Robust Areal Landslide Prediction (RALP)

version 1.00

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Content

1. Installation and Setup

RALP software versions

- If want access to code for quick implementation or running in Linux or MacOS, use “RALP_v1_00”

RALP_v1_00

- If user is using Windows PC for the software and do not want to install new Python version, use “RALP_v1_00_window” or install in local computer using “RALP_v1_00_window_setup.exe”

RALP_v1_00_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_00" folder

MacOS or Linux

follow these steps:

(a) open the terminal

(b) navigate to your terminal into the "RALP_v1_00" folder by typing the following command:

cd <filepath of the folder containing the “RALP_v1_00" folder>/RALP_v1_00

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

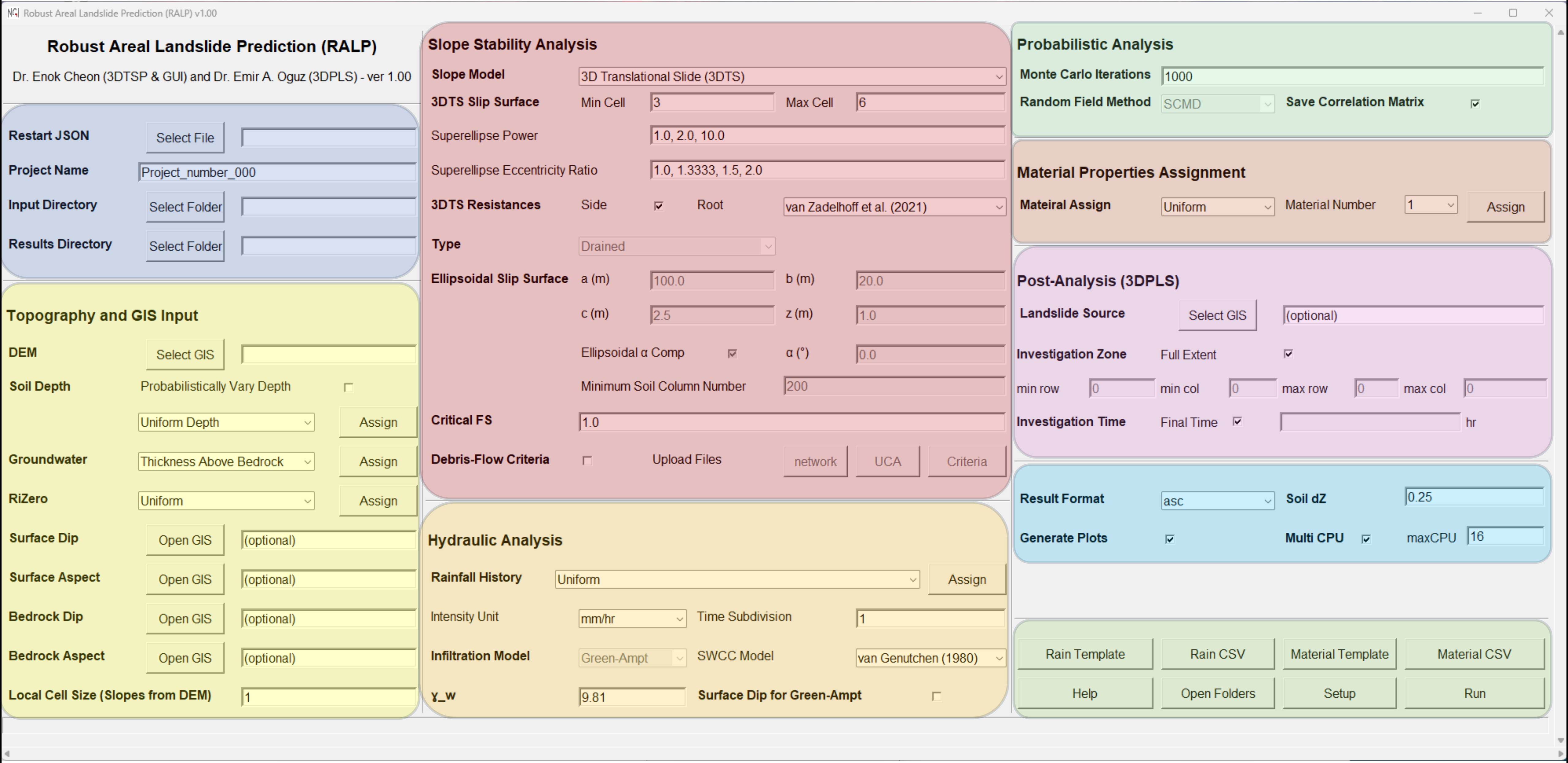
sh start_GUI_linux_mac.sh

Folder Contents – for windows only

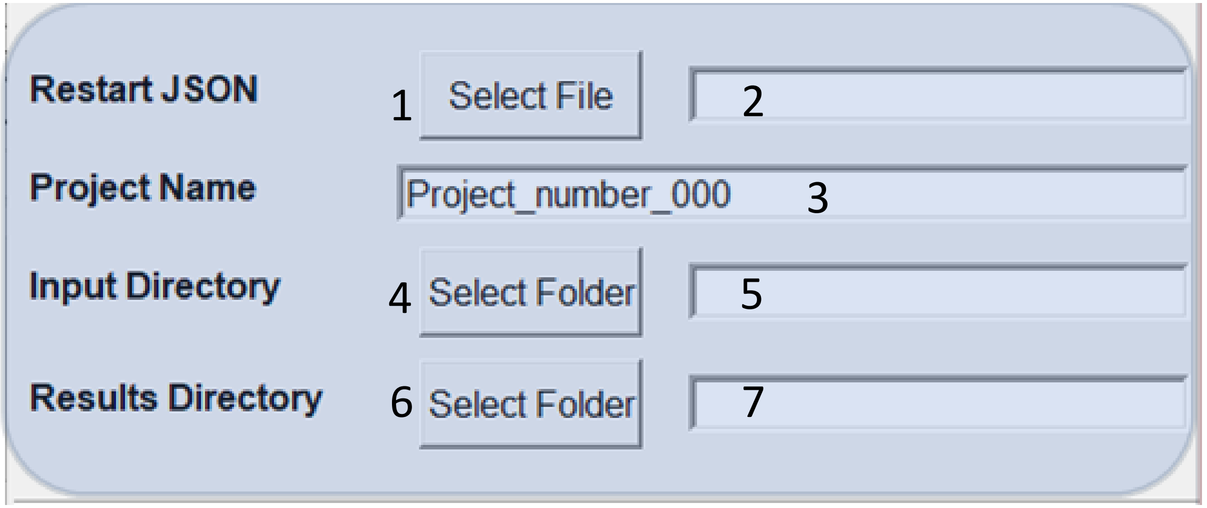
help	User manual and template for input YAML file
python-3.10.11-embed-amd64	Local Python to run RALP
script	Python and batch scripts for running RALP
test_case_3DPLS	Example case to run 3DPLS analysis
test_case_3DTSP	Example case to run 3DTSP analysis
license.txt	License text
NGI_logo_cropped.ico	NGI 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

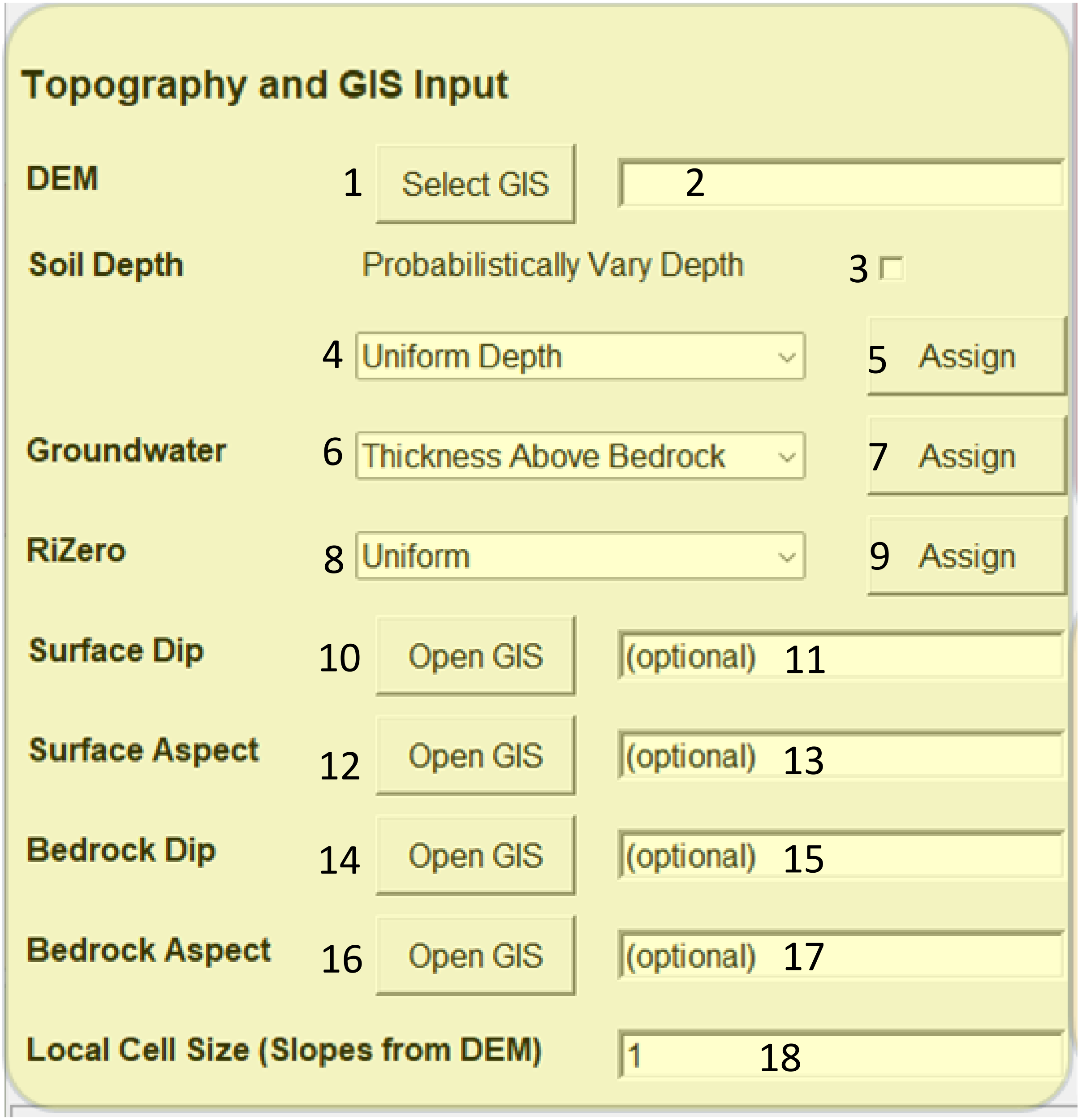


User Interface – Project name and Directory



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



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 ≤ soil depth [=mean*(1 + CoV * normal(0, 1))] ≤ 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):

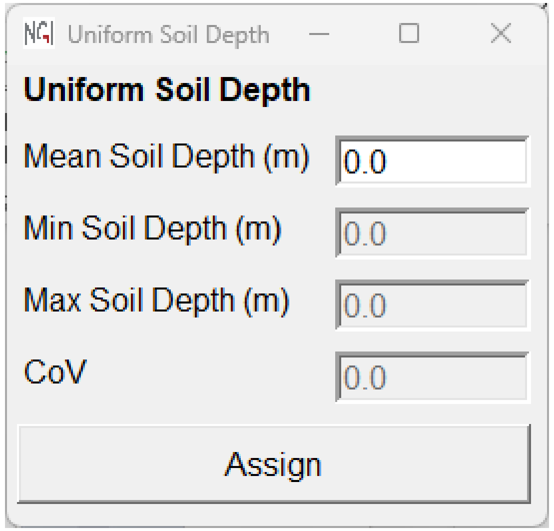
     depth = -2.578*tan(surface_dip) + 2.612
   - *Linear Multiregression* – use multilinear regression:

     $depth = b_0 + p_1*b_1 + \ldots + p_n*b_n$
   - *Power Multiregression* – use multilinear regression:

     $depth = b_0 * p_1^{b1} * \ldots * p_n^{bn}$
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)

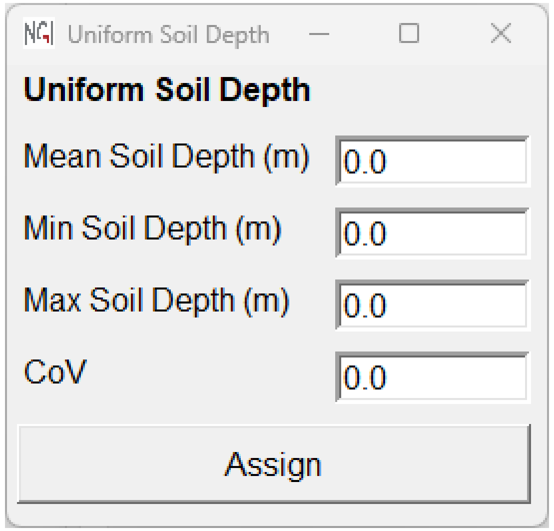
User Interface – Topography and GIS Input

Probabilistically Vary Depth ☐ and **Soil Depth Option:** *Uniform Depth*



Assign uniform soil depth

Probabilistically Vary Depth ☑ and **Soil Depth Option:** *Uniform Depth*

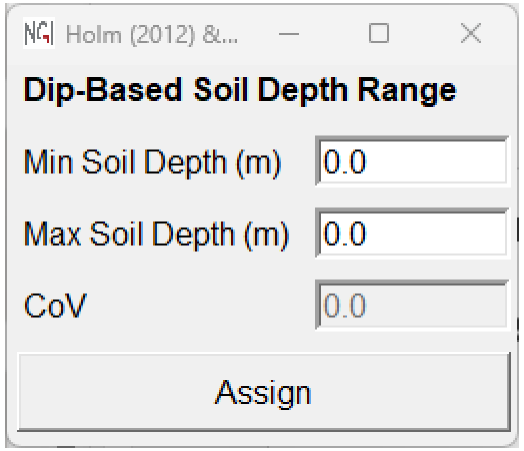


Assign uniform mean soil depth.
For probabilistic soil depth, the minimum, maximum, and coefficient of variation (CoV) can be assigned.

min soil depth ≤ uniform depth*(1 + CoV * normal(0, 1)) ≤ max soil depth

User Interface – Topography and GIS Input

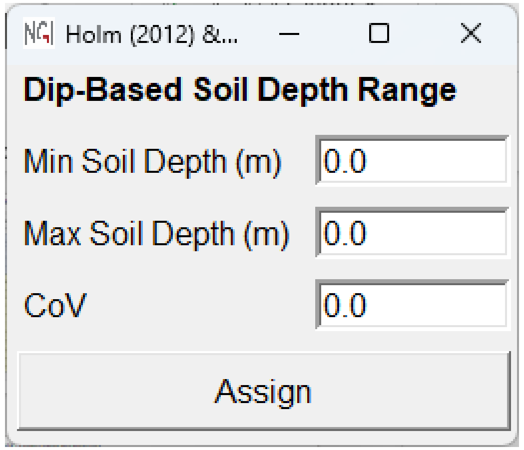
Probabilistically Vary Depth ☐ and **Soil Depth Option:** *Holm (2012) & Edvarson (2013)*



Assign minimum and maximum soil depth range,
Such that the following equation does not compute negative values:

depth = -2.578*tan(surface_dip) + 2.612

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



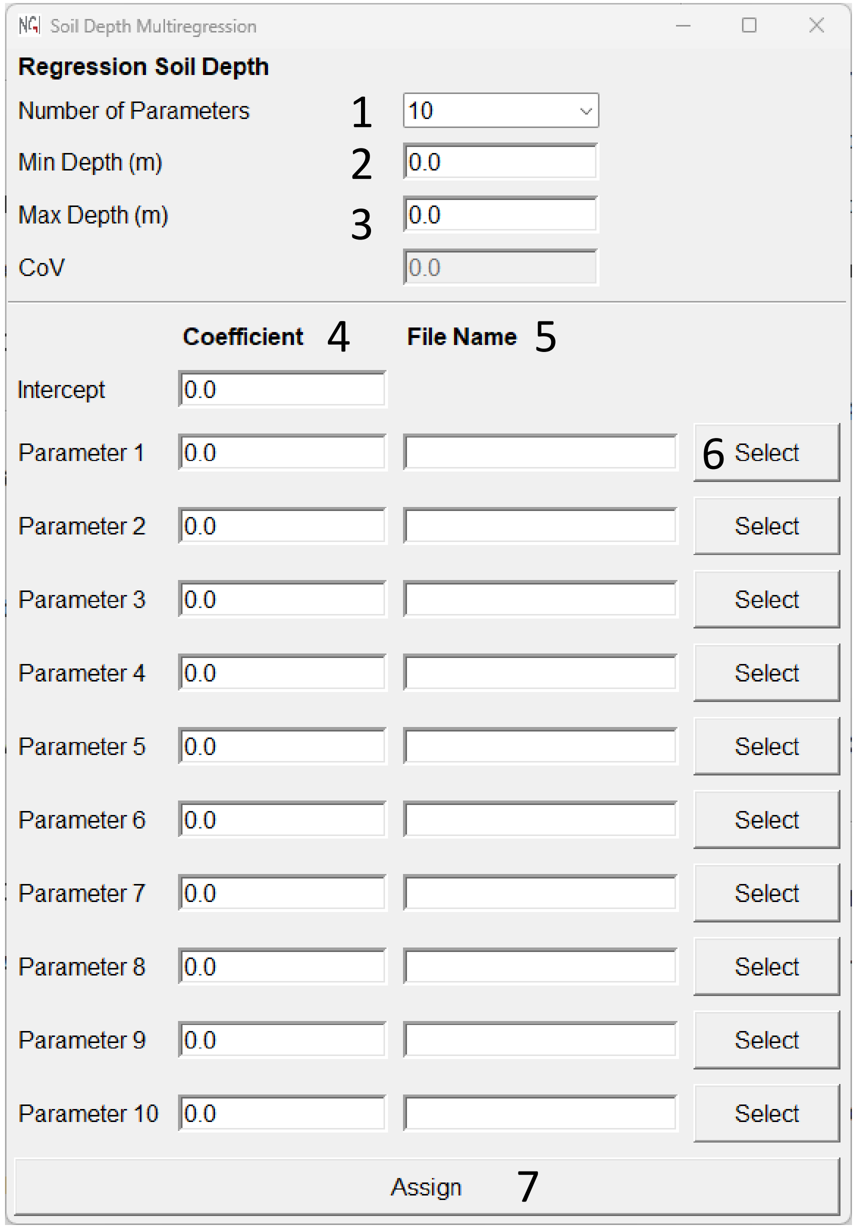
Assign minimum and maximum soil depth range,
Such that the following computed mean depth does not compute negative values:

mean depth = -2.578*tan(surface_dip) + 2.612

Coefficient of variation (CoV) can be assigned for:
min soil depth ≤ mean depth*(1 + CoV * normal(0, 1)) ≤ max soil depth

User Interface – Topography and GIS Input

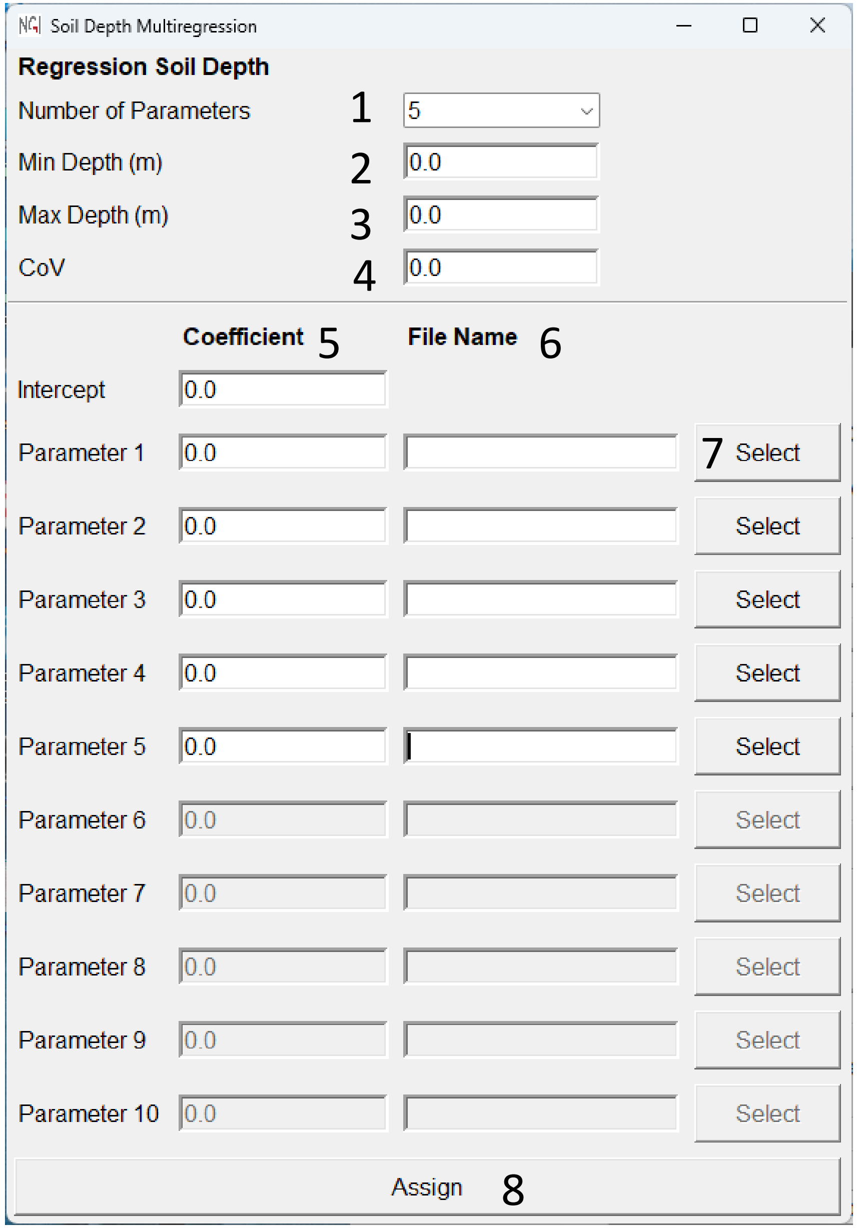
Probabilistically Vary Depth ☐ and **Soil Depth Option:** *Power Multiregression* or *Linear Multiregression*



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 = $(b_0 + p_1 * b_1 + \ldots + p_n * b_n)$
   - *Power Multiregression:* soil depth = $(b_0 * p_1^{b1} * \ldots * p_n^{bn})$
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

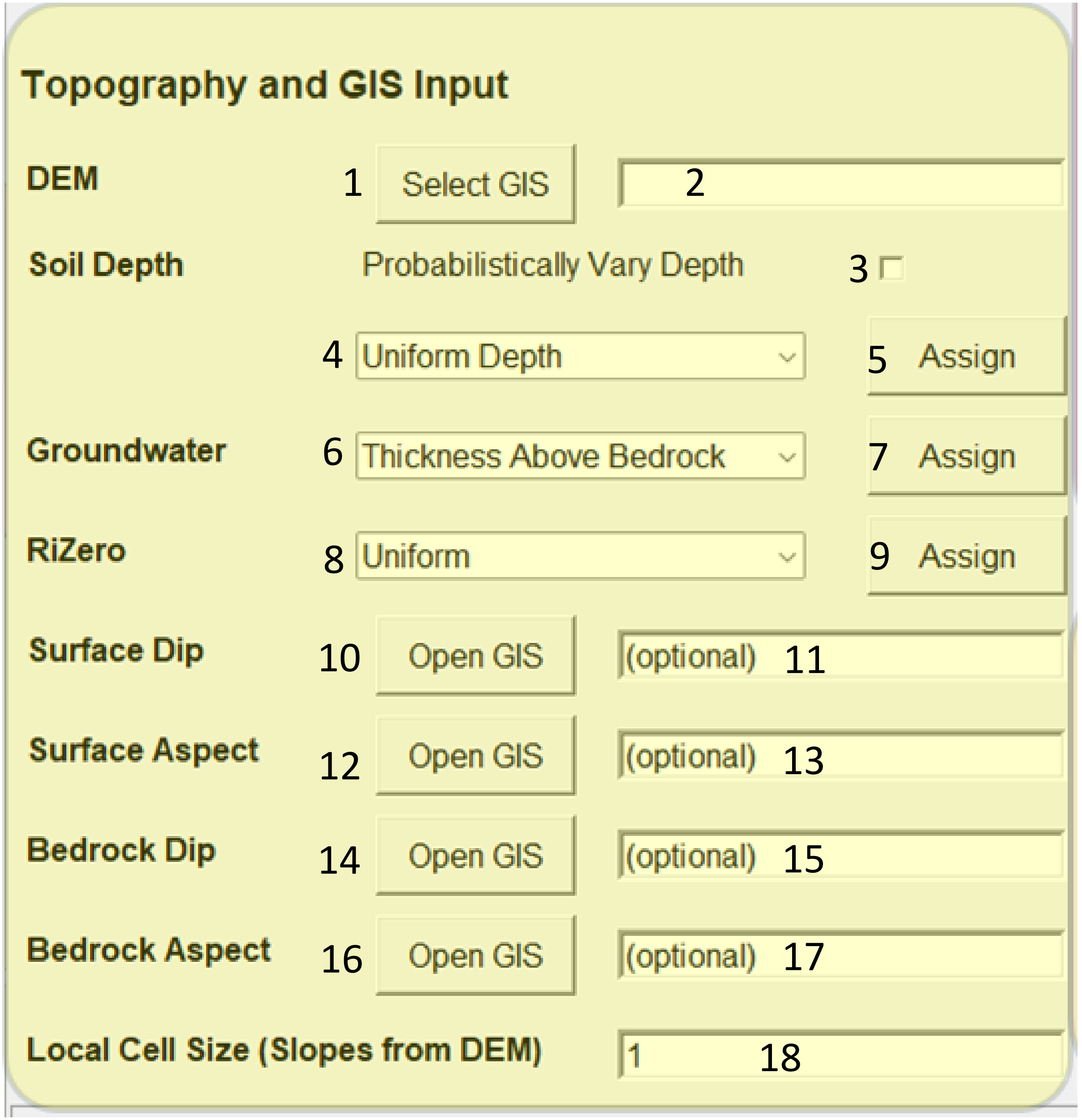
Probabilistically Vary Depth ☑ and **Soil Depth Option:** *Power Multiregression* or *Linear Multiregression*



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 = $(b_0 + p_1*b_1 + \ldots + p_n*b_n)$
   - *Power Multiregression:* mean soil depth = $(b_0 * p_1^{b1} * \ldots * p_n^{bn})$

   min soil depth ≤ mean depth*(1 + CoV * normal(0, 1)) ≤ 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

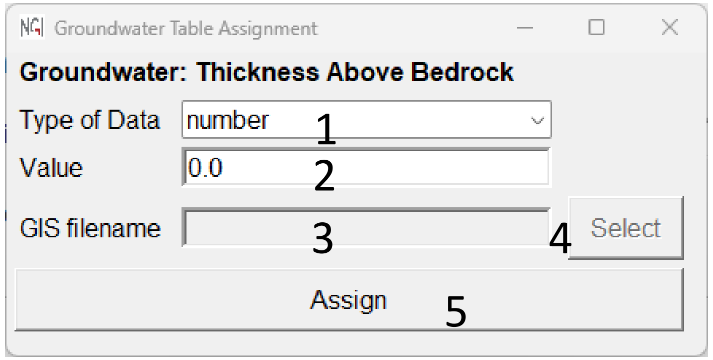
User Interface – Topography and GIS Input



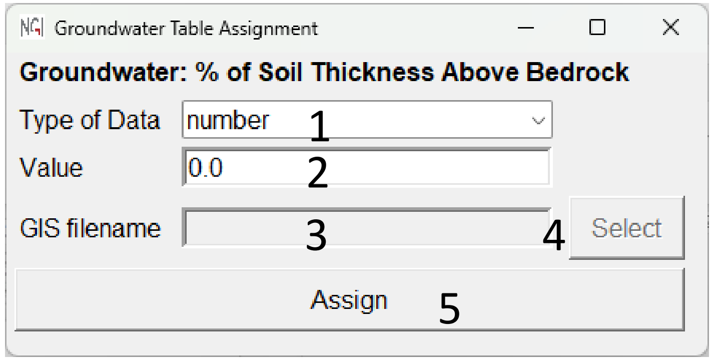
6. **Options for Modelling Groundwater Table**
   - *Thickness Above Bedrock* – assign the groundwater table (henceforth, GWT) to be a vertical distance above the bedrock level
     GWT = min{ground surface, bedrock surface + thickness}
   - *Depth From Surface* – assign the GWT to be a vertical distance 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 *GIS file* option)

User Interface – Topography and GIS Input

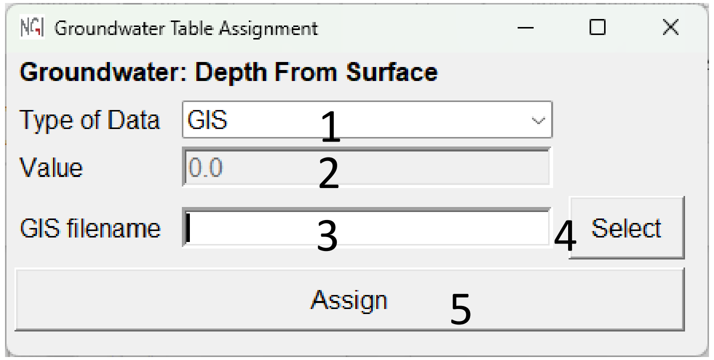
Groundwater Option: *Thickness Above Bedrock*



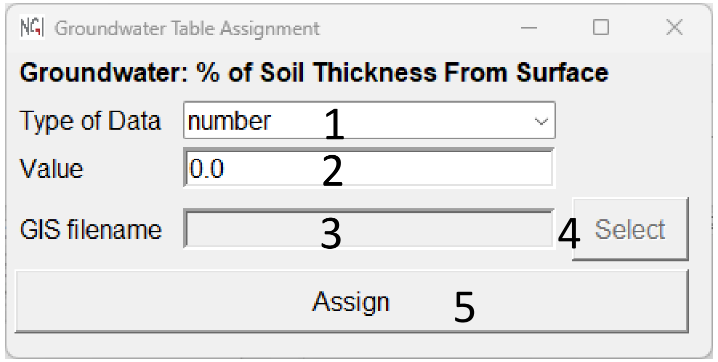
Groundwater Option: *% of Soil Thickness Above Bedrock*



Groundwater Option: *Depth From Surface*

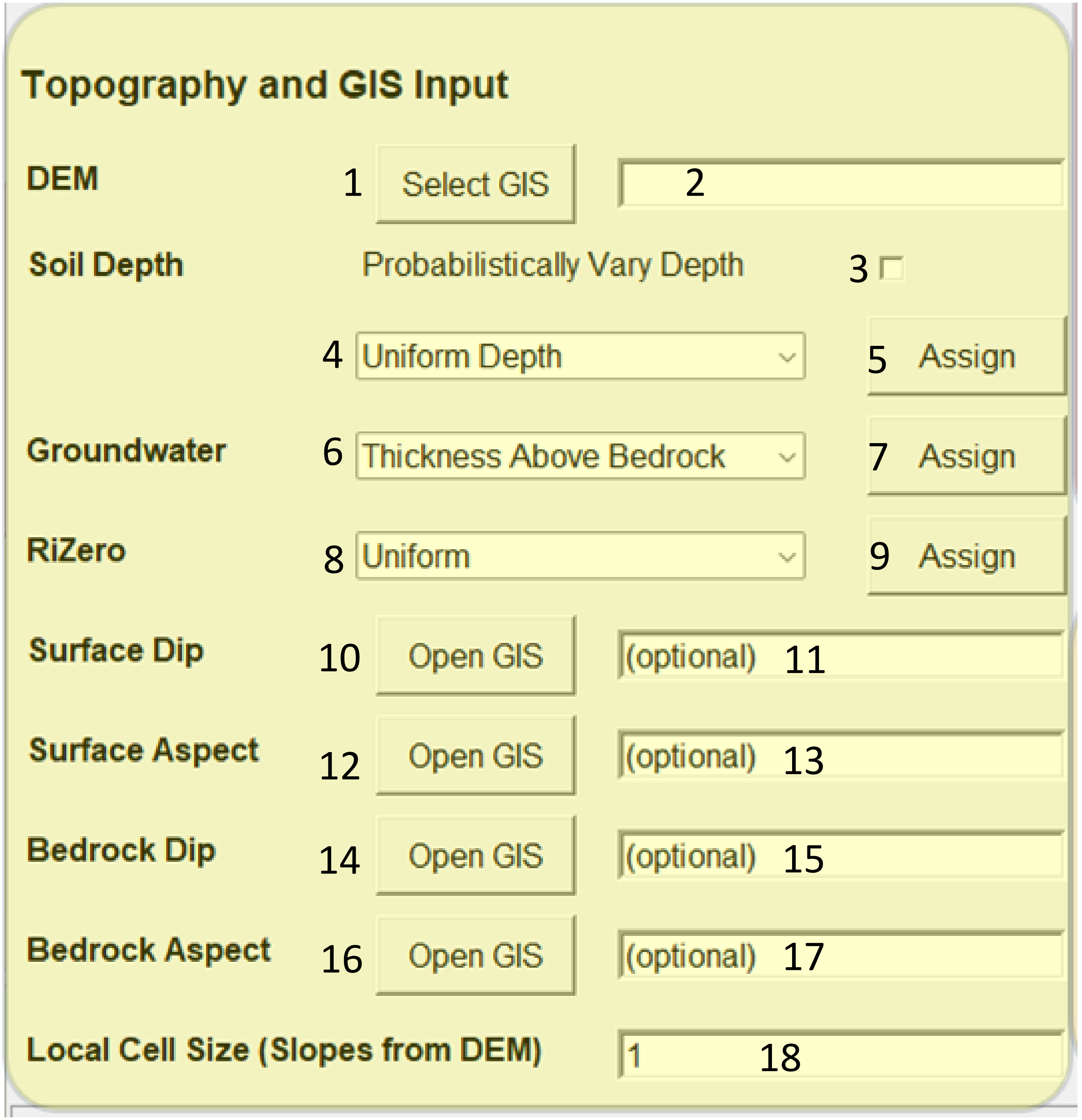


Groundwater Option: *% of Soil Thickness From Surface*



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

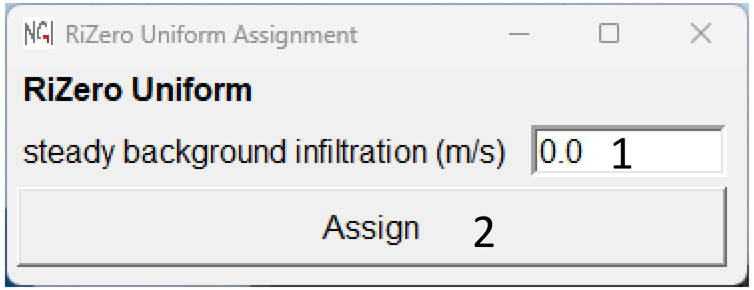
User Interface – Topography and GIS Input



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

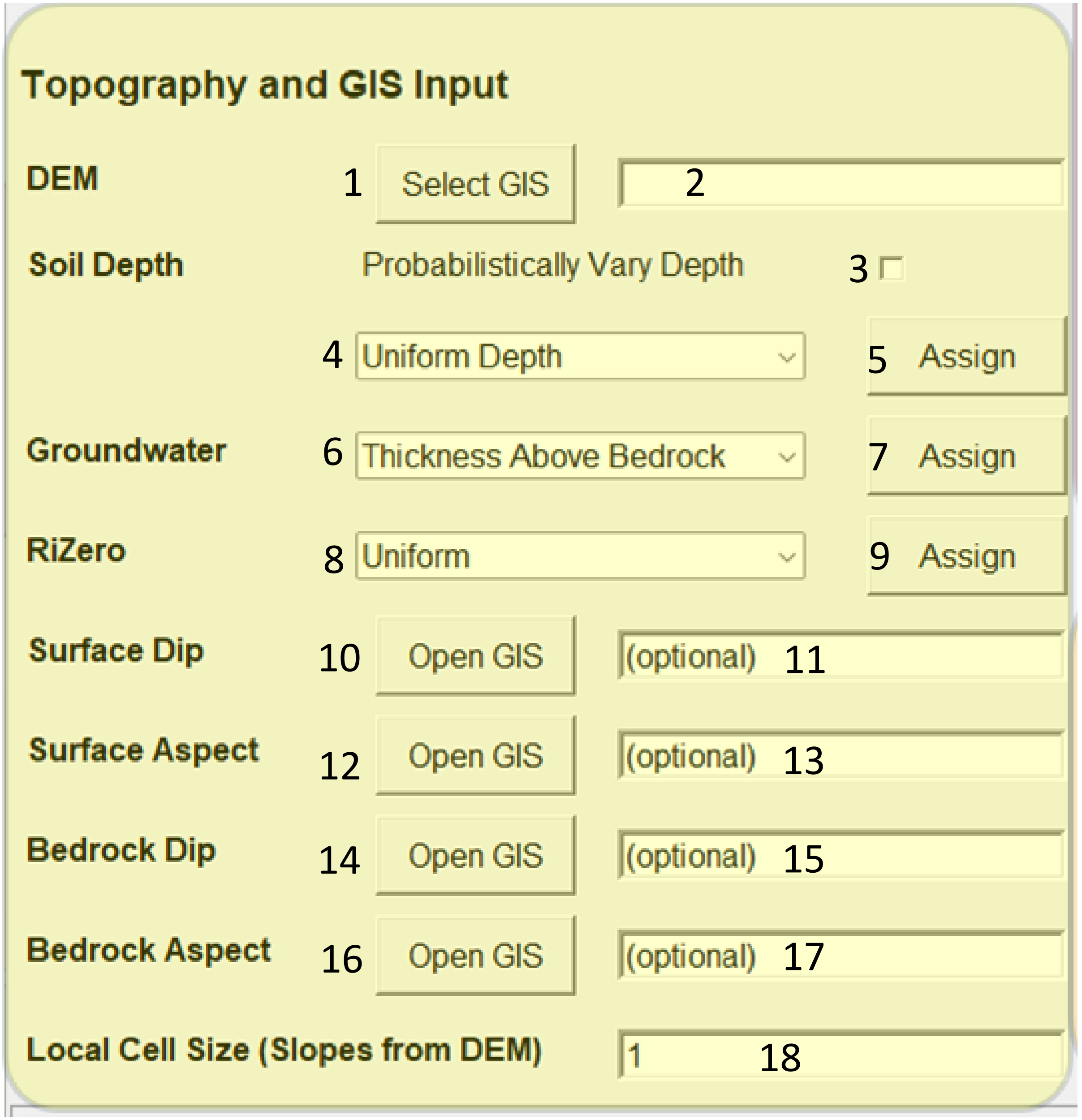
User Interface – Topography and GIS Input

RiZero Option: *Uniform*



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

User Interface – Topography and GIS Input



14. Select bedrock dip file (optional)
- Navigate and select the GIS file containing the bedrock surface dip value

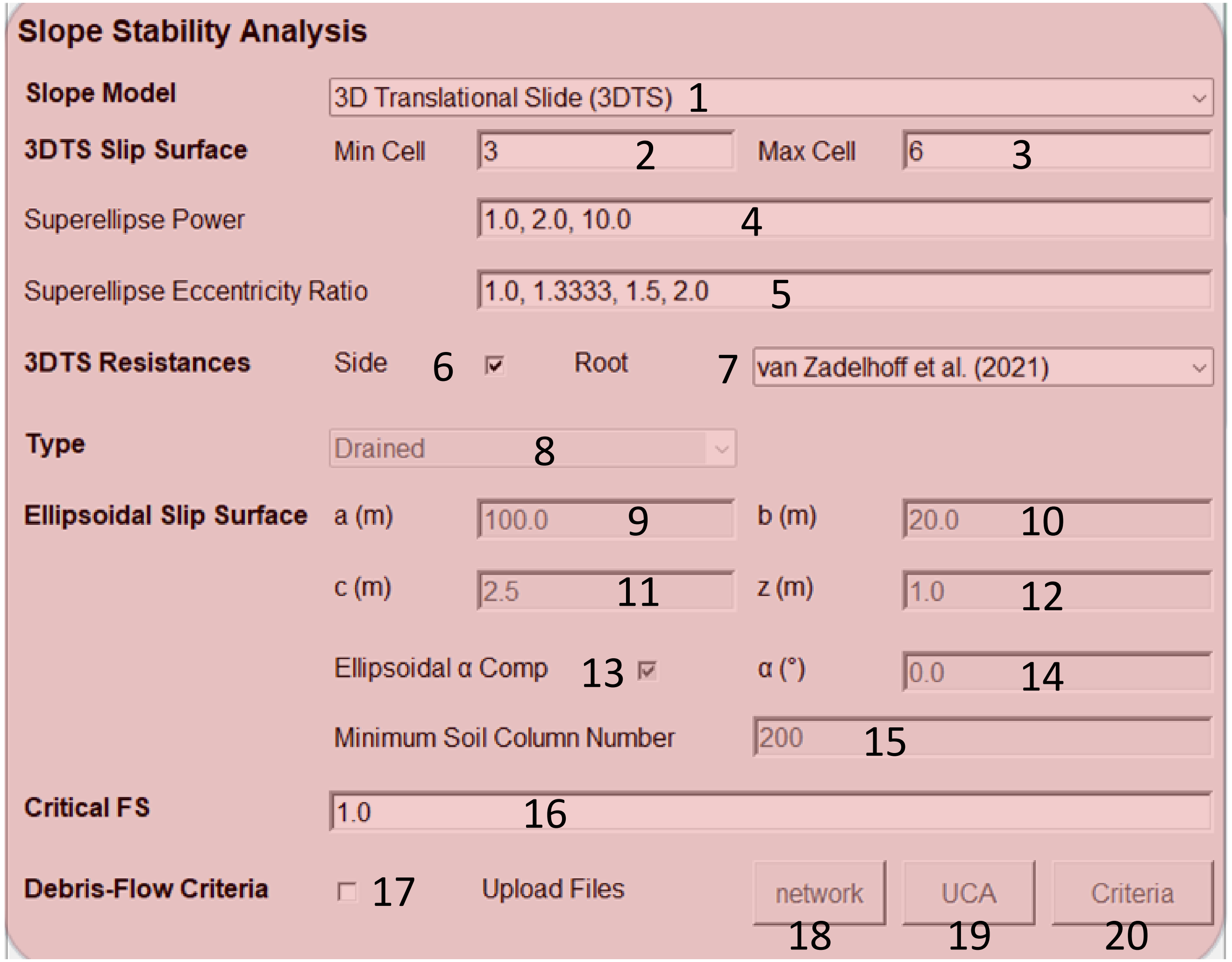
15. Bedrock dip GIS file name (optional)
- If assigned, it shows the file name of the bedrock surface dip GIS file, which can manually be changed with this text box
- If unassigned, computed from DEM and soil depth

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

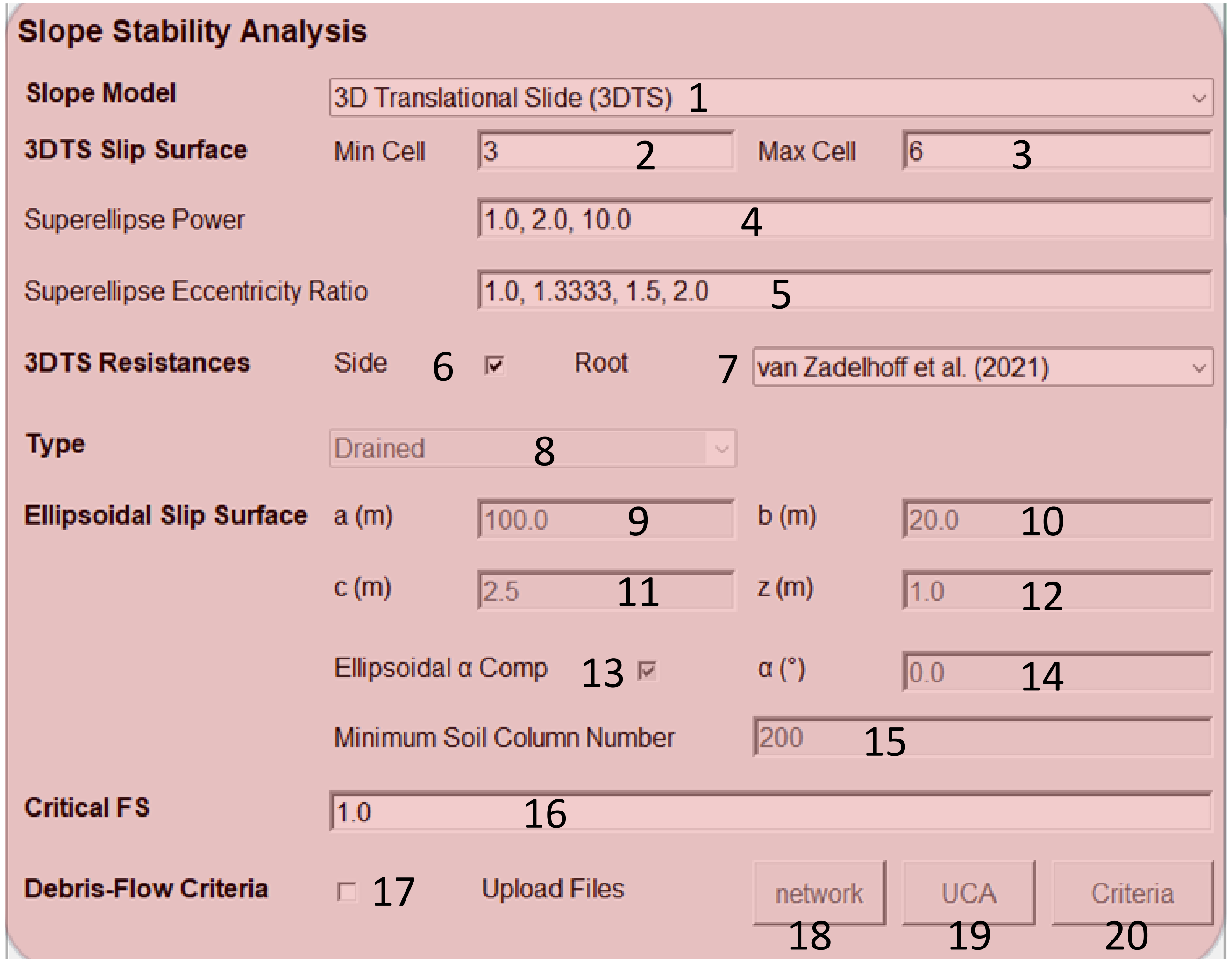
18. Local cell size
- Integer number indicating the size of DEM cell used to perform bilinear interpolation to compute the dip and aspect data
- Default = 1

User Interface – Slope Stability Analysis Input

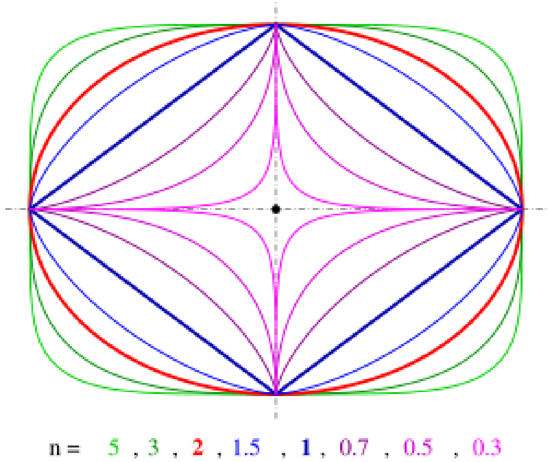


1. **Select slope stability analysis model**
   - (Opt. 1) *Skip (only perform infiltration)* – no slope stability analysis is performed – only perform Green-Ampt rainfall infiltration
   - (Opt. 2) *Infinite Slope*
   - (Opt. 3) *3D Translational Slide (3DTS)* – assign model parameters from 2 to 7
   - (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



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 (,)



Superellipse Equation

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

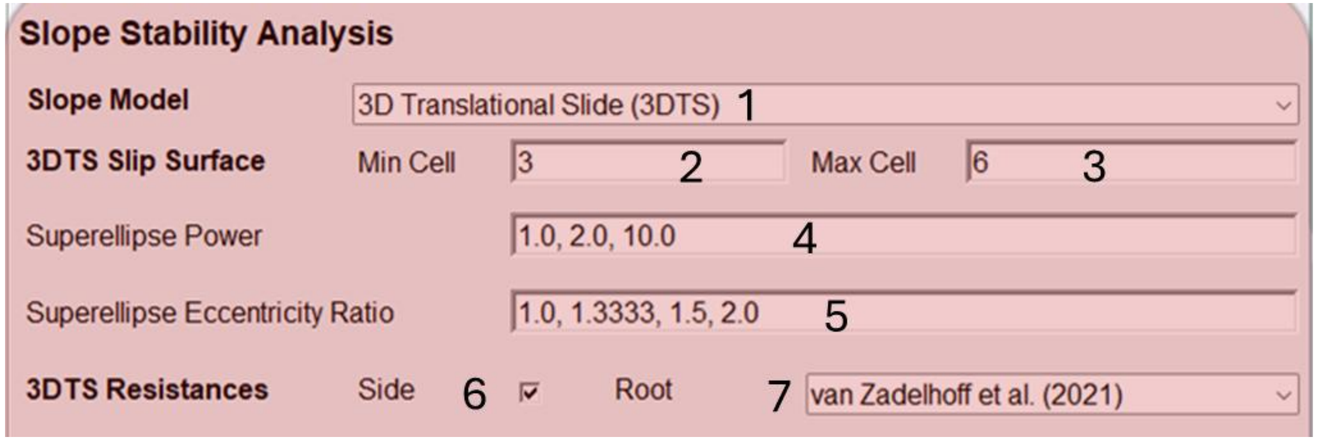
n = Superellipse Power

$a/b = b/a$ = Superellipse Eccentricity Ratio

a = size in x-direction

b = size in y-direction

User Interface – Slope Stability Analysis Input



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_r *= depth of root present*

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

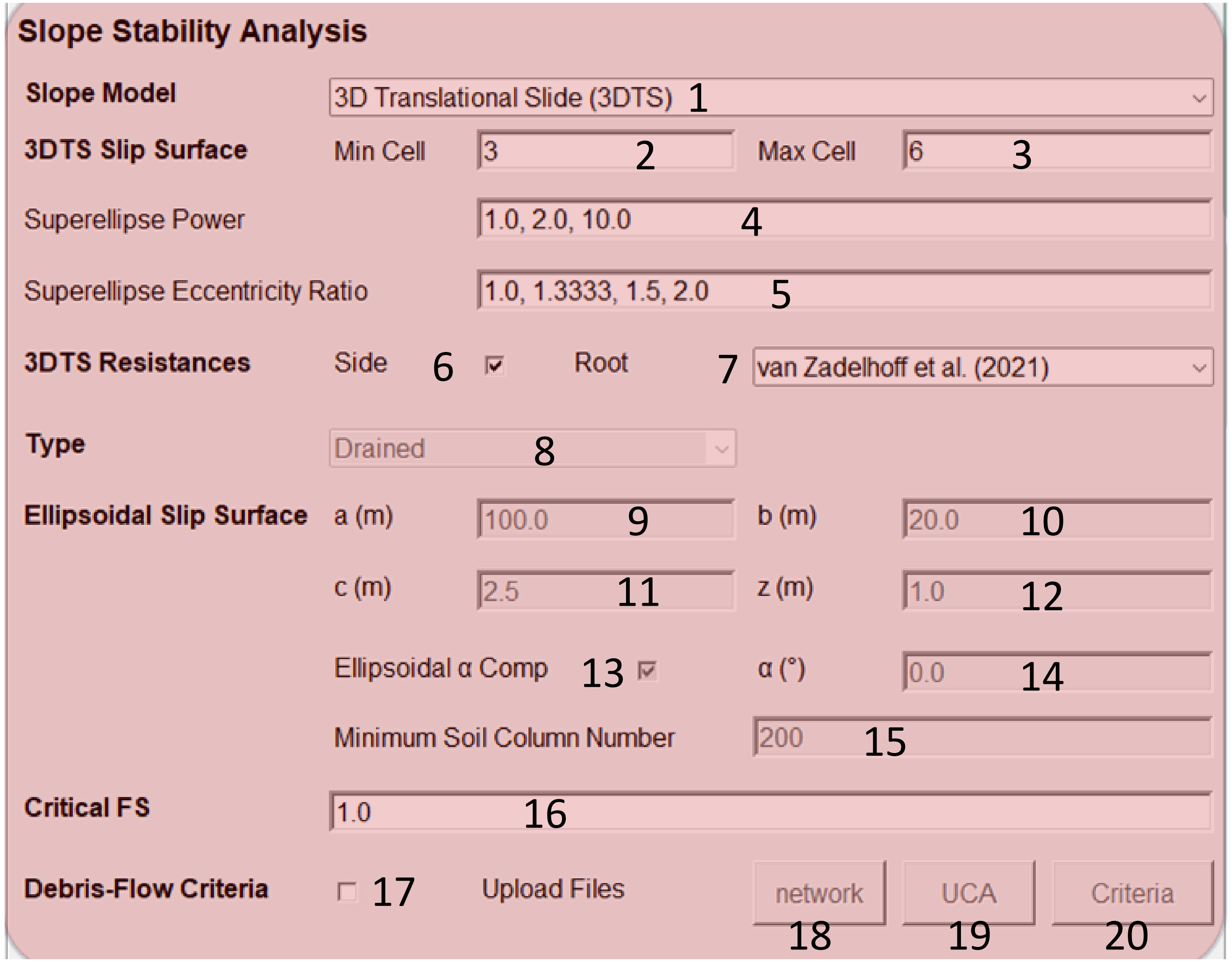
$$\Gamma_{\mathrm{PDF}}(x|\alpha,\sigma) = \frac{x^{\alpha-1} e^{-x/\sigma}}{\sigma^{\alpha}\Gamma(\alpha)}, (x, \alpha, \sigma > 0).$$

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

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

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

User Interface – Slope Stability Analysis Input



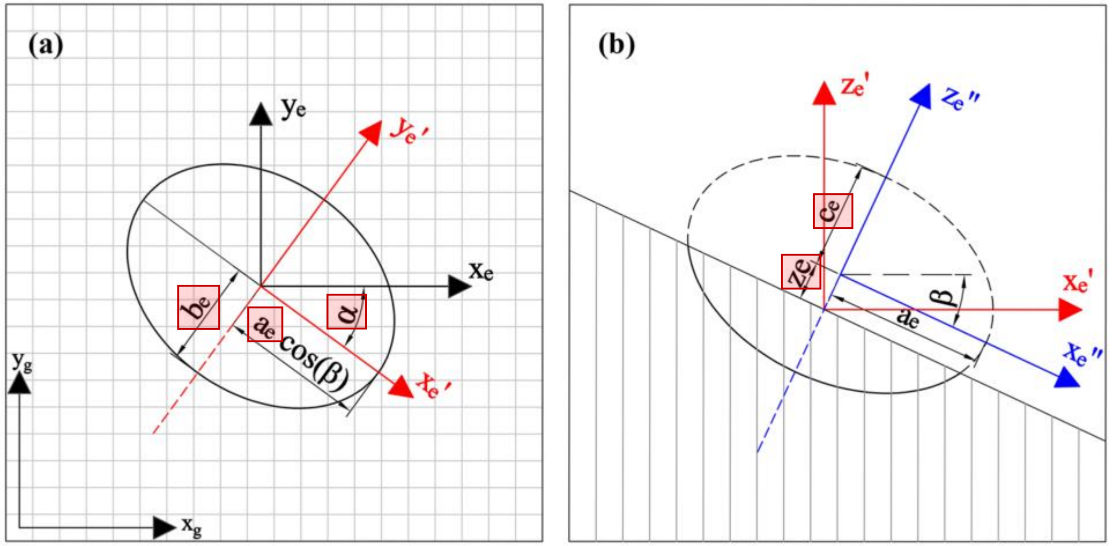
8. 3DPLS model soil condition type
- (Opt. 1) *Drained*
- (Opt. 2) *Undrained*

9 ~ 14. Ellipsoidal slip surface parameter for 3DPLS model
- Parameter a, b, c, z, and α defined in figure below

13. Direction angle α auto-compute option
- If checked, the direction angle α is computed from the average aspect direction

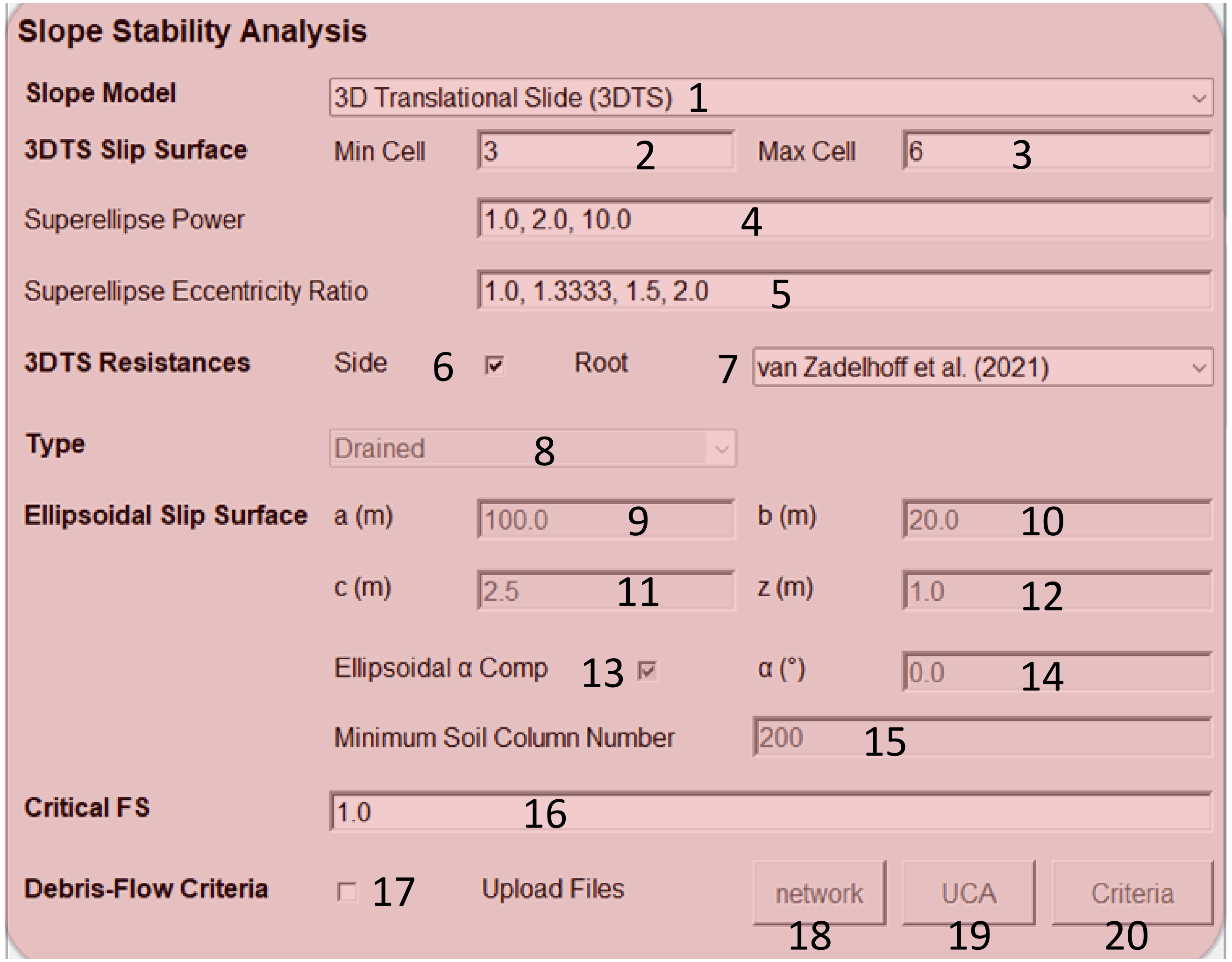
14. Direction angle α assign
- If the auto-compute option (13.) is unchecked, the direction angle α can directly assigned

15. Minimum soil column required for ellipsoidal surface
- The 3DPLS model will generate soil columns that would exceed the specified minimum value



Oguz et al. (2022)

User Interface – Slope Stability Analysis Input



16. **Critical factor of safety (FS)**
    - FS threshold at which any DEM cell with computed FS < critical FS will be considered to have failed
    - For probabilistic analysis, it will be used to compute the frequency of incidents where FS < 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)

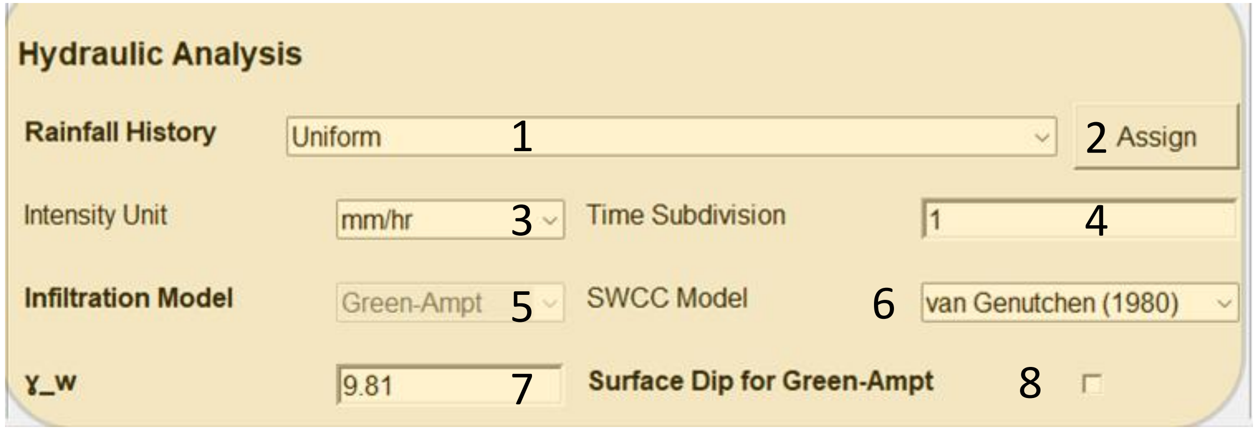
If a landslide occurs (FS < critical FS) and satisfies these two criteria, the shallow landslide will transition to debris flow.

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

Criteria 1: $UCA \geq 500\ m^2$

Criteria 2: $\mathrm{slope} \geq 34\exp(-0.003 * \mathrm{UCA}) + 14.32°$

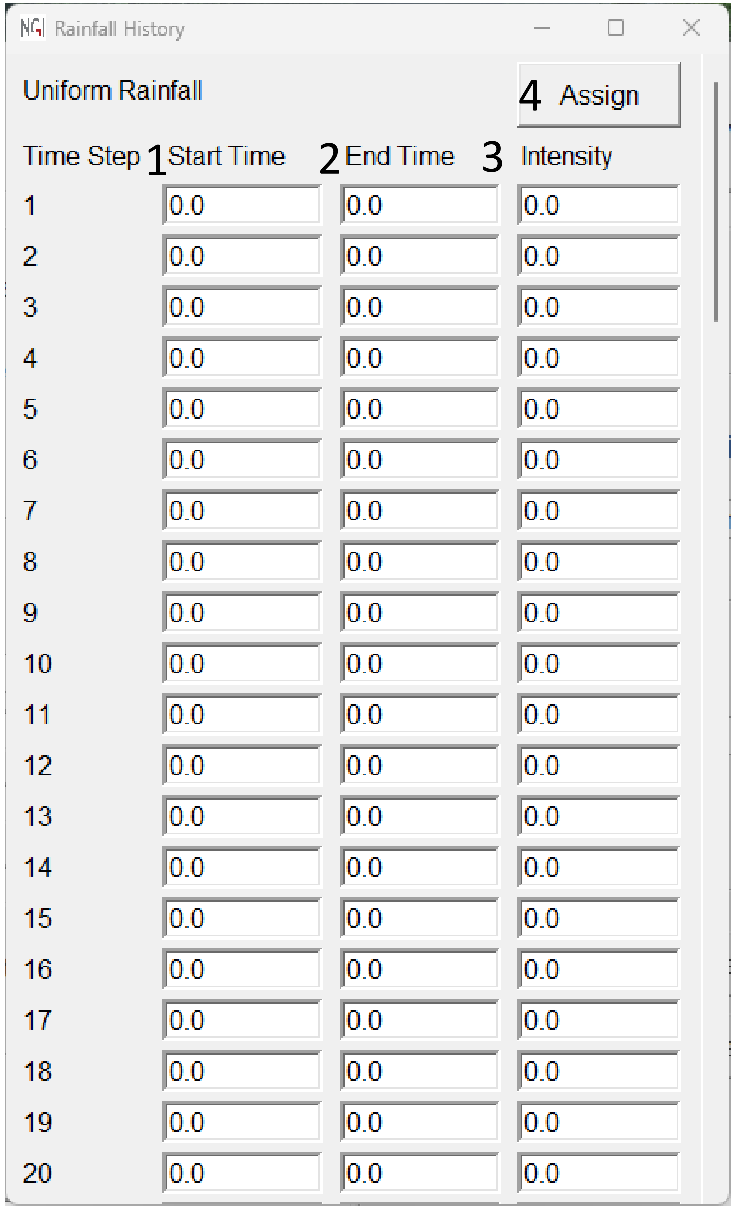
User Interface – Hydraulic Analysis



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

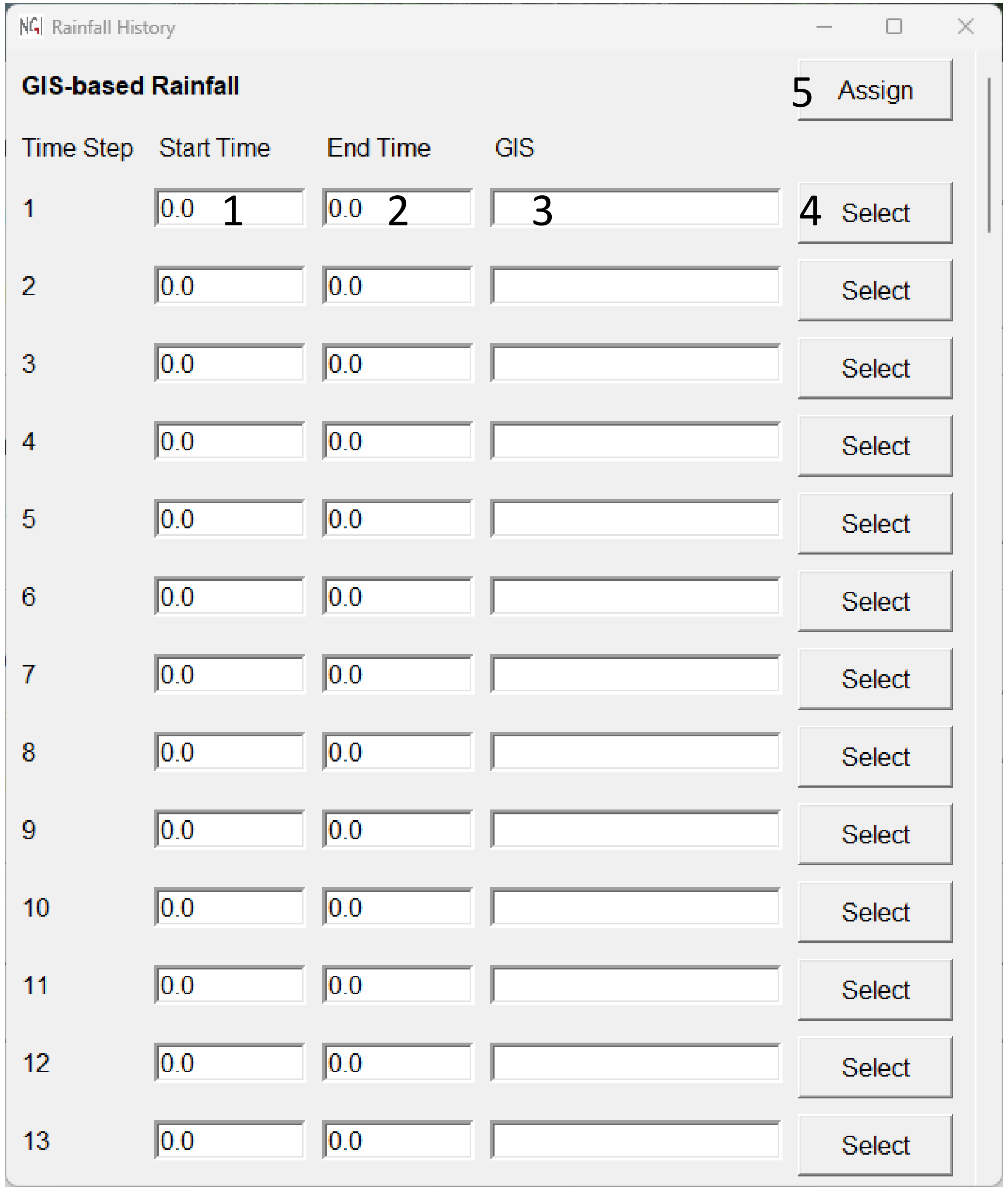
Rainfall History Option: *Uniform*



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

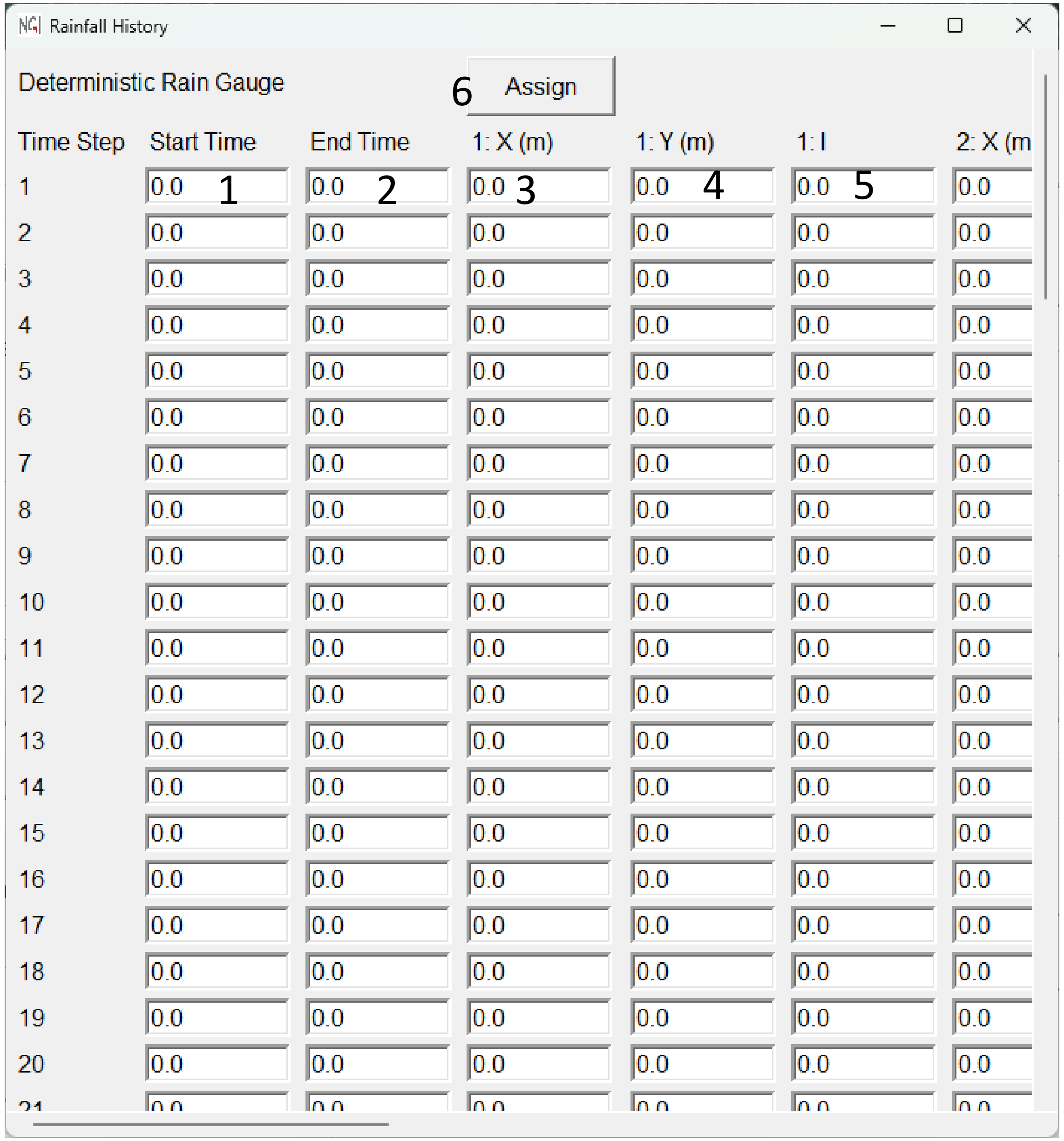
Rainfall History Option: *GIS file*



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*



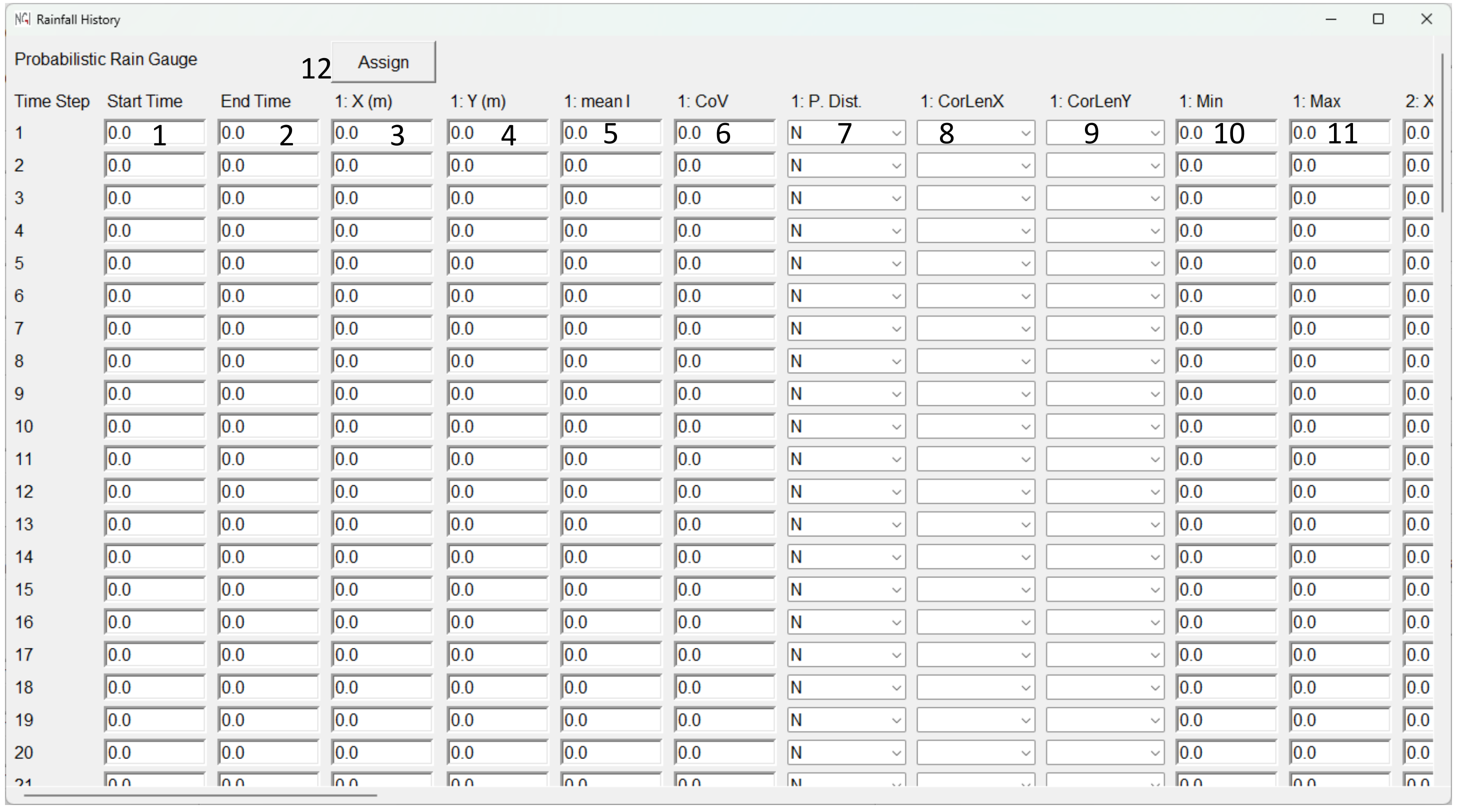
1. Start time
   - starting time of the given rainfall intensity
   - always exclusive, except when time = 0
2. End Time
   - ending time of the given rainfall intensity
   - always inclusive
3. Rain gauge location X
4. Rain gauge location Y
5. Rain gauge recorded rainfall intensity
6. Confirm the data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

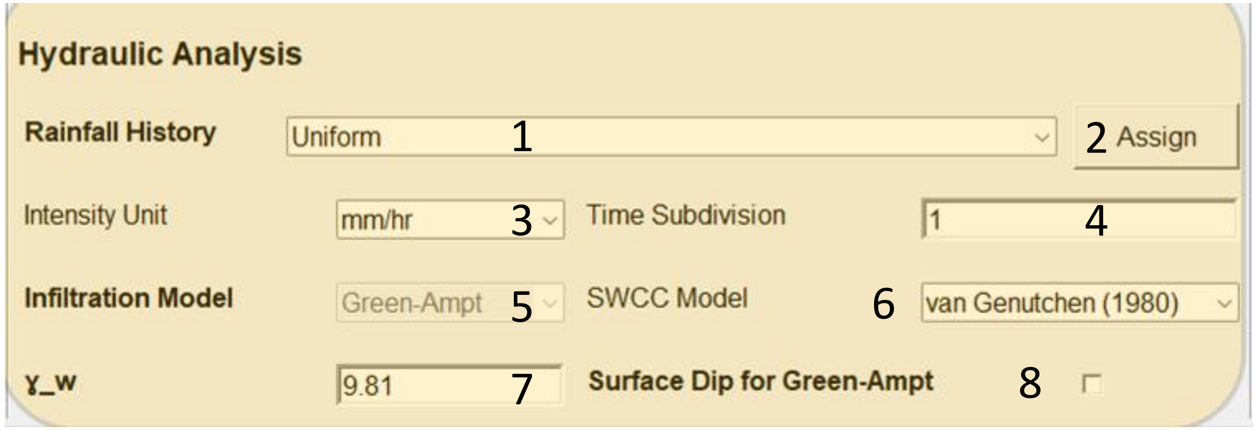


1. Start time
   - starting time of the given rainfall intensity
   - always exclusive, except when time = 0
2. End Time
   - ending time of the given rainfall intensity
   - always inclusive
3. Rain gauge location X
4. Rain gauge location Y
5. Rain gauge recorded mean rainfall intensity
6. Rain gauge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

Note

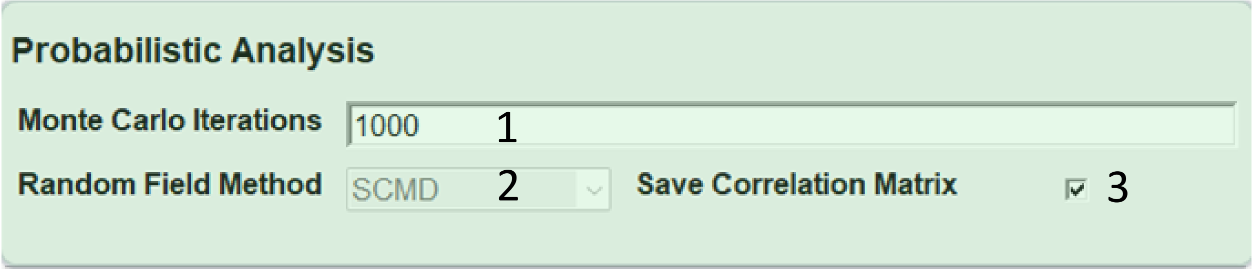
- Up to 5 rain gauges can be assigned
- Each rain gauges are assigned by a number (1 – 5)

User Interface – Hydraulic Analysis



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^3)**
   - Default: 9.81 kN/m^3
   - For *Iverson* infiltration, fixed to 10.0 kN/m^3
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



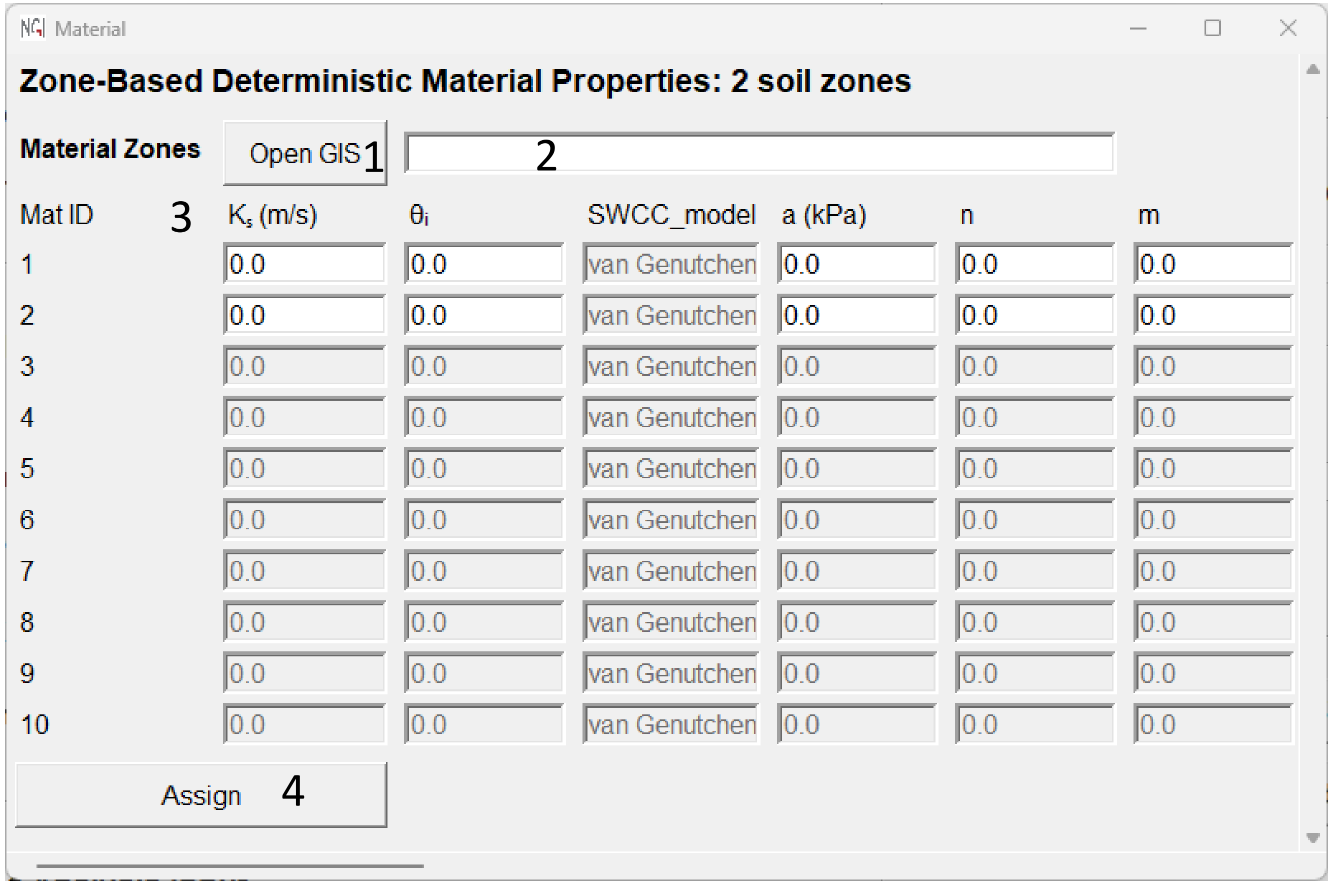
1. **Maximum iteration number of Monte Carlo Simulation**
   - If the value is one (1), deterministic analysis is performed
2. **Random field generation method**
   - (Opt. 1) CMD – covariance matrix decomposition (Fenton and Griffiths 2008) – correlation length in X- and Y-directions considered both
   - (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

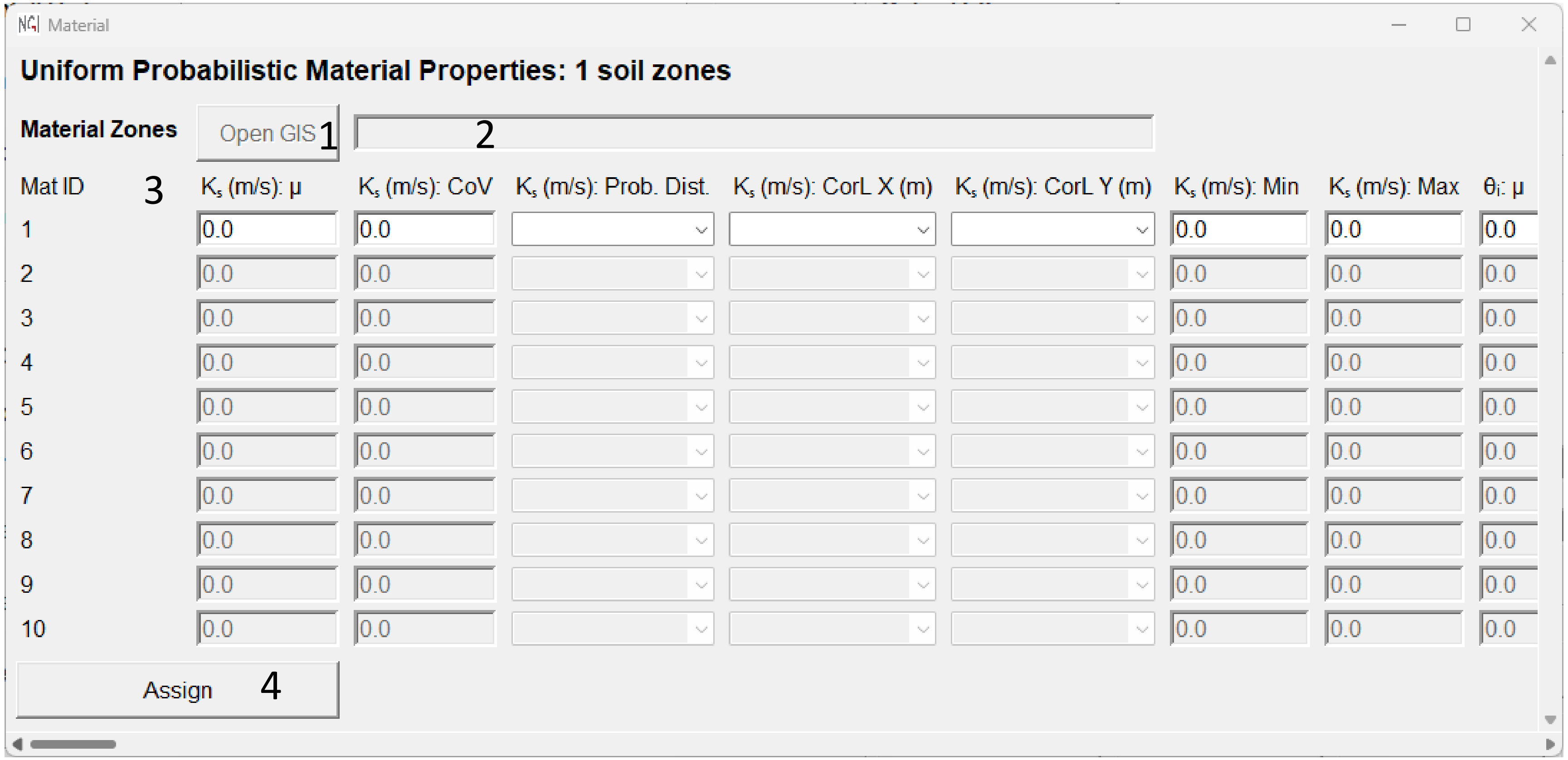
Material Option: *Uniform* and *Zone-based* [Deterministic]



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

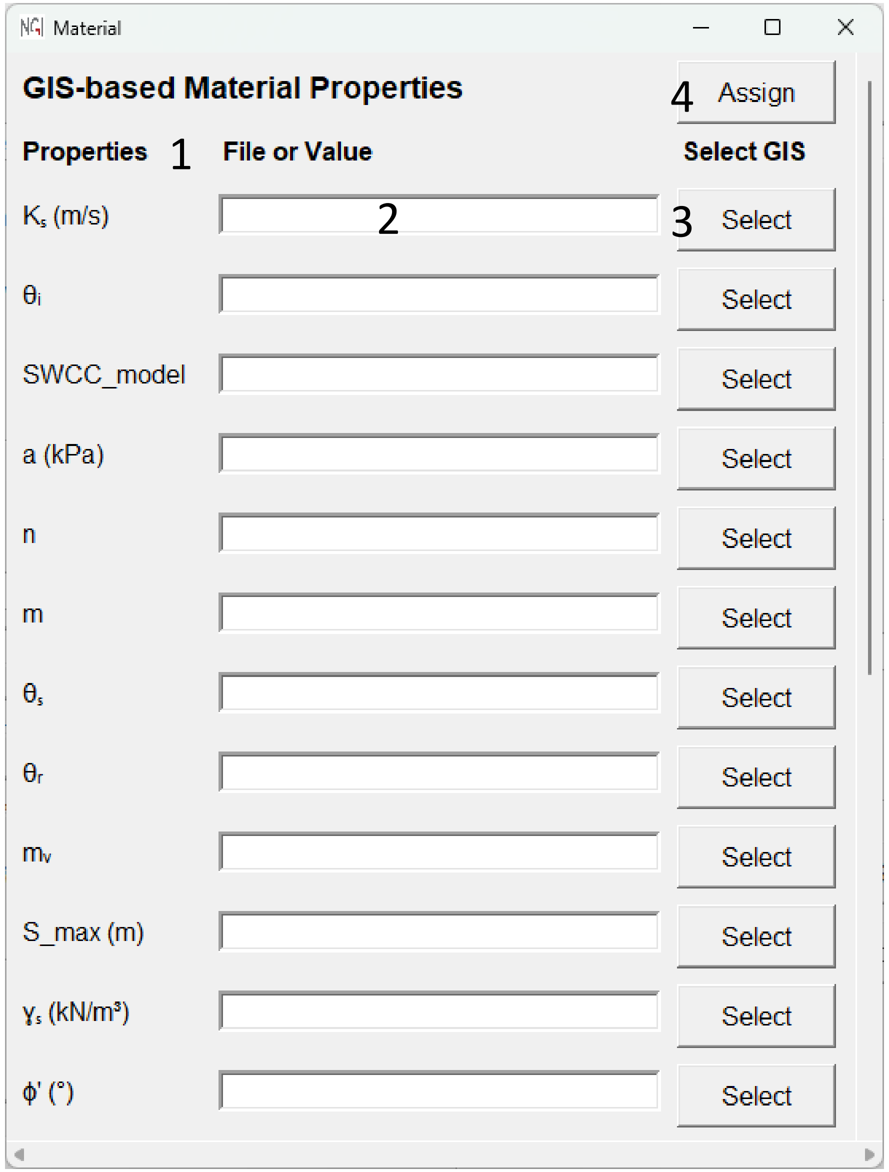
Material Option: *Uniform* and *Zone-based* [Probabilistic]



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: *GIS file*



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

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

Category	Column Headings (unit)	Descriptions
	ID	ID number of soil group (i.e., MatID)
Hydraulics	**k_sat (m/s)**	Saturated permeability rate
	initial_suction (kPa)	Initial suction pressure
	SWCC_a (kPa)	Soil-water characteristic curve (SWCC) - a parameter
	SWCC_n	Soil-water characteristic curve (SWCC) - n parameter
	SWCC_m	Soil-water characteristic curve (SWCC) - m parameter
	theta_sat	Saturated volumetric water content
	theta_residual	Residual volumetric water content
	soil_m_v	Soil mass compressibility index
	max_surface_storage (m)	Maximum water height possible on surface ponding
	diffusivity (m^2/s)	Diffusivity for Iverson (2000) infiltration
Soil	**soil unit weight (kN/m^3)**	Soil unit weight
	phi (deg)	Mohr-Coulomb effective soil friction angle
	phi_b (deg)	Unsaturated pore-water pressure friction angle
	c/Su (kPa)	Mohr-Coulomb effective soil cohesion or undrained shear strength

Material properties

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

root reinforcement model	Column Headings (unit)	Descriptions
None		*No additional data needs to be provided*
Constant with Depth	**root unit weight (kN/m^3)**	Unit weight addition for roots/vegetation
	root c_base (kPa)	Constant base cohesion from root reinforcement
	root c_side (kPa)	Constant side cohesion from root reinforcement
	root depth (m)	Depth from the ground surface where root is present
van Zadelhoff et al. (2022)	**root unit weight (kN/m^3)**	Unit weight addition for roots/vegetation
	root alpha2	Fitting parameter
	root beta2	Fitting parameter
	root RR_max (kN/m)	Mohr-Coulomb effective soil cohesion

Material properties - Probabilistic

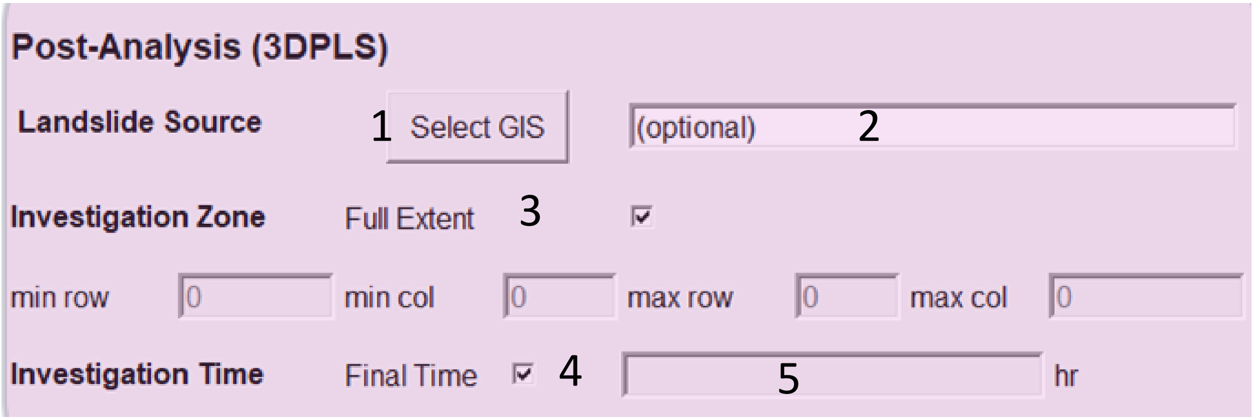
- These hydraulic and soil properties must be provided under the heading in the Material properties

Probabilistic Heading	Descriptions
μ (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

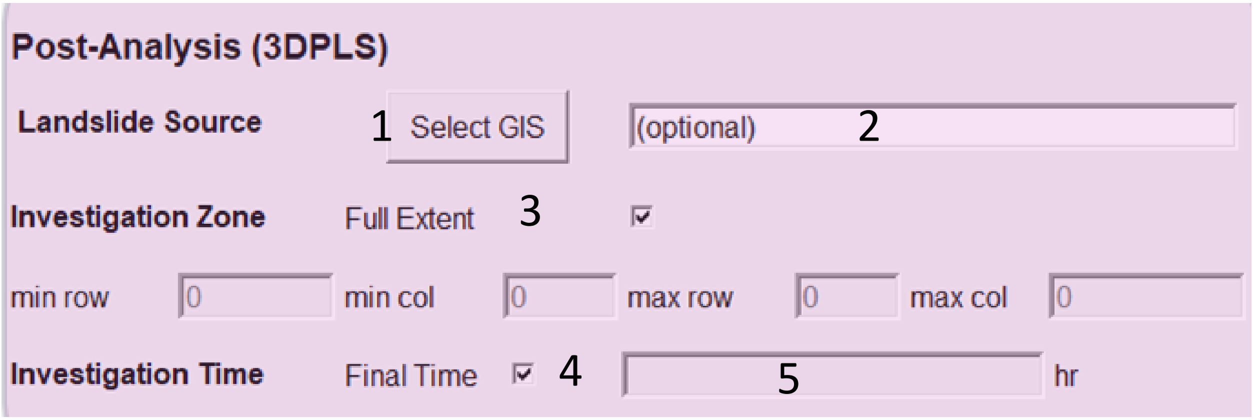
- Probabilistic data are noted in the following format: {parameter}: {probabilistic input}

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



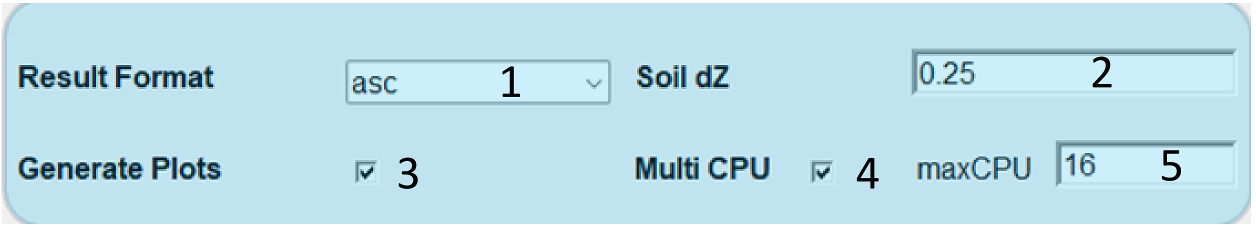
1. **Select landslide source file (optional)**
   - Navigate and select the GIS file identifying landslide source locations. At each cell, 0 = no landslide and 1 = landslide occurrence locations
   - Optional to whether analyze performance or not
2. **Landslide source file name**
   - Text showing the 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)



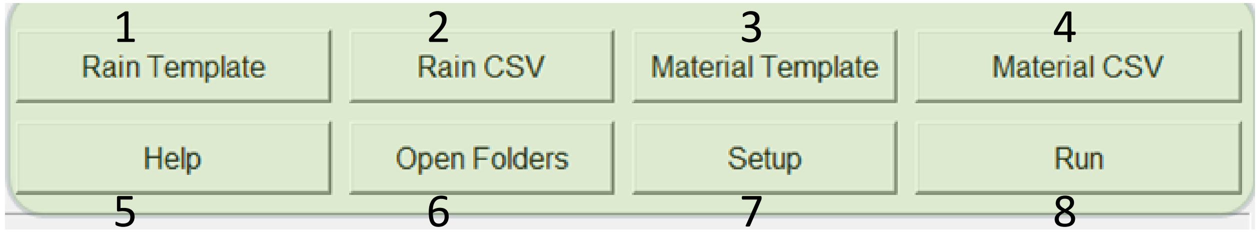
4. **Option for auto-compute investigation time**
   - If checked the 3DPLS model will use the final simulation time for analyzing landslide geohazard risk
   - If unchecked, the user must provide the simulation times to investigate
5. **Option for auto-compute investigation time**
   - Times at which 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 < 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 (<length>/<time>) between 0 (<time>) [including] and 1 (<time>) [including]
- Uniform rainfall intensity of 5.0 (<length>/<time>) between 1 (<time>) [excluding] and 3 (<time>) [including]
- Geospatially varying rainfall intensity provided by “rainfall_GIS_hr_3_to_4.asc” with unit of (<length>/<time>) between 3 (<time>) [excluding] and 4 (<time>) [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 2nd 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 2nd 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

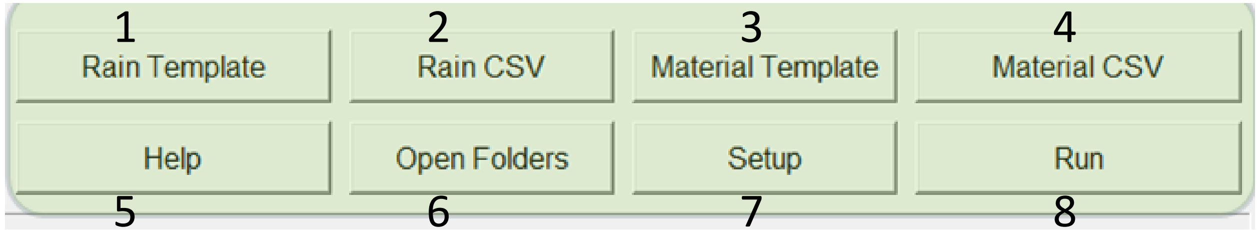
ID	k_sat (m/s)	initial_suction (kPa)	SWCC_a (kPa)	…
1	1.00E-06	0	33.33	…
2	1.50E-06	10	20.0	…
⋮	⋮	⋮	⋮	⋱

GIS files

- Assign all the material properties in 2nd 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_root_unit_weight	Assigned root unit 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)
rizero.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 ≤ critical FS at each DEM cell

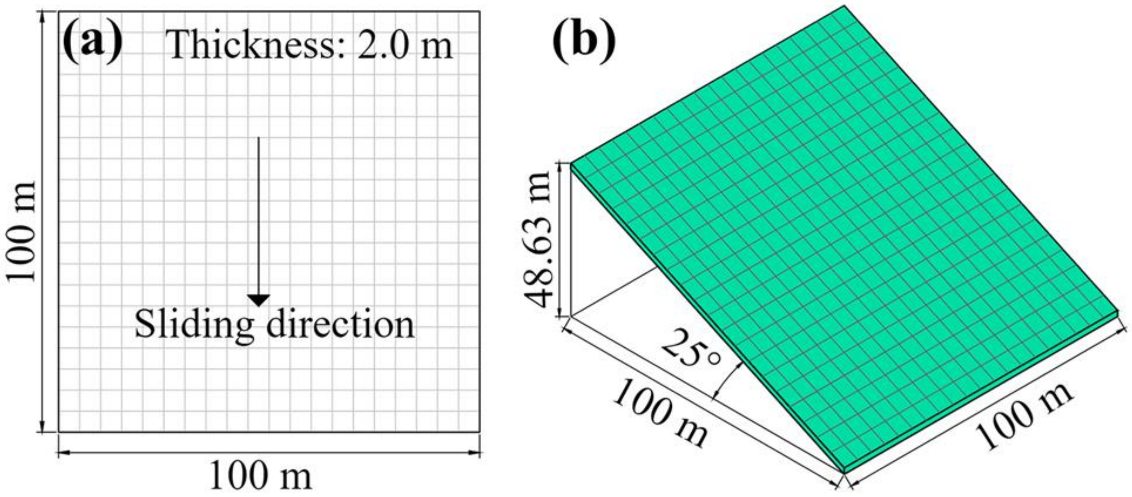
3. 3DTS example

Example for double-checking whether

3DTS model performs on the installed computer

Problem definition

Slope Geometry



Oguz et al. (2022)

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.

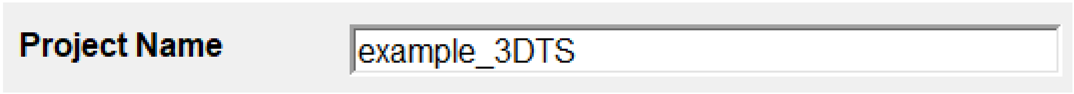
The entire region is the same soil unit. A deterministic and probabilistic analysis will be performed in this example. For the probabilistic analysis, the min and max values are always assigned such that (min < mean < max) is established.

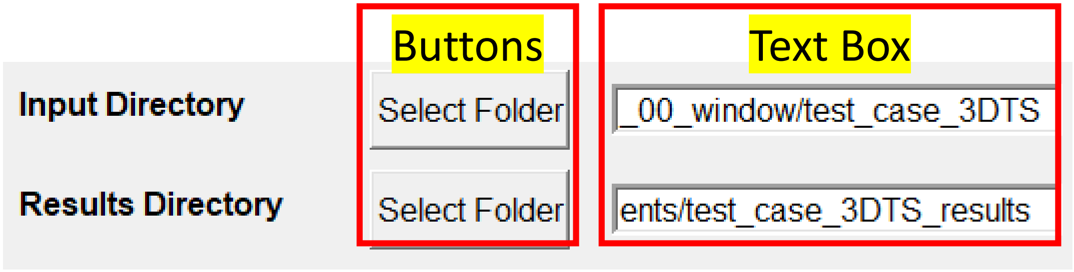
Material properties

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^{-6}	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
	max_surface_storage (m)	0	0	Normal	inf	inf	0	1
Soil	soil unit weight (kN/m^3)	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
	c/Su (kPa)	6	0.1	Lognormal	100	100	0	50
Root *van Zadelhoff et al. (2022)*	root unit weight (kN/m^3)	5	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)	0.01	0.05	Lognormal	20	20	0	1

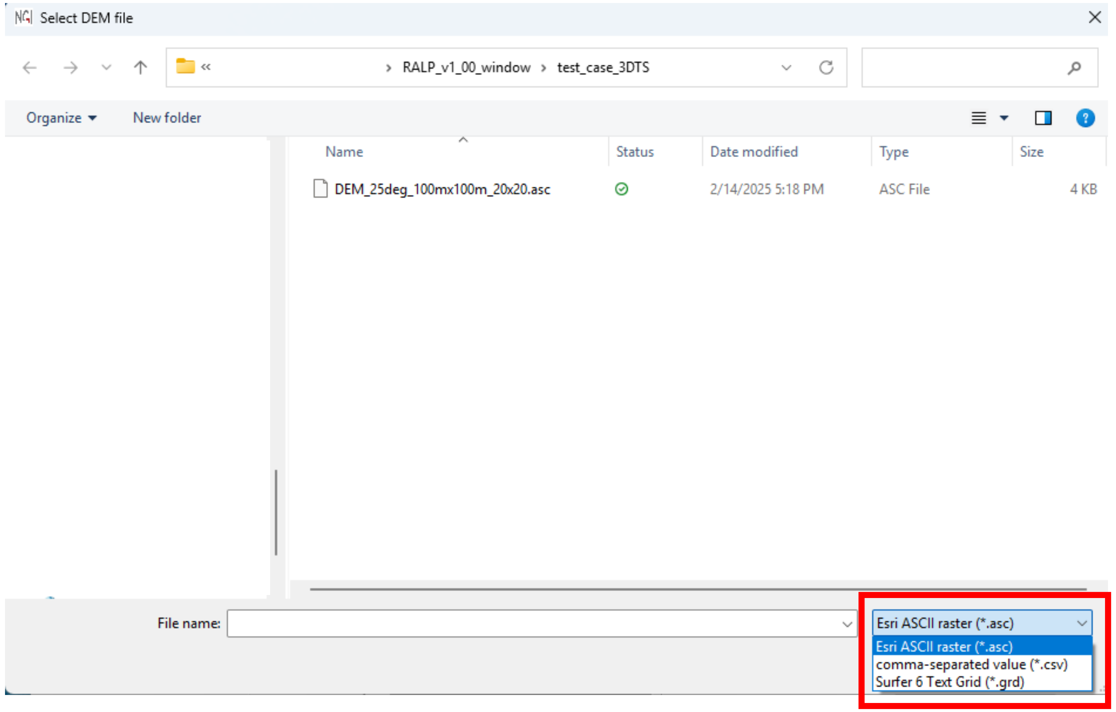
3DTSP example – step-by-step





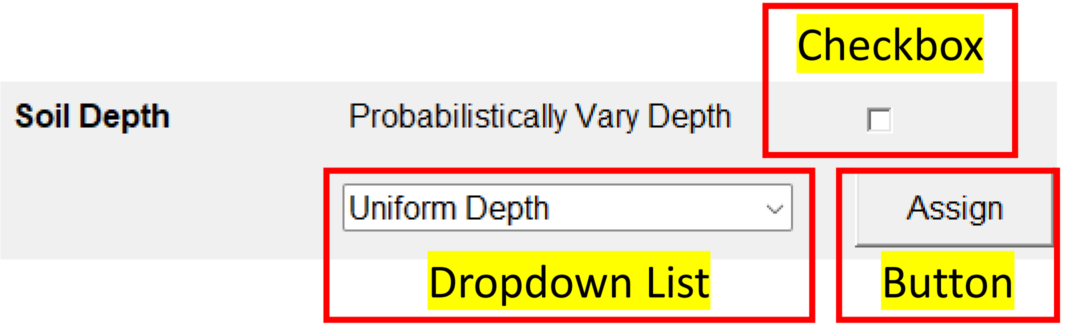
1. **Assign project name**
   - The project name will be used throughout the analysis for generating output files
   - Please name them anything. In our case, we are going to use "example_3DTS"
   - Please note that white spacing is allowed, but replacing them with underscore ("_") or minus ("-") is 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

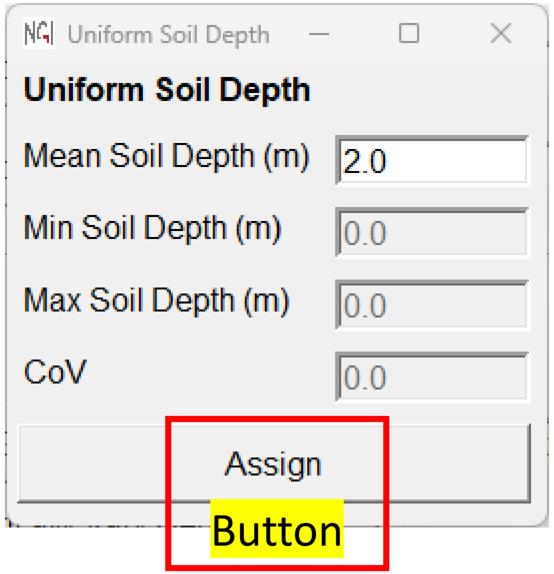
3DTSP example – step-by-step



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

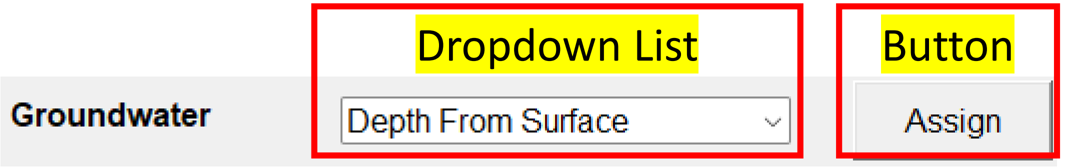


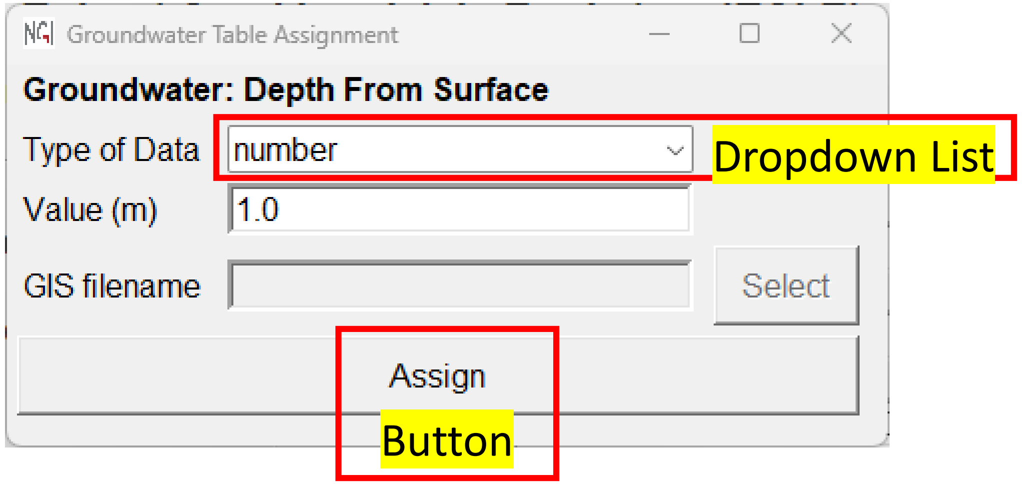


5. **Assign soil depth**
   - Since we are performing deterministic soil depth in the example, make sure the checkbox next to the **Probabilistically Vary Depth** is unchecked
   - In the dropdown list, make sure the *Uniform Depth* is selected
   - Press the **Assign** button

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

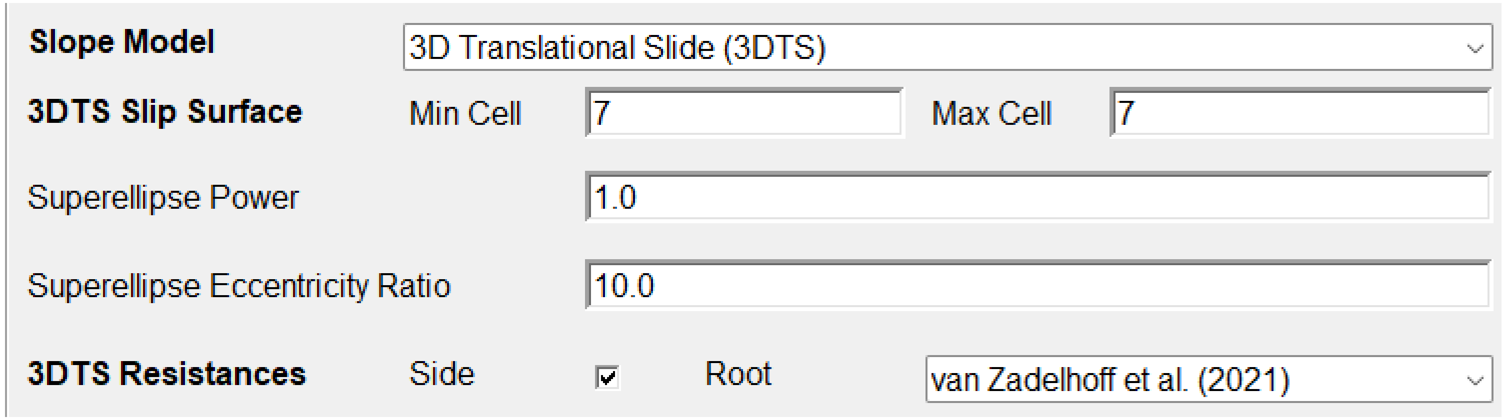




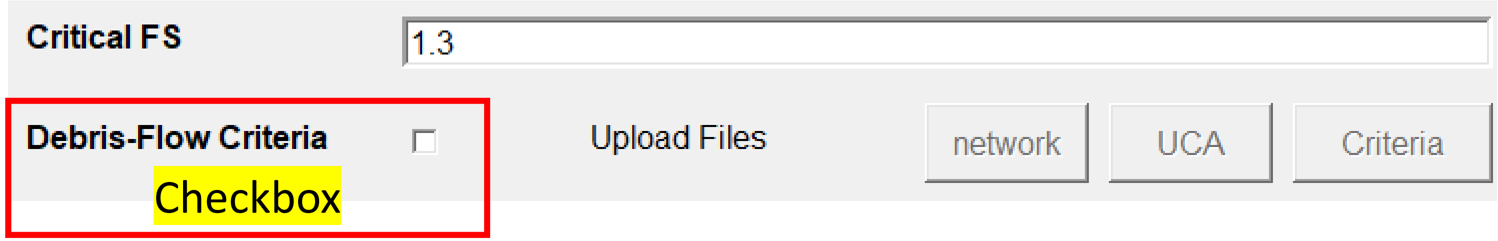
7. **Select groundwater table assign method**
   - As previously mentioned, the groundwater table is located 1m depth below the ground surface
   - The user can take any method to assign the groundwater table. In our example, we took the most convenient method with *Depth From Surface* approach
   -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

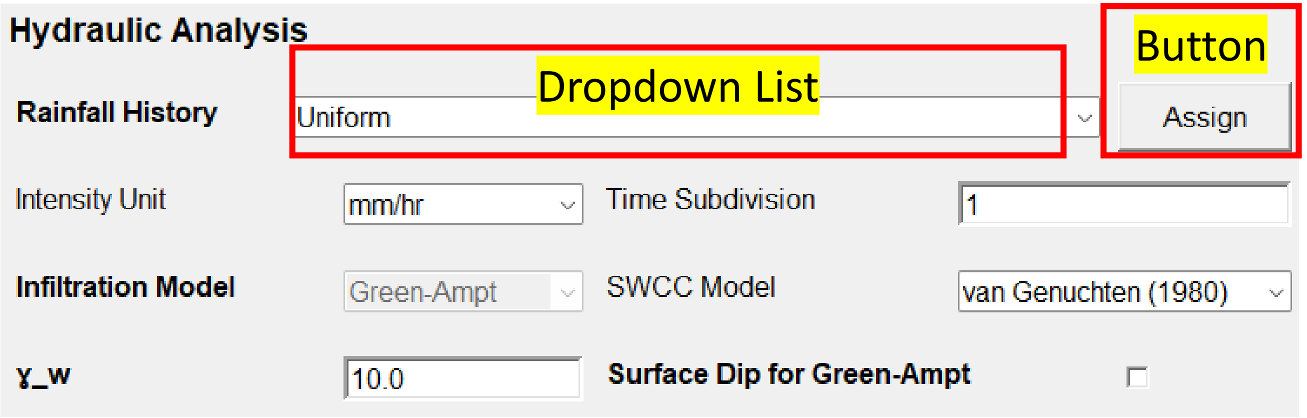


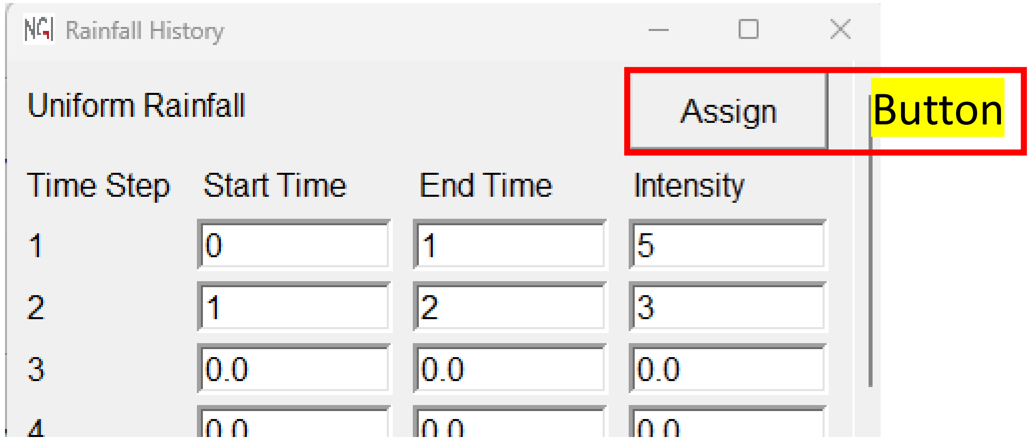
9. **Select slope model**
   - This example will perform 3DTS model
   - For the 3DTS slip surface, we will test a slip surface of square shape of 7 cells per side. Hence, the parameters requires should match the image above
10. **Assign side and root resistance**
    - The example is testing effect of side resistance and root reinforcement.
    - For the root reinforcement, we will use the *van Zadelhoff et al. (2021)* model



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





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

14. Select infiltration model options

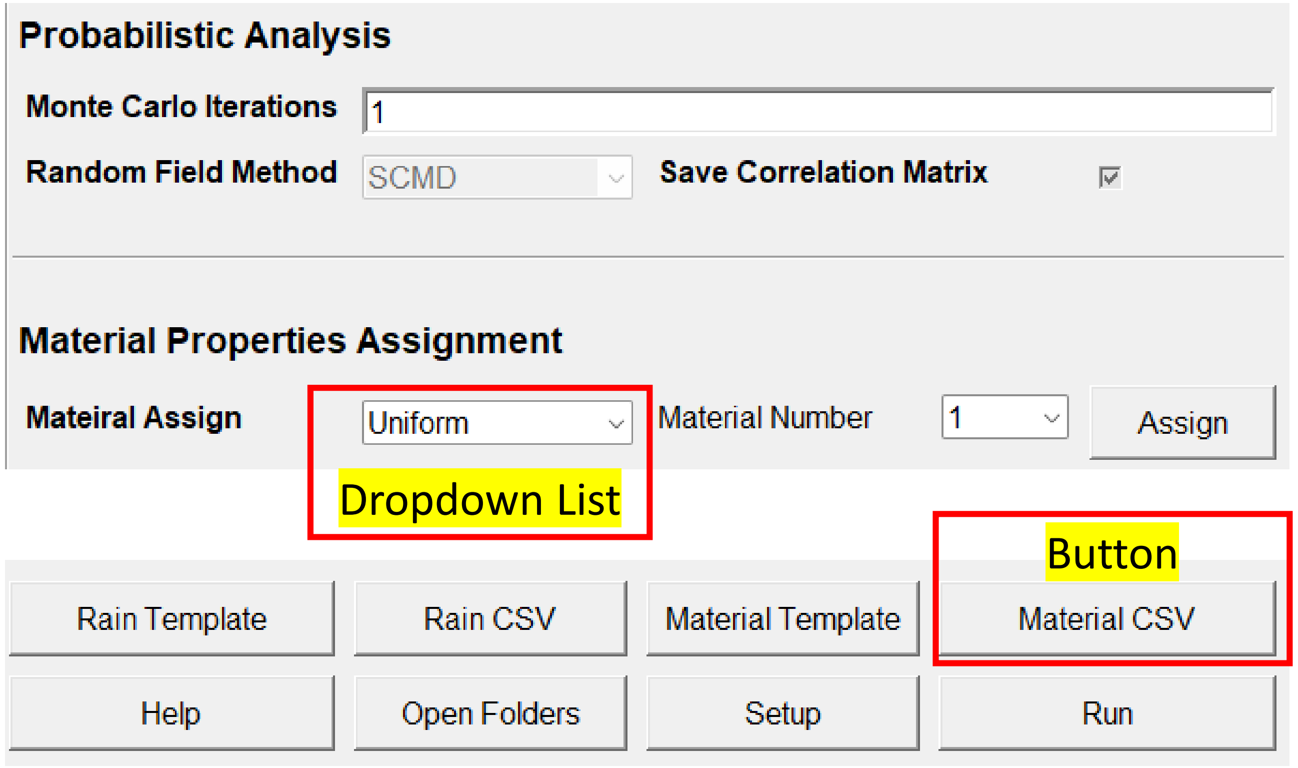
- Select the *van Genuchten (1980)* as the soil-water characteristic curve (SWCC) model
- Assign the unit weight of water (γ_w) as 10.0 kN/m^3

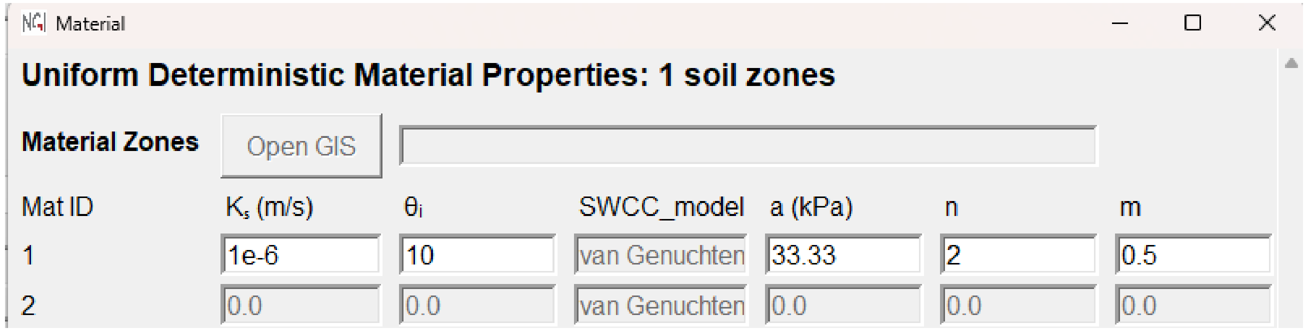
15. Assign rainfall history

- 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





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

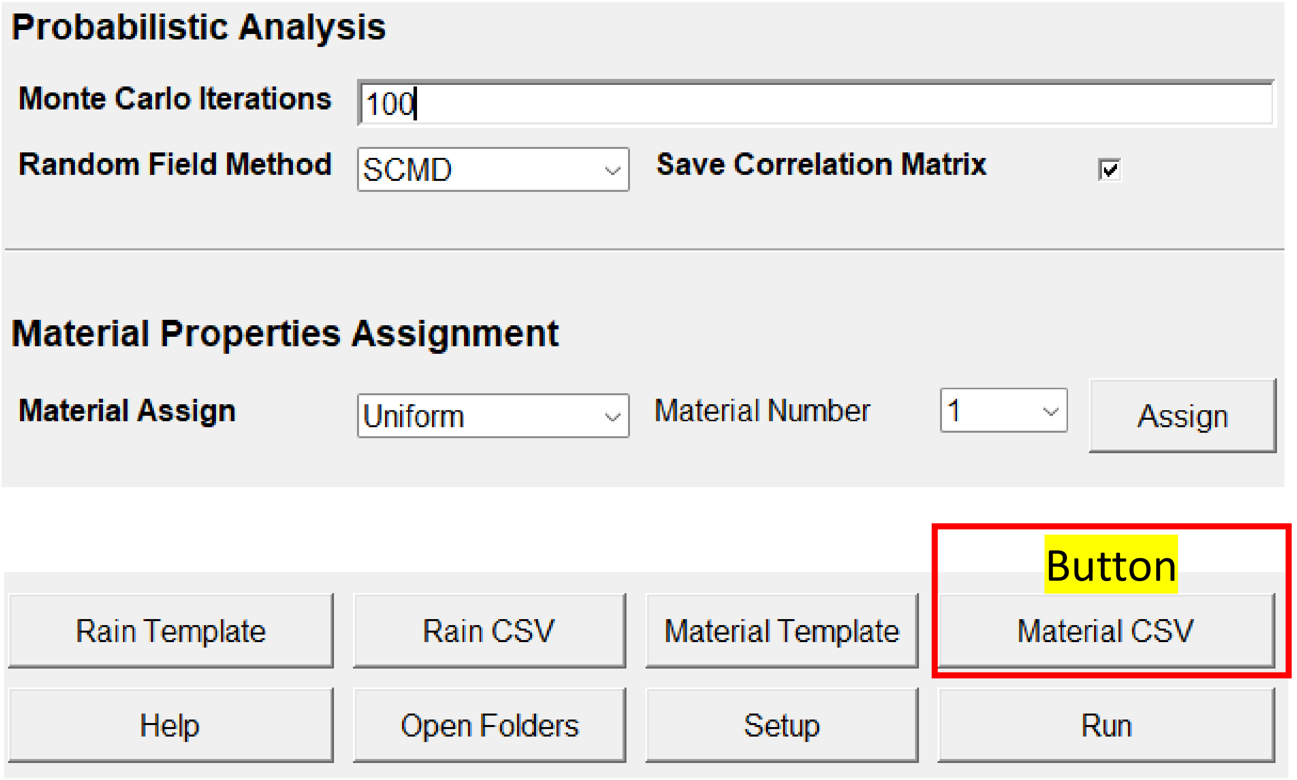
- Since the entire slope has the same soil, select *Uniform* soil properties from the **Material Assign dropdown list**

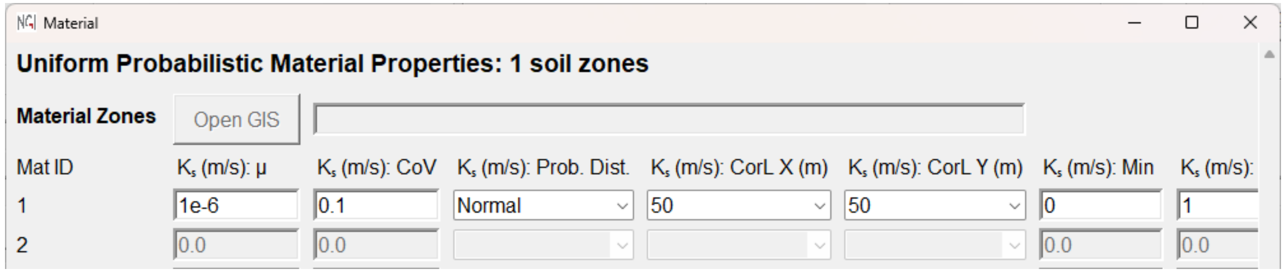
16-3. Assign material properties with CSV

- 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

3DTSP example – step-by-step

Probabilistic Analysis Version





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)

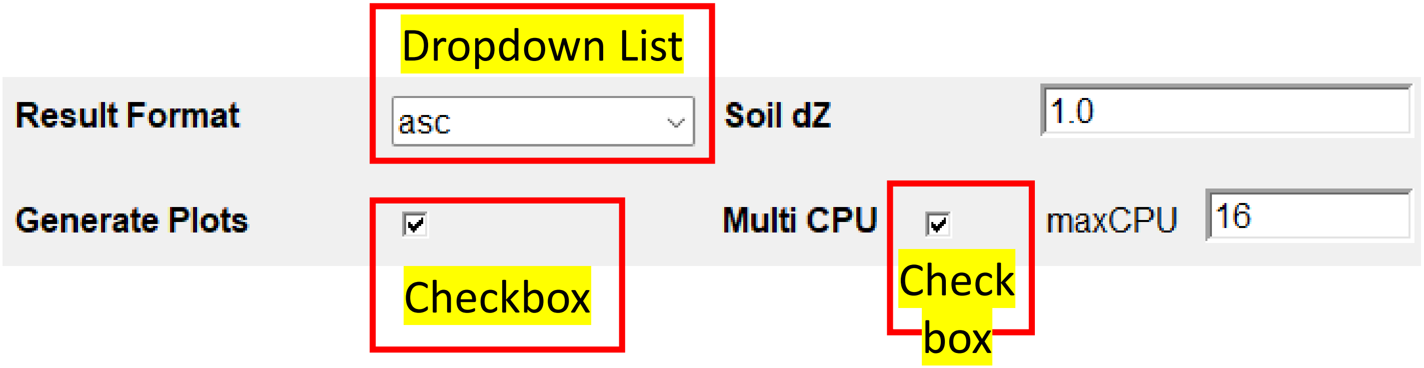
17-2. Material properties assign method

- 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

3DTSP example – step-by-step



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**

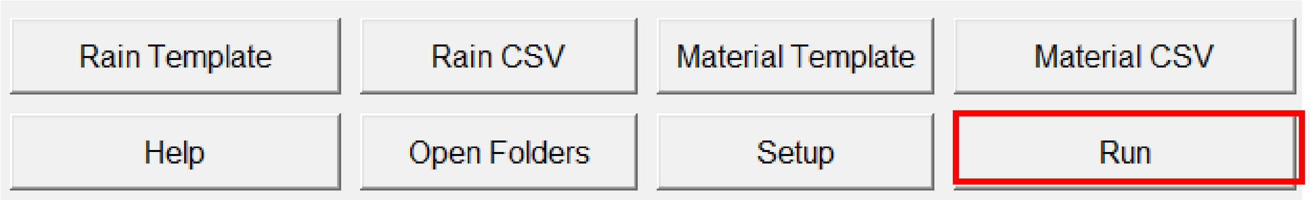
19. Soil vertical axis resolution (for 3DTS model)

- 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



```
################################################################################
#                                                                              #
#  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 Translatio
nal Slope Probabilistic (3DTSP) Model
Language:   Python3
License:

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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!
```

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**

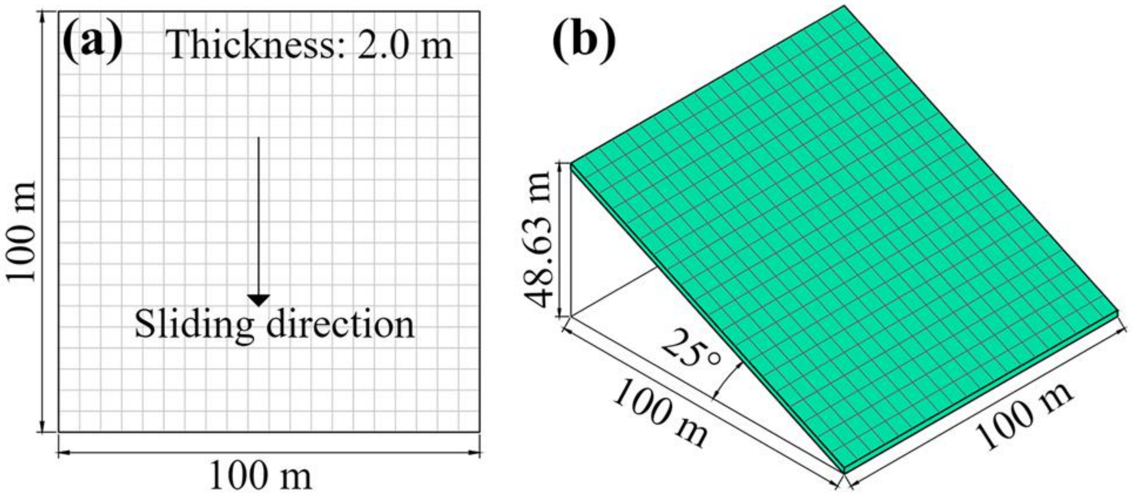
4. 3DPLS example

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.

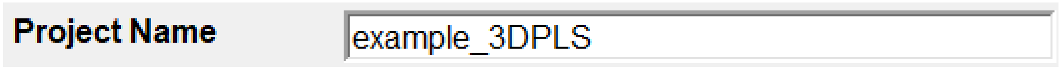
The entire region is the same soil unit. A deterministic and probabilistic analysis will be performed in this example. For the probabilistic analysis, the min and max values are always assigned such that (min < mean < max) is established.

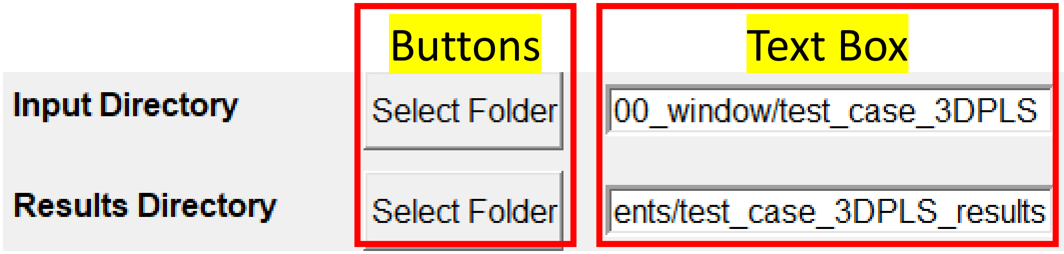
Material properties

For deterministic analysis, assign the mean values

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

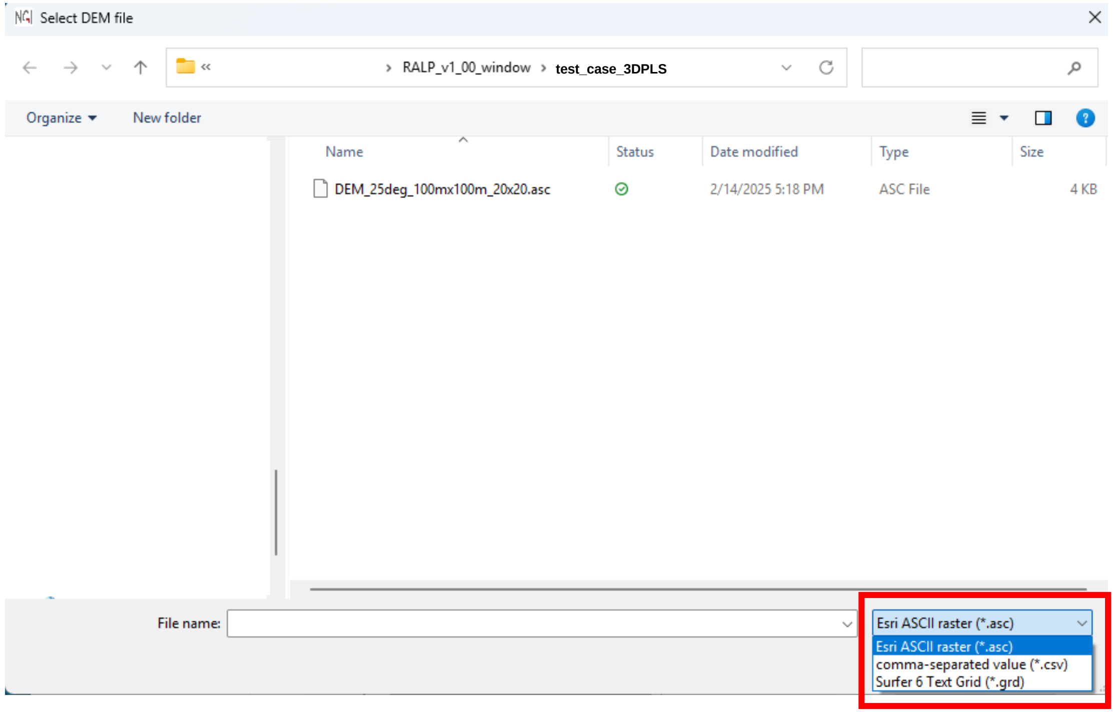
3DPLS example – step-by-step





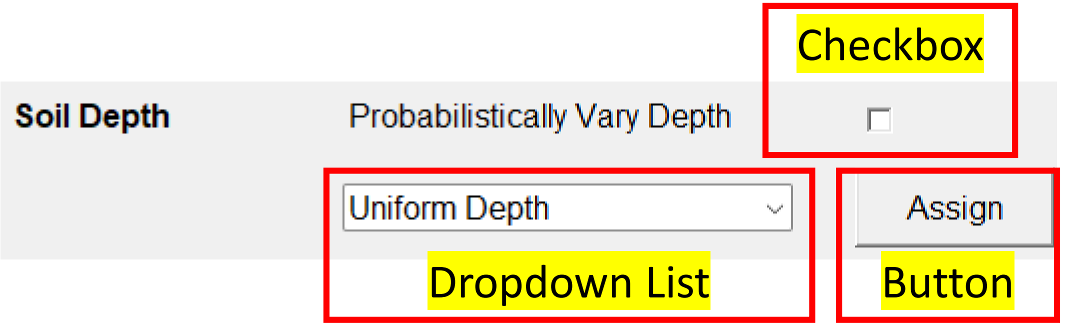
1. **Assign project name**
   - The project name will be used throughout the analysis for generating output files
   - Please name them anything. In our case, we are going to use "example_3DPLS"
   - Please note that white spacing is allowed, but replacing them with underscore ("_") or minus ("-") is 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

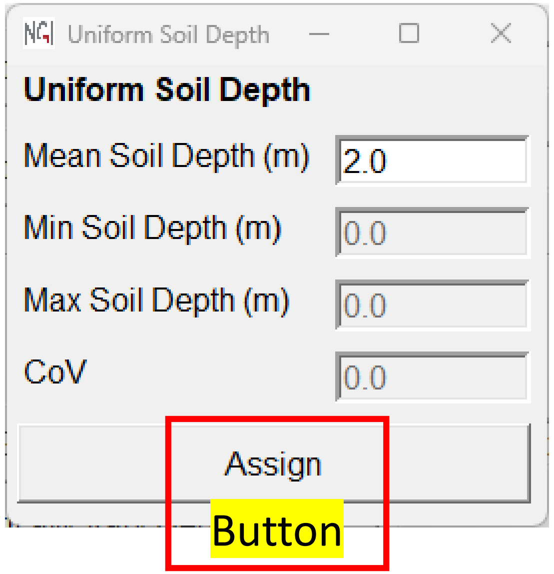
3DPLS example – step-by-step



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

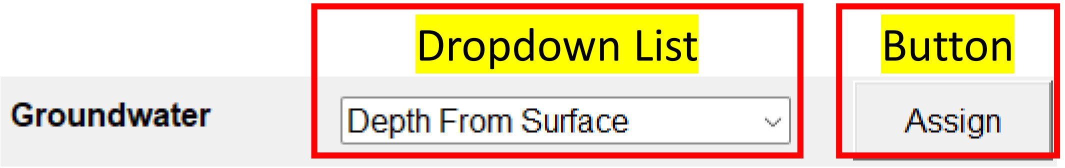


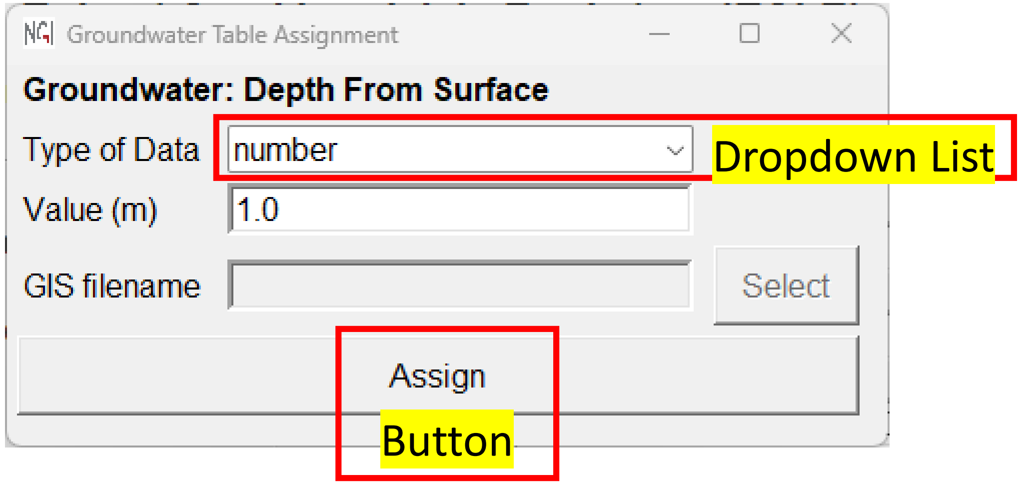


5. **Assign soil depth**
    - Since we are performing deterministic soil depth in the example, make sure the checkbox next to the **Probabilistically Vary Depth** is unchecked
    - In the dropdown list, make sure the *Uniform Depth* is selected
    - Press the **Assign** button

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

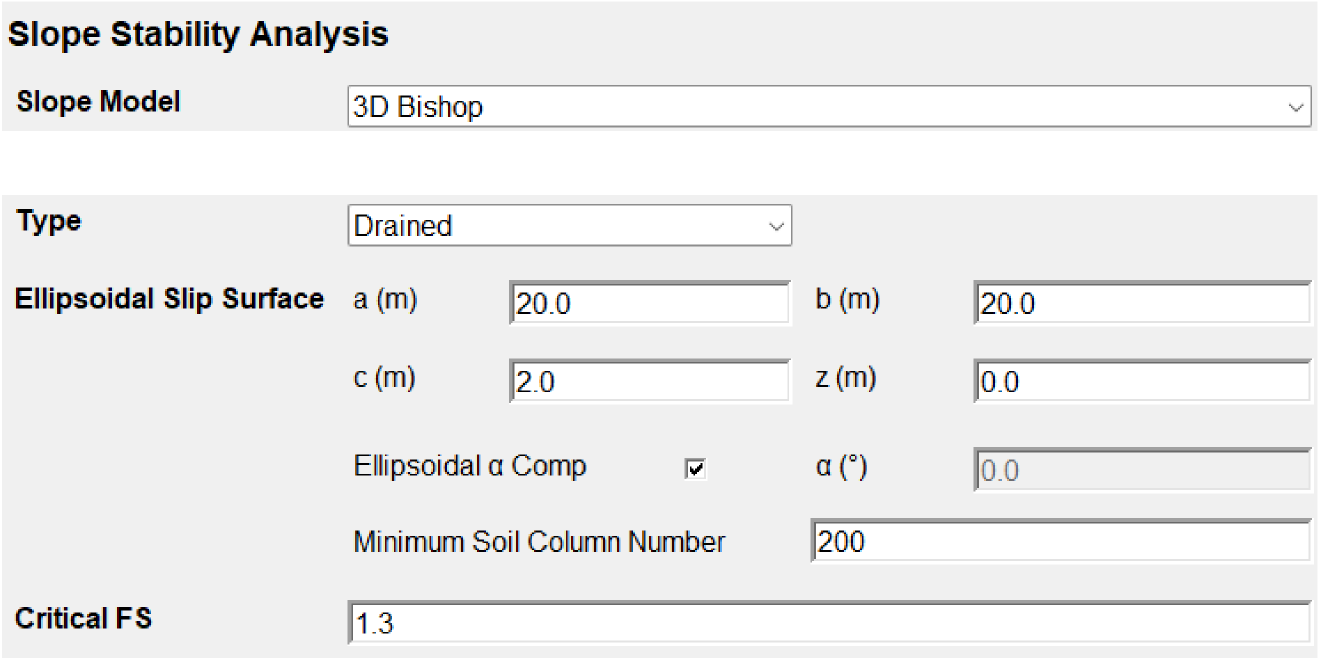




7. **Select groundwater table assign method**
   - As previously mentioned, the groundwater table is located 1m depth below the ground surface
   - The user can take any method to assign the groundwater table. In our example, we took the most convenient method with *Depth From Surface* approach
   -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

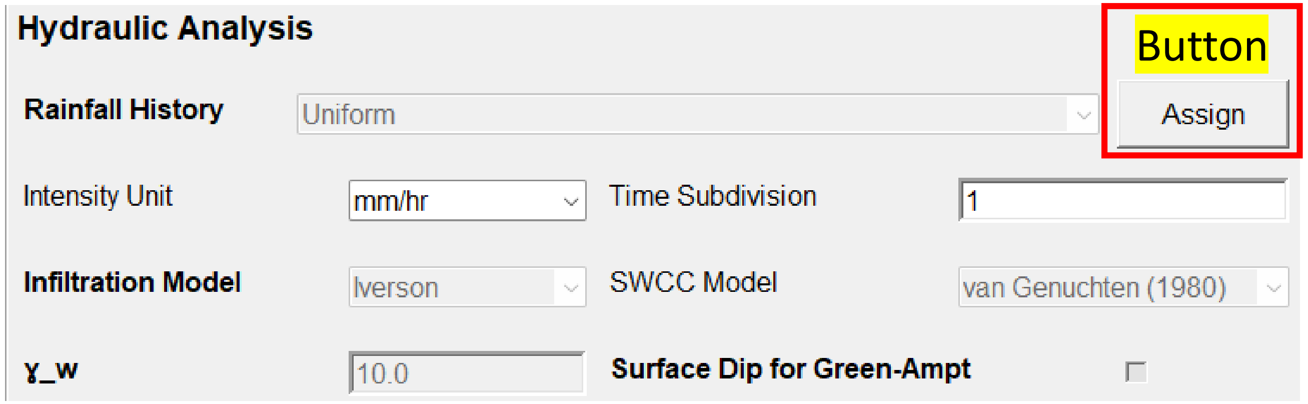


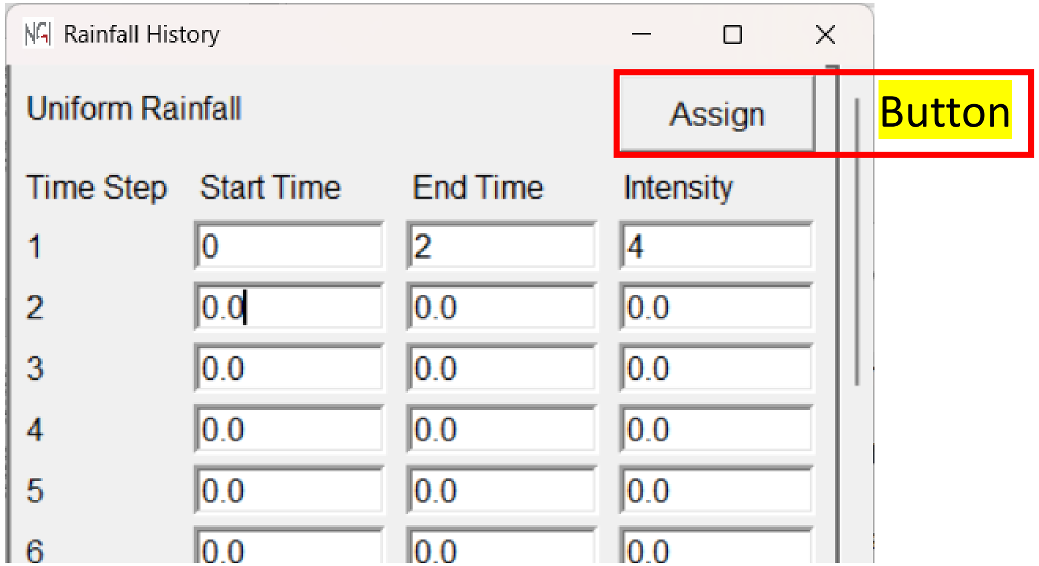
9. **Select slope model**
   - This example will perform 3DPLS model with 3D Bishop slope method
   - Select *Drained* for the **Type**

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 α
    - 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





13. Select rainfall history

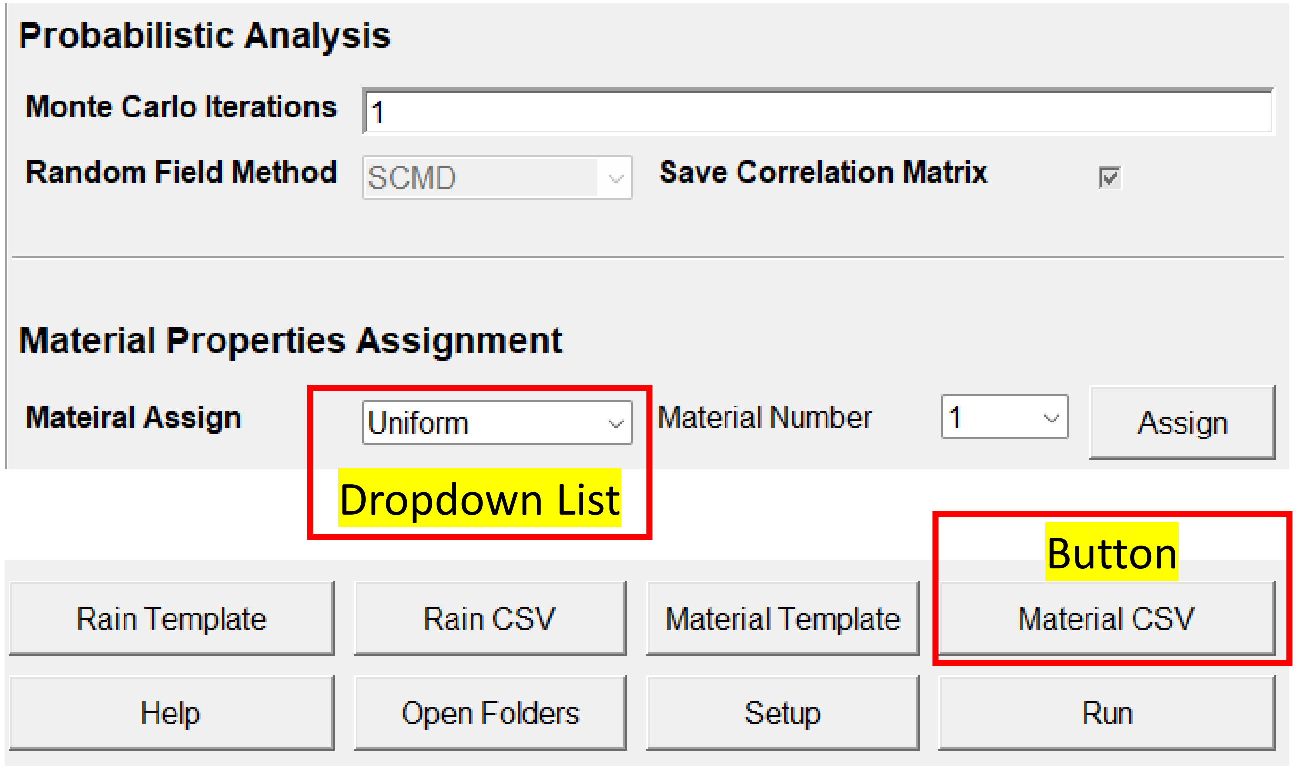
- Since this example will perform the 3DPLS model, the Iverson method is selected. Therefore, the following parameters are automatically assigned:
  - *Uniform* option – same rainfall intensity everywhere
  - unit weight of water (γ_w) as 10.0 kN/m^3
  - No need to select the SWCC model
- Since the rainfall 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

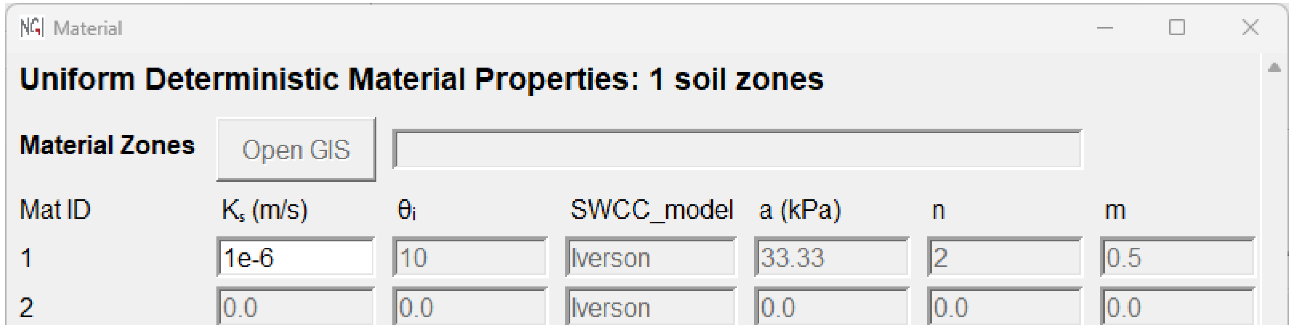
14. Assign rainfall history

- 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





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

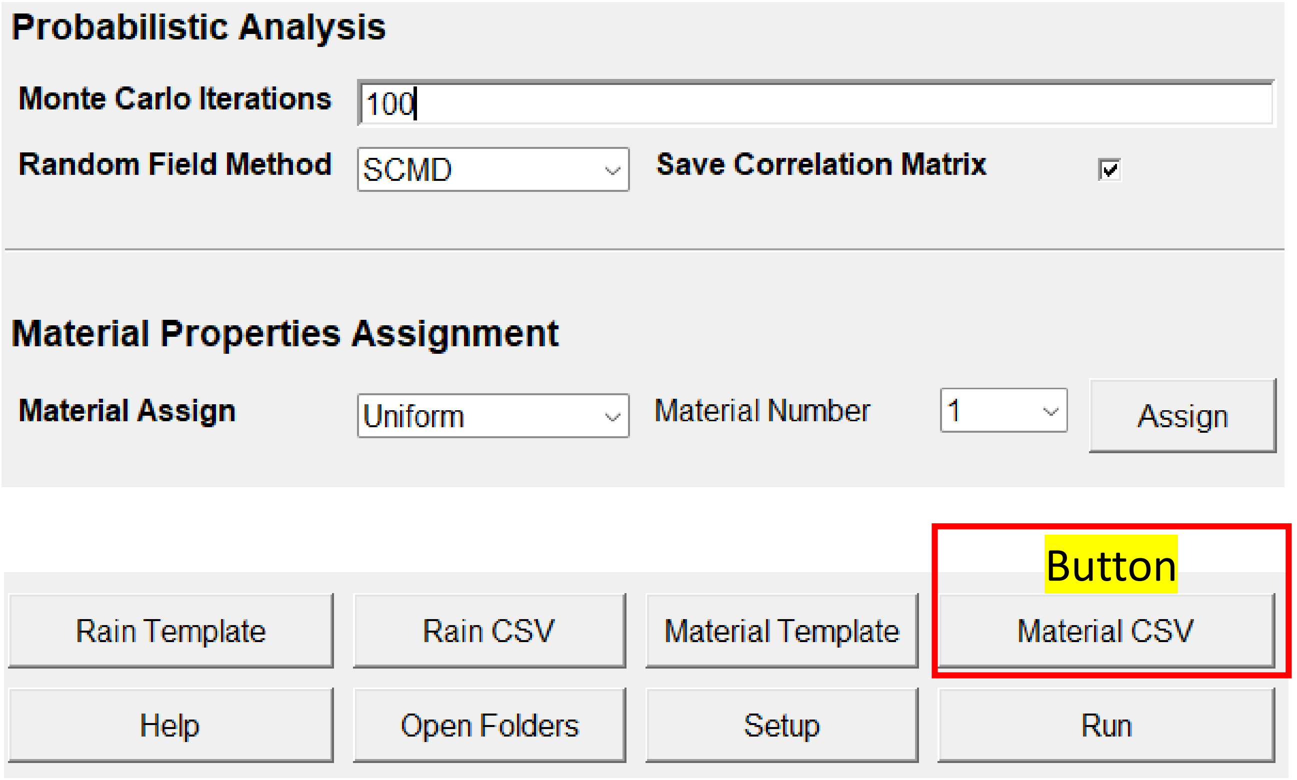
- Since the entire slope has the same soil, select *Uniform* soil properties from the **Material Assign dropdown list**

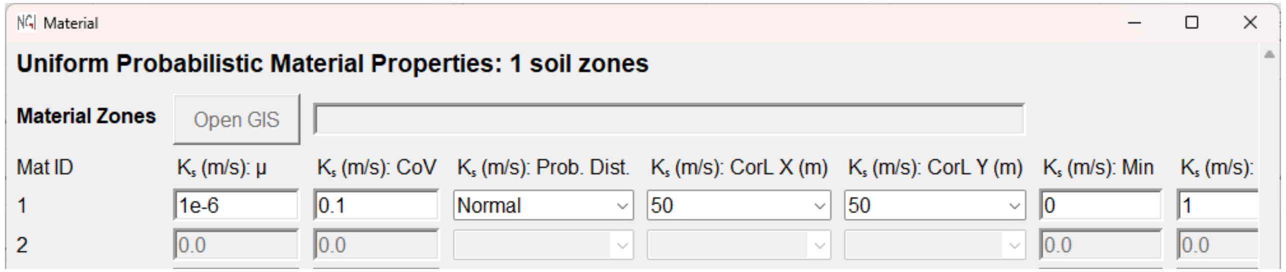
15-3. Assign material properties with CSV

- 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





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)

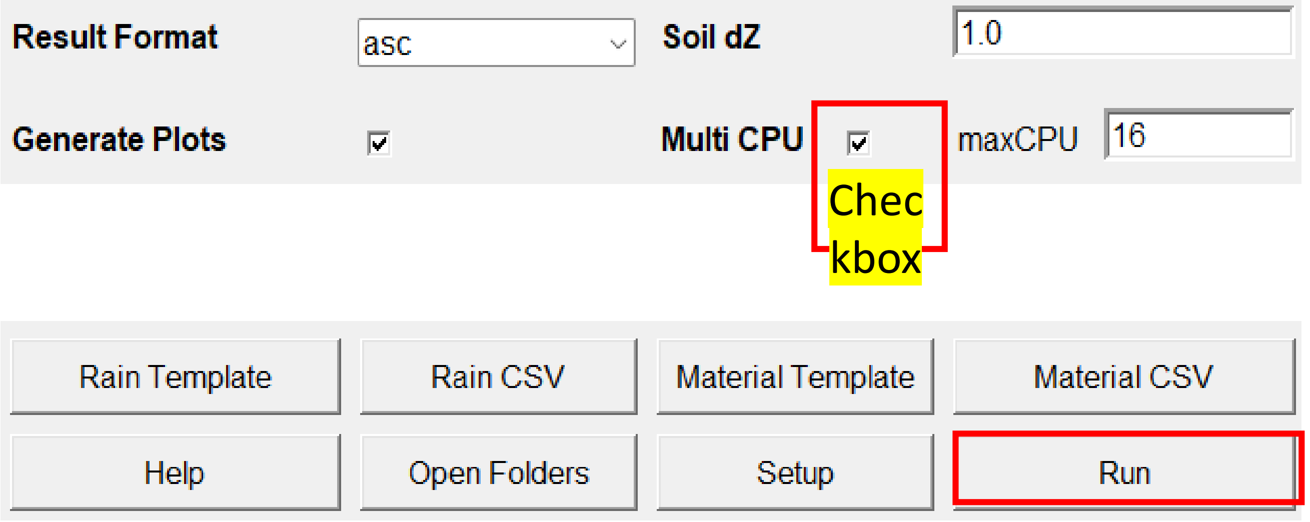
16-2. Material properties assign method

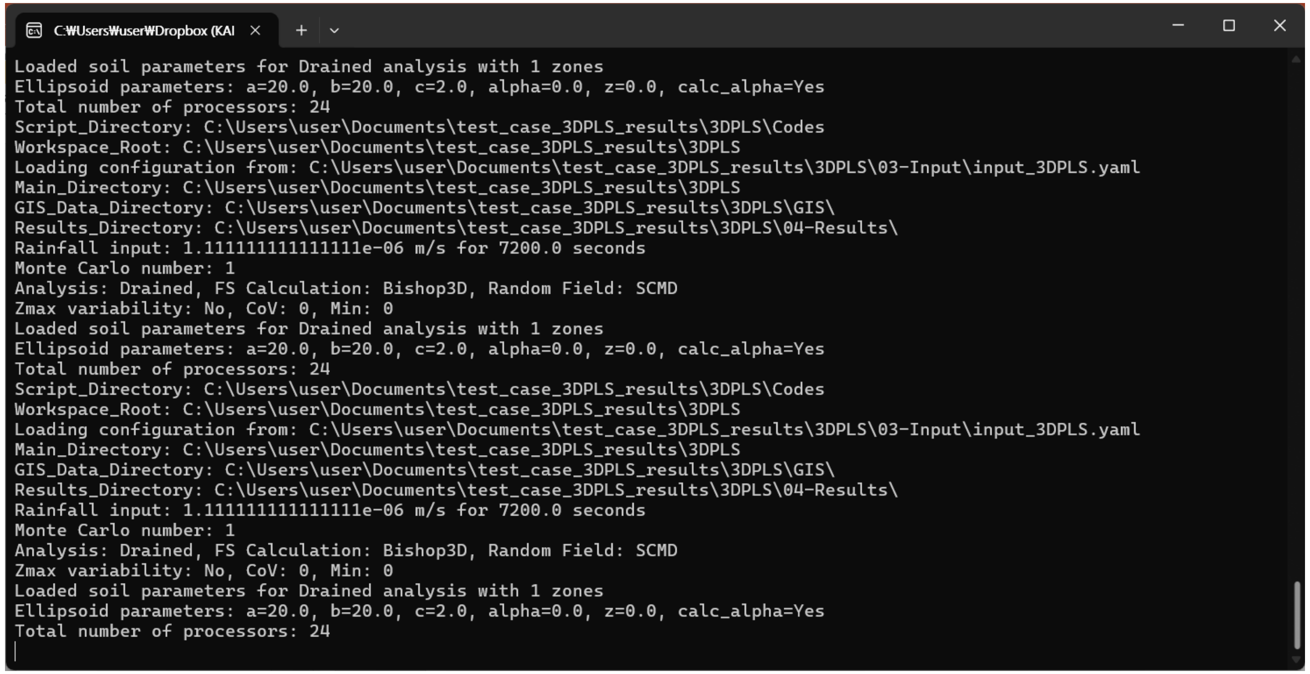
- Since the entire slope has the same soil, select *Uniform* soil properties from the **Material Assign dropdown list**

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**

License Agreement

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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: Sep 05, 2025
Purpose: Robust Areal Landslide Prediction (RALP) - 3DTSP and 3DPLS
Language: Python3
License: MIT