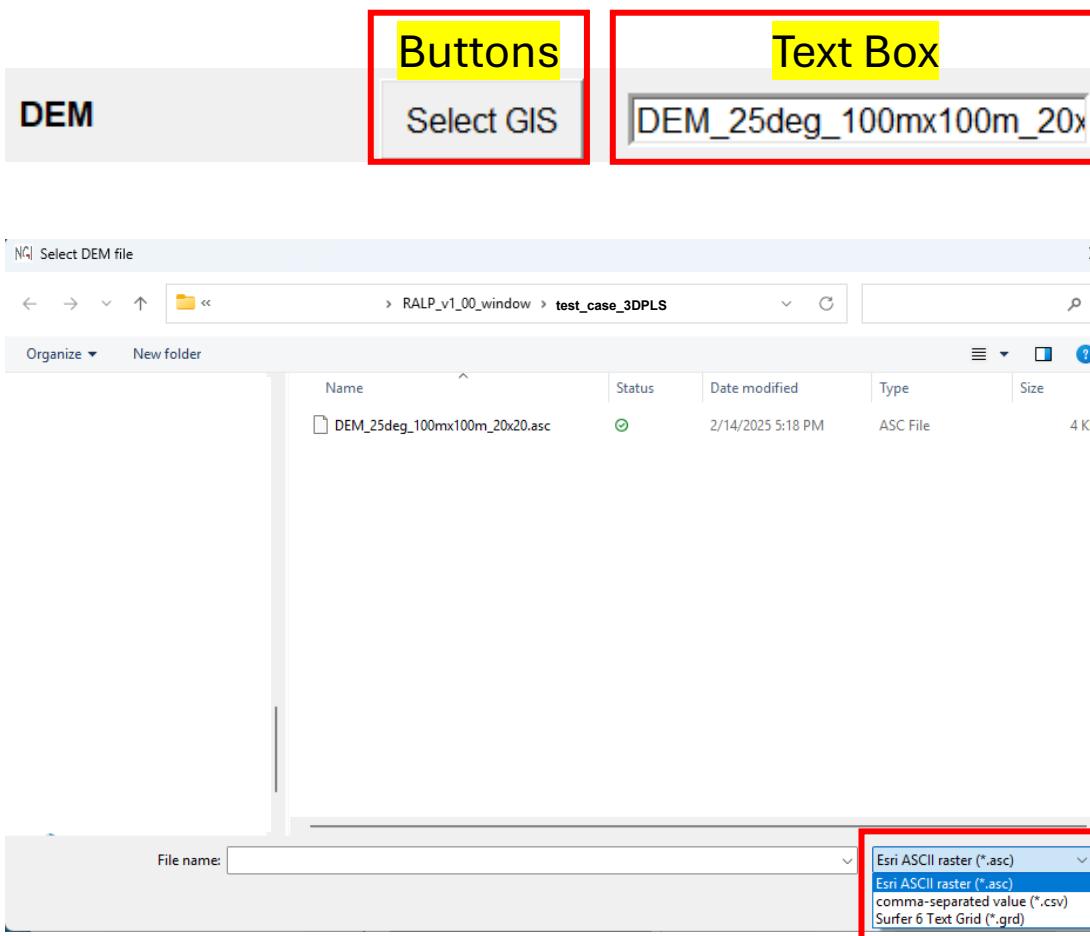
### 2. Input and output directory

- The input directory should be the folder containing all the necessary GIS and CSV files required for the 3DTS analysis
- The 3DTS example should be located at “C:\Program Files\RALP\_window\test\_case\_3DPLS” (for Windows version) or in the directory the user has saved the files.
- Assign a directory in the **Results Directory** where the user wants to save the analysis results. For this example, it was saved in the “Documents/test\_case\_3DPLS\_results” folder
- To assign the directories, either press the corresponding **Select Folder button** and navigate to the folder, or directly copy and paste the directory to the **text box**

### 3. Open Folders

- Press the **Open Folders button (highlighted with a red box)** to check that the directories assigned are correct. You will have two file explorers (or equivalent) opened. One is for the input directory and the other is for the results directory

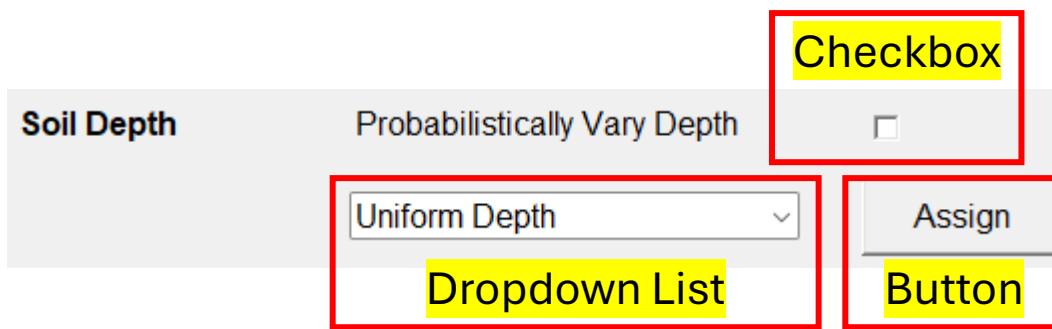
## 3DPLS example – step-by-step



### 4. Assign digital elevation model (DEM)

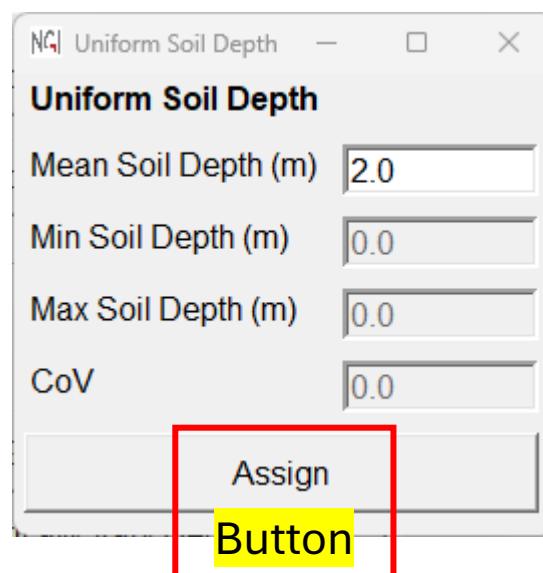
- Press **Select GIS button** and select the either "DEM\_25deg\_100mx100m\_20x20.asc" or "DEM\_25deg\_100mx100m\_20x20.csv"
- Since the software can accept three different types of DEM, please use one of these file formats for future use. To change the type of files you want to select, please change the in this drop-down list (highlighted with red box)
- As typical, if the user knows exactly the name of the DEM file, the user can copy and paste the DEM file name into the textbox

## 3DPLS example – step-by-step



### 5. Assign soil depth

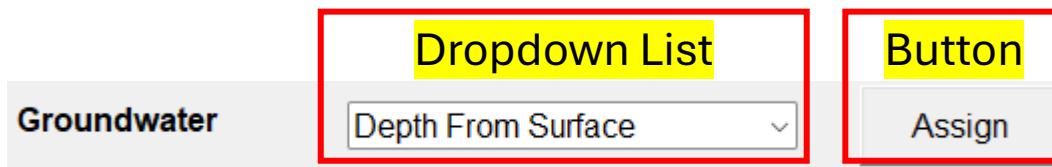
- Since we are performing deterministic soil depth in the example, make sure the checkbox next to the **Probabilistically Vary Depth** is unchecked
- In the dropdown list, make sure the *Uniform Depth* is selected
- Press the **Assign** button



### 6. Assign uniform soil depth

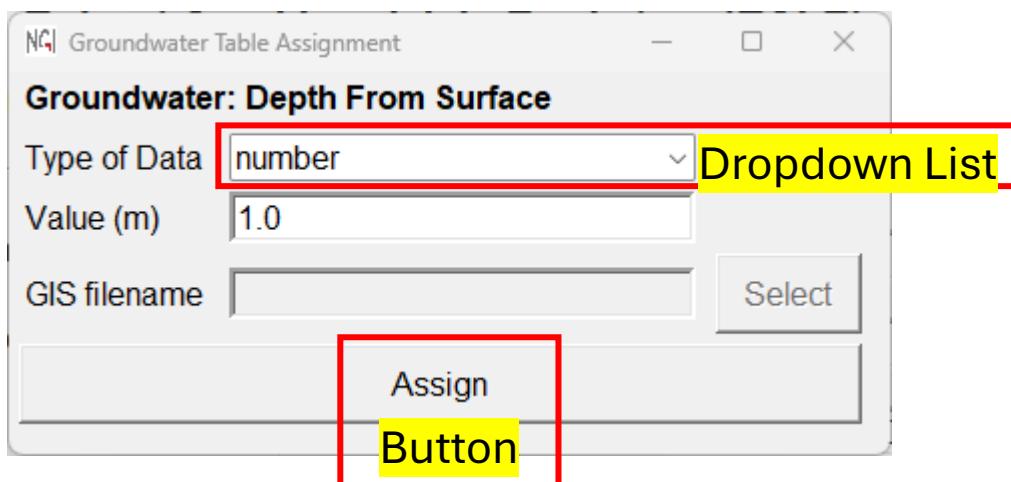
- The slope geometry shows uniform 2 m thickness, so assign 2 m to the **Mean Soil Depth (m)**
- Press the **Assign** button

## 3DPLS example – step-by-step



### 7. Select groundwater table assign method

- As previously mentioned, the groundwater table is located 1m depth below the ground surface
- The user can take any method to assign the groundwater table. In our example, we took the most convenient method with *Depth From Surface* approach
- Press the **Assign** button



### 8. Assign groundwater table

- Since the uniform soil depth is assigned, the groundwater table location will be uniformly 1 m below the ground surface
- Select the number option in the **Type of Data** dropdown list and assign 1.0 m to the **Value (m)**
- Press the **Assign** button

## 3DPLS example – step-by-step

Slope Stability Analysis

Slope Model      3D Bishop

Type      Drained

Ellipsoidal Slip Surface      a (m) 20.0      b (m) 20.0  
c (m) 2.0      z (m) 0.0  
Ellipsoidal  $\alpha$  Comp        $\alpha$  ( $^{\circ}$ ) 0.0  
Minimum Soil Column Number      200

Critical FS      1.3

### 9. Select slope model

- This example will perform 3DPLS model with 3D Bishop slope method
- Select **Drained** for the **Type**

### 10. Assign ellipsoidal slip surface

- Assign an ellipsoidal slip surface by assigning the values as shown in the left image
- Automatically compute the direction angle  $\alpha$
- Assign the default number for **Minimum Soil Column Number**

### 11. Critical slope factor of safety (Critical FS)

- This example will assume any slope with a factor of safety (FS) < 1.3 will be considered to have failed

## 3DPLS example – step-by-step

Hydraulic Analysis

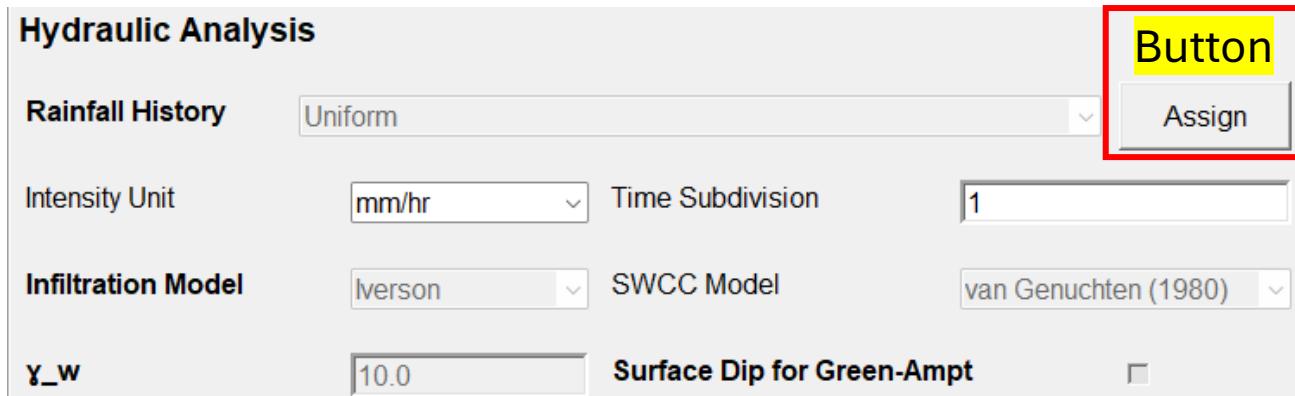
Rainfall History: Uniform

Intensity Unit: mm/hr Time Subdivision: 1

Infiltration Model: Iverson SWCC Model: van Genuchten (1980)

$\gamma_w$ : 10.0 Surface Dip for Green-Ampt

**Button** **Assign**



### 13. Select rainfall history

- Since this example will perform the 3DPLS model, the Iverson method is selected. Therefore, the following parameters are automatically assigned:
  - Uniform* option – same rainfall intensity everywhere
  - unit weight of water ( $\gamma_w$ ) as 10.0 kN/m<sup>3</sup>
  - No need to select the SWCC model
- Since the rainfall intensity used is “mm/hr”, ensure that the **Intensity Unit** is consistent
- We want results at the end of simulation, so keep **Time Subdivision** as one (1)
- Press the **Assign button** to assign rainfall history

Rainfall History

Uniform Rainfall

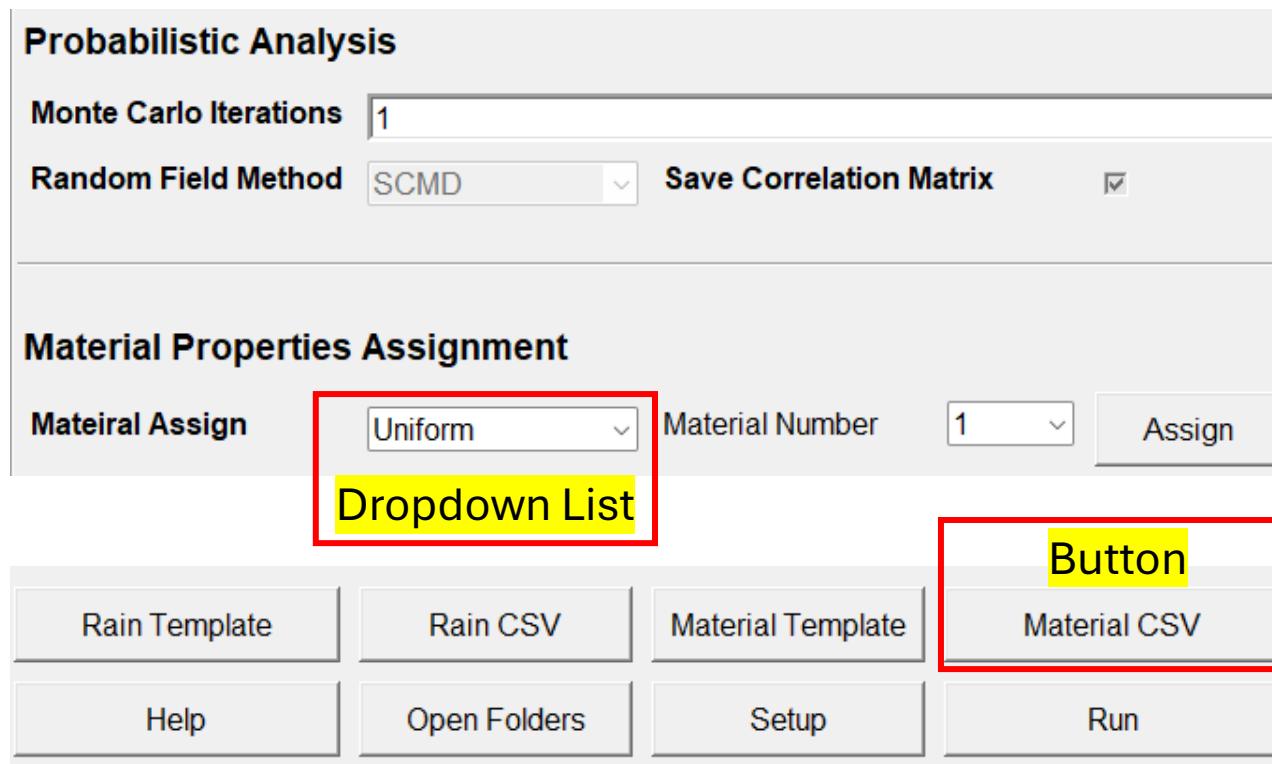
Time Step	Start Time	End Time	Intensity	Assign	Button
1	0	2	4		
2	0.0	0.0	0.0		
3	0.0	0.0	0.0		
4	0.0	0.0	0.0		
5	0.0	0.0	0.0		
6	0.0	0.0	0.0		

### 14. Assign rainfall history

- Assign the uniform rainfall history as shown in the image on the left.
- Press the **Assign button** to confirm the rainfall history

# 3DPLS example – step-by-step

## Deterministic Analysis Version



Uniform Deterministic Material Properties: 1 soil zones						
Material Zones	Open GIS					
Mat ID	K <sub>s</sub> (m/s)	ψ <sub>i</sub>	SWCC_model	a (kPa)	n	m
1	1e-6	10	Iverson	33.33	2	0.5
2	0.0	0.0	Iverson	0.0	0.0	0.0

### 15-1. Assign the number of iterations

- To perform deterministic analysis, assign integer one (1) to the **Monte Carlo Iterations**

### 15-2. Material properties assign method

- Since the entire slope has the same soil, select *Uniform* soil properties from the **Material Assign** dropdown list

### 15-3. Assign material properties with CSV

- The soil properties are already prepared in a CSV file
- Press the **Material CSV** button to read the material properties.
- In the directory specified in the **Input Directory** from Step 2, select the CSV file named "material\_info\_example\_deterministic.csv"
- To double-check the material properties, press the **Assign** button next to the **Material Number**. Changes to the material properties can be made in the new window titled **Uniform Deterministic Material Properties: 1 soil zones**. To confirm, the user can either select the **Assign button** or close the window

# 3DPLS example – step-by-step

## Probabilistic Analysis Version

Probabilistic Analysis

Monte Carlo Iterations

Random Field Method  Save Correlation Matrix

Material Properties Assignment

Material Assign  Material Number

**Button**

Rain Template	Rain CSV	Material Template	<b>Material CSV</b>
Help	Open Folders	Setup	Run

Material

Uniform Probabilistic Material Properties: 1 soil zones

Material Zones

Mat ID	K <sub>s</sub> (m/s): $\mu$	K <sub>s</sub> (m/s): CoV	K <sub>s</sub> (m/s): Prob. Dist.	K <sub>s</sub> (m/s): CorL X (m)	K <sub>s</sub> (m/s): CorL Y (m)	K <sub>s</sub> (m/s): Min	K <sub>s</sub> (m/s): Max
1	1e-6	0.1	Normal	50	50	0	1
2	0.0	0.0				0.0	0.0

### 16-1. Assign the number of iterations

- To perform deterministic analysis, assign an integer 100 to the **Monte Carlo Iterations**
- The Random Field Method by default uses the separated covariance matrix decomposition (SCMD) by Li et al. (2019)

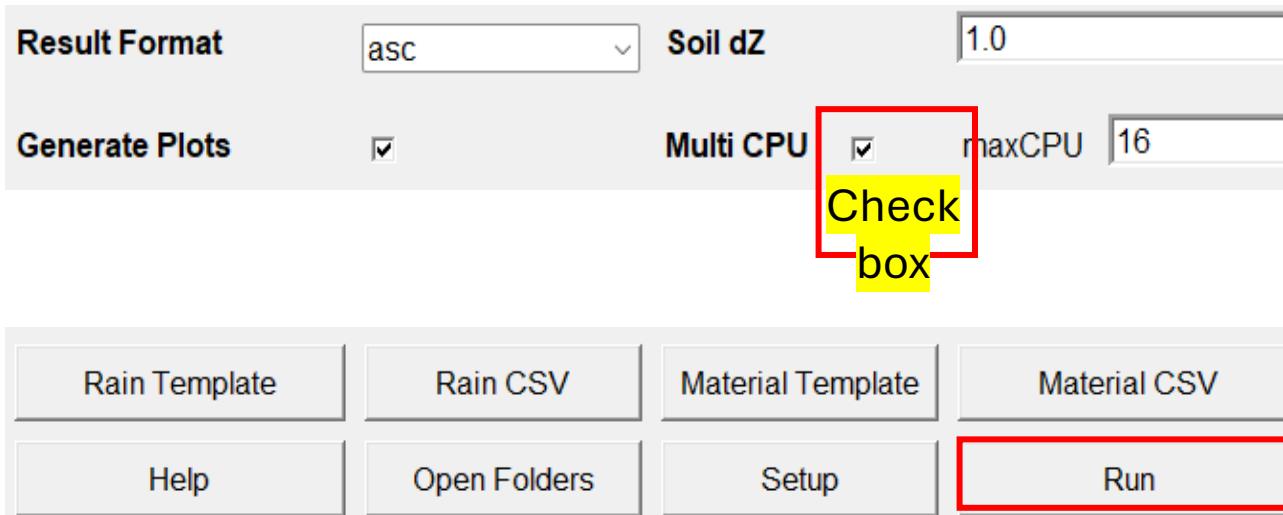
### 16-2. Material properties assign method

- Since the entire slope has the same soil, select *Uniform* soil properties from the **Material Assign** dropdown list

### 16-3. Assign material properties with CSV

- The soil properties are already prepared in a CSV file
- Press the **Material CSV** button to read the material properties.
- In the directory specified in the **Input Directory** from Step 2, select the CSV file named “material\_info\_example\_probabilistic.csv”
- To double-check the material properties, press the **Assign** button next to the **Material Number**. Changes to the material properties can be made in the new window titled **Uniform Probabilistic Material Properties: 1 soil zones**. To confirm, the user can either select the **Assign button** or close the window

## 3DPLS example – step-by-step



### 17. CPU Multiprocessing

- To allow faster computation, CPU multiprocessing is utilized to perform analysis in parallel
- Check the **Multi CPU checkbox** and assign the maximum number of CPU threads utilized by assigning 16 to **maxCPU**
- Even if the specified **maxCPU** number exceeds the CPU hardware capability, the software will automatically assign the maximum number of CPUs capable in the local computer

### 18. Start 3DPLS analysis on the local computer

- Press the **Run button** to initiate the 3DPLS analysis
- A new command prompt, powershell, or terminal window will open and start the 3DPLS analysis
- All input and results files are saved in the **Results Directory**

```
C:\Users\user\Dropbox (KA) + 
Loaded soil parameters for Drained analysis with 1 zones
Ellipsoid parameters: a=20.0, b=20.0, c=2.0, alpha=0.0, z=0.0, calc_alpha=Yes
Total number of processors: 24
Script_Directory: C:\Users\user\Documents\test_case_3DPLS_results\3DPLS\Codes
Workspace_Root: C:\Users\user\Documents\test_case_3DPLS_results\3DPLS
Loading configuration from: C:\Users\user\Documents\test_case_3DPLS_results\3DPLS\03-Input\input_3DPLS.yaml
Main_Directory: C:\Users\user\Documents\test_case_3DPLS_results\3DPLS
GIS_Data_Directory: C:\Users\user\Documents\test_case_3DPLS_results\3DPLS\GIS\
Results_Directory: C:\Users\user\Documents\test_case_3DPLS_results\3DPLS\04-Results\
Rainfall input: 1.1111111111111e-06 m/s for 7200.0 seconds
Monte Carlo number: 1
Analysis: Drained, FS Calculation: Bishop3D, Random Field: SCMD
Zmax variability: No, CoV: 0, Min: 0
Loaded soil parameters for Drained analysis with 1 zones
Ellipsoid parameters: a=20.0, b=20.0, c=2.0, alpha=0.0, z=0.0, calc_alpha=Yes
Total number of processors: 24
Script_Directory: C:\Users\user\Documents\test_case_3DPLS_results\3DPLS\Codes
Workspace_Root: C:\Users\user\Documents\test_case_3DPLS_results\3DPLS
Loading configuration from: C:\Users\user\Documents\test_case_3DPLS_results\3DPLS\03-Input\input_3DPLS.yaml
Main_Directory: C:\Users\user\Documents\test_case_3DPLS_results\3DPLS
GIS_Data_Directory: C:\Users\user\Documents\test_case_3DPLS_results\3DPLS\GIS\
Results_Directory: C:\Users\user\Documents\test_case_3DPLS_results\3DPLS\04-Results\
Rainfall input: 1.1111111111111e-06 m/s for 7200.0 seconds
Monte Carlo number: 1
Analysis: Drained, FS Calculation: Bishop3D, Random Field: SCMD
Zmax variability: No, CoV: 0, Min: 0
Loaded soil parameters for Drained analysis with 1 zones
Ellipsoid parameters: a=20.0, b=20.0, c=2.0, alpha=0.0, z=0.0, calc_alpha=Yes
Total number of processors: 24
```

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Authors: Dr. Enok Cheon (3DTSP and GUI), Dr. Emir A. Oguz (3DPLS)  
Association: Dept. of Natural Hazards, NGI, Sandakerveien 140, 0484 Oslo  
Date: Feb 02, 2026  
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Language: Python3  
License: MIT

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