User Manual for SSSPAM
(Version 2.0)

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1 Installing SSSPAM and SSSPAM data analysis software

The SSSPAM model and SSSPAM data analysis software have been packaged as standalone executable files. However SSSPAM and SSSPAM data analysis software needs to be installed separately.

1.1 Installing SSSPAM model

1) Run the "SSSPAM_setup.exe" file from the installation folder.
2) Select whether you need to create a shortcut on the desktop or not and click next.
3) Click the install button to begin the installation.

The SSSPAM model software will be installed in a folder called "SSSPAM" in drive C of your computer. After installation you may move this folder to any other location except C:\Program Files or any variant of this folder (i.e C:\Program Files (x86)). However If you created a desktop shortcut during the installation you may need to edit its path accordingly.

1.2 Installing SSSPAM data analysis software

SSSPAM data analysis software is designed to convert the specialised Python based data files created by SSSPAM into user readable format such as ASCII or CSV while providing a platform to visualise the SSSPAM results in 2-dimensional or 3-dimensional plots. Different modules of the SSSPAM data analysis software will be discussed later. To install SSSPAM data analysis software on your computer,

1) Run the "SSSPAM_analysis_setup.exe" file from the installation folder.
2) Select whether you need to create a shortcut on the desktop or not and click next (it is highly recommended that you create a desktop shortcut for the program).
3) Click the install button to begin the installation.

The SSSPAM data analysis software will be installed into the program files folder in your computer. After installation you may move this folder to any other location in the computer. However If you created a desktop shortcut during the installation you may need to edit its path accordingly.

2 SSSPAM soilscape-landform evolution model theoretical framework

The SSSPAM model was developed by coupling a landform evolution model based on detachment-limited and transport-limited erosion (Willgoose, Bras, & Rodriguez-Iturbe, 1991a, 1991b) with a soil pedogenesis model. In the latest version of SSSPAM a diffusion model is also incorporated to simulate the net effect of rain splash and soil creep including gully bank collapse.

SSSPAM uses a state-space matrix formulation to simplify the physically based process equations allowing efficient simulation of the linked pedogenic and landform evolution processes. SSSPAM simulates fluvial erosion and armouring, diffusive erosion (surface), sediment deposition, and weathering within the soil profile and uses a number of layers to simulate soil profile evolution.

SSSPAM is capable of describing the particle size distribution of the soil profile at each pixel at any (modelled) soil depth as well as the grading distribution of the eroded sediments in the water flow. Eroded material from each upstream pixel (node) contribute to the grading distribution of the sediments suspended in the flow. The total mass of the sediments which needs to be deposited or eroded at a node is calculated as the difference between the transport capacity and the sediment load in the flow.

Detachment-limited erosion occurs when the total of sediment load in the flow and the potential erosion load is less than the transport capacity. Transport-limited erosion occurs when the total of sediment load in the flow and the potential erosion load is higher than the transport capacity. Diffusive erosion occurs at all the pixels where the transport capacity has not been exceeded by the sediment in the flow. Deposition occurs when the transport capacity at a node is less than the total sediment load in the pixel. Elevation differences are then determined based on the mass of the fluvial and diffusive erosion or deposition, and the landform is evolved accordingly. This in turn allows analysis of soil-landform interactions and soil self-organization both spatially and temporally. Similar to SIBERIA, SSSPAM also uses a Digital Elevation Model (DEM) to determine the hydrological characteristics of the landform and evolve the landform.

The SSSPAM soilscape-landform evolution model is developed by incorporating elevation changes of the landform due to erosion and deposition into SSSPAM soil grading evolution modelling framework coupled with a sediment transport model. A process flowchart of SSSPAM is shown in Figure 1. Detailed information regarding the development and testing of SSSPAM soil grading evolution model is provided elsewhere (Cohen, Willgoose, & Hancock, 2010; Welivitiya, Willgoose, Hancock, & Cohen, 2016).

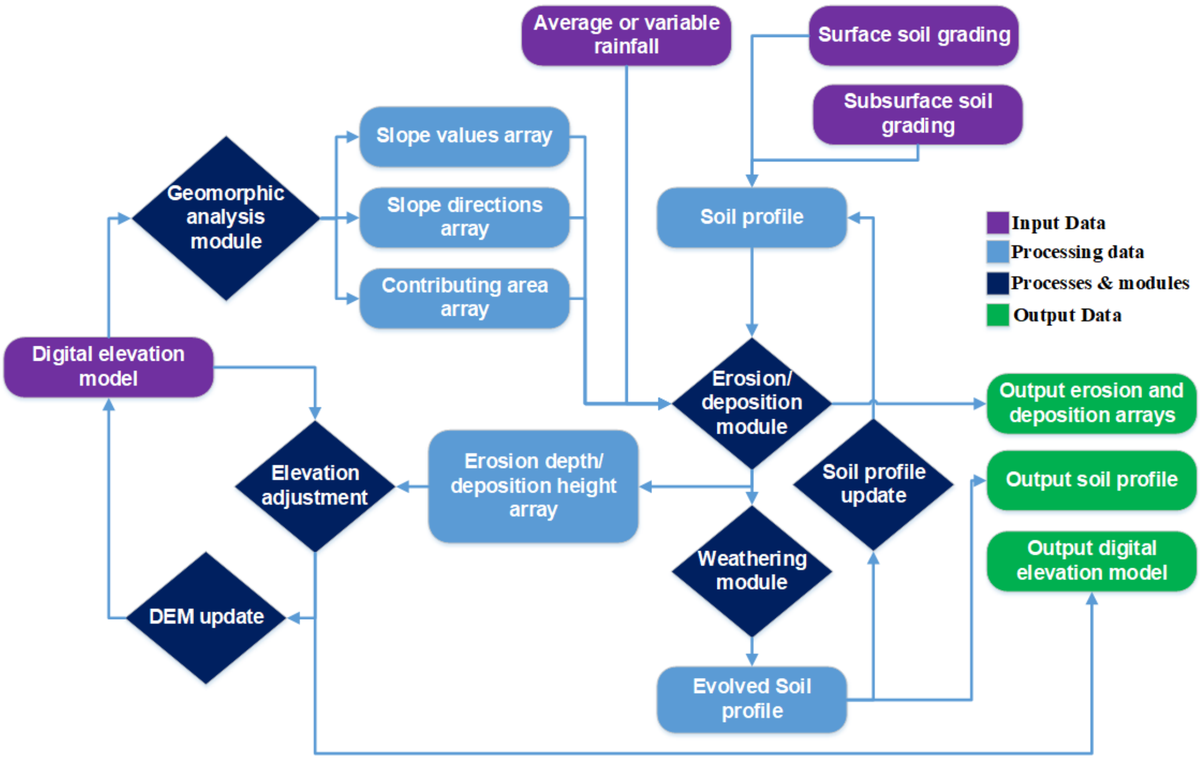

Figure 1.Flow diagram of SSSPAM model operations.

In SSSPAM, a regular square grid Digital Elevation Model is used to represent the landform and erosion or deposition at each pixel increase or decrease the elevation value at the said pixel leading to landform evolution. The structure of the landform evolution model follows that for transport-limited erosion (Willgoose et al., 1991a) but modified so as to facilitate its coupling with the SSSPAM soil grading evolution model. Using the “steepest-slope” criterion (Tarboton, 1997) the flow direction and the slope value of each pixel is determined. Then using the created flow direction matrix, the contributing area of each pixel is determined using the “D8” method (O'Callaghan & Mark, 1984) with a non-recursive iterative algorithm.

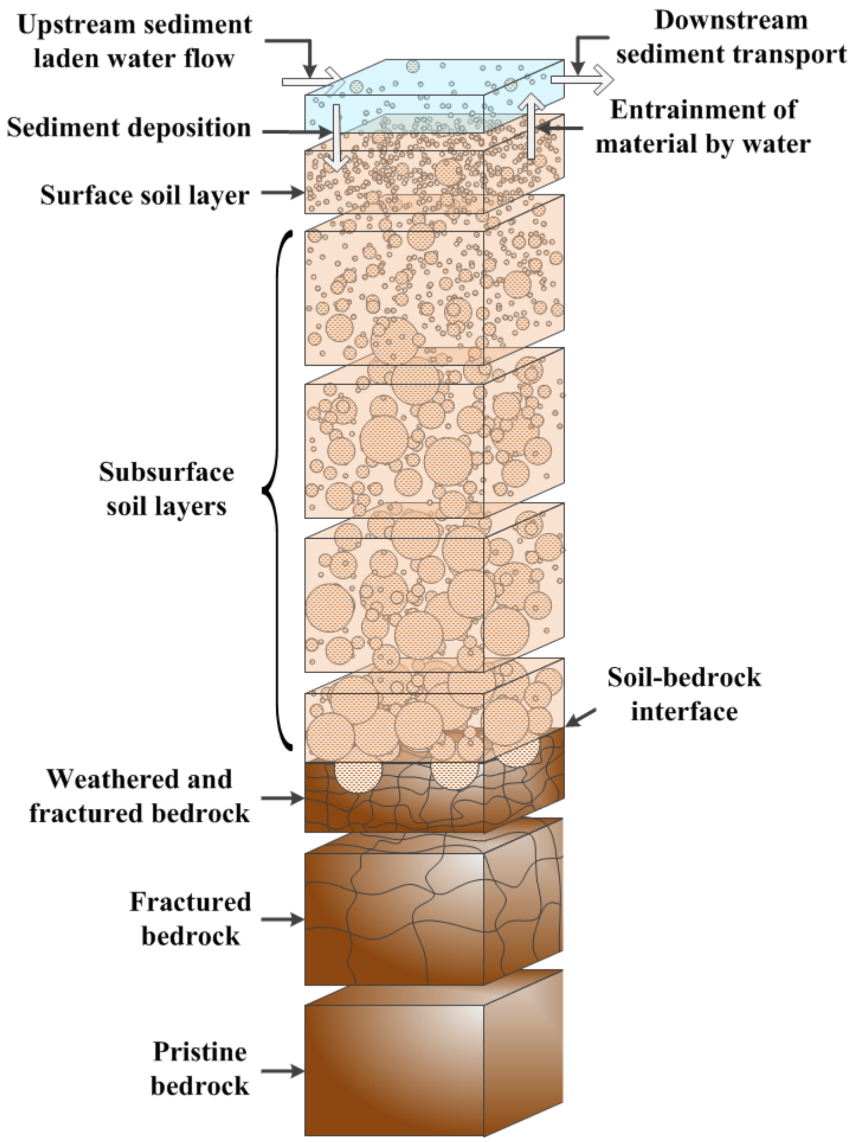

Figure 2 Schematic diagram of the SSSPAM model.

The soil profile evolution of each pixel is characterized using the interactions between the soil profile and the flowing water at the surface. Figure 2 shows these layers and their potential interactions. The water layer acts as the medium in which soil particle entrainment or deposition occur depending on the transport capacity of the flow at that pixel. The water flow provides lateral coupling across the landform, by the sediment transport process. The soil profile is modelled as several layers to reflect the fact that the soil grading changes with soil depth depending on the weathering characteristics of soil. Erosion of soil and/or sediment deposition occurs at the surface soil layer (surface armour layer). In SSSPAM, mass conservation of the surface armour layer is achieved by exchange soil material from the 1st subsurface layer equal to the eroded or deposited amount of material at the surface.

This material exchange propagates down the soil profile (one soil layer exchanging material with the layer above and the layer below) all the way to the bedrock layer which is semi-infinite in thickness. Since the soil grading of different layers are different to each other, this flux of material through the soil profile changes the soil grading of all the subsurface layers. Conceptually the position of the modelled soil column moves downward in case of erosion and moves up in case of deposition since all vertical distances for the soil layers are relative to the soil surface. This movement of the "soil model-space" during erosion is illustrated in Figure 3.

Once erosion and deposition mass is determined, elevation changes are calculated and the DEM is modified accordingly. Once the algorithm completes modifying the DEM matrix, the calculation of flow direction and contributing area is completed and the process is repeated until a given number of iterations (evolution time) is reached.

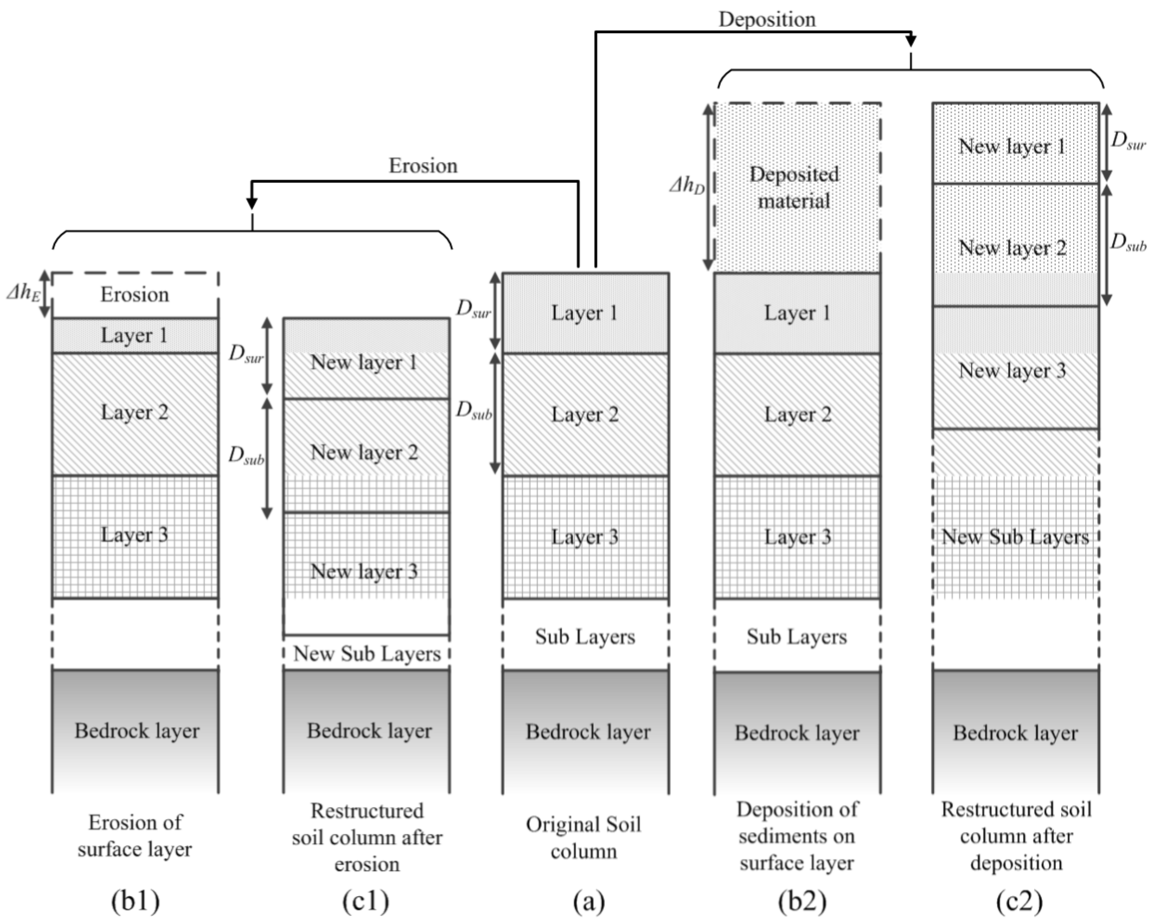

Figure 3 Erosion, Deposition and the restructuring of the soil profile (a) original soil profile, (b1, c1) for erosion, (b2, c2) for deposition.

2.1 Erosion and armouring

Erosion is the process of removing material from the soil surface due to flowing water. Armouring of the surface soil layer is a by-product of erosion. Depending on the energy of the erosion medium, transportable fine fraction materials are preferentially entrained and transported from the surface soil layer. This process coarsens the remaining surface soil layer enriching it with less mobile material (Figure 4).

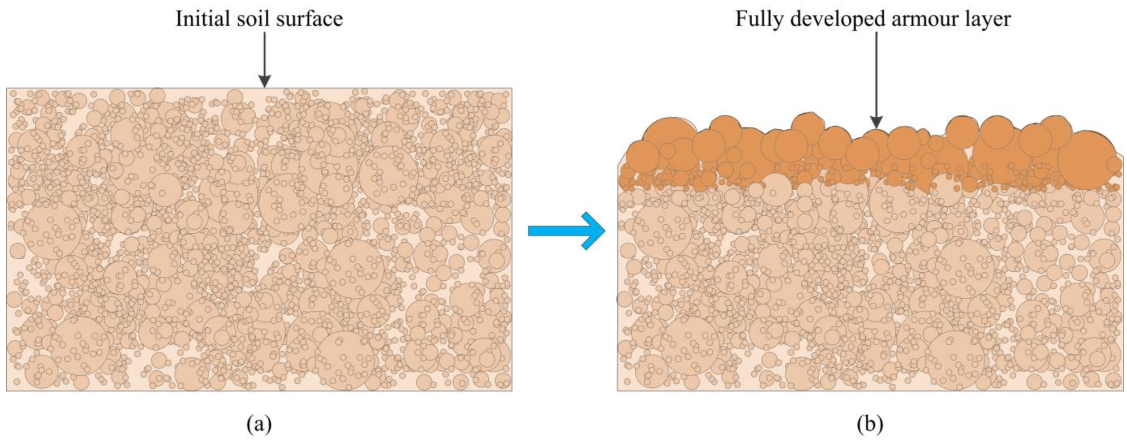

Figure 4 Schematic of the armouring process: (a) original surface; (b) armoured surface.

In SSSPAM, the potential fluvial erosion rate is calculated depending on discharge per unit width and slope using both detachment and transport limited erosion models (Welivitiya et al., 2016) .The potential rate of fluvial erosion per unit width ($m^3\ s^{-1} m^{-1}$) is given by

$$E_f = Keq^{\alpha_1} S^{\alpha_2} T \qquad (1)$$

where e is the edibility factor, q is discharge per unit width ($m^3\ s^{-1} m^{-1}$), S is slope, α_1 and α_2 are exponents governing the erosion process and T is the length of time step used (s). The parameter K determines the maximum volume of erosion that potentially could occur depending on the surface soil grading and the threshold entrainment diameter. Threshold entrainment diameter (TED) is the maximum diameter of the particles which could entrain by the overland water flow and it is calculated using Shield's shear stress criteria. TED is given by,

$$TED = C_{th}(nq)^{0.6}S^{0.7} \tag{2}$$

where C_{th} is a parameter that needs to be calibrated and n is the Manning friction factor. All the particles in the surface grading below the TED can potentially be eroded and particles larger than TED will remain on the surface leading to armouring.

In SSSPAM, discharge per unit width (q) is calculated using the runoff excess generation factor r (m s^{-1}) and the contributing area of the pixel A (m^2) and flow width (typically equal to the DEM resolution) w_f(m) as,

$$q = \frac{rA}{w_f} \tag{3}$$

Armouring of the soil surface occurs due to the selective entrainment of soil particles through erosion. This size selectivity of the erosion process in characterized by the erosion transition matrix **A**. TED mentioned earlier is used to generate the entries of erosion transition matrix **A.**

$$\mathrm{A}_{kk} = \begin{cases} \dfrac{a}{{d_k}^m} {g_k}^v & for \;\; k < M \\ 0 & for \;\; k \geq M \end{cases} \tag{4}$$

where, d_k is the mean diameter of particle size class k, m and v are exponent factors for the mean diameter of particle size class and grading fraction g_k respectively, a is a scaling factor which governs the erosion from each grading class. M is the grading class that the TED falls into (i.e. the largest particle which can be entrained by the water flow).

2.2 Soil diffusion

Soil diffusion is the process of soil movement down the slope due the steepness of the hillslope itself. Processes such as rain-splash and soil creep can be identified as the main processes of diffusion on a hillslope. The process of diffusion is important in landforms with steep slopes such as mine waste dumps which are highly prone for gullying.

SSSPAM uses a diffusion model (similar to SIBERIA) to determine diffusive erosion E_d depending on the slope. It also considers a maximum threshold slope (S_{th}) which is the maximum slope the landform can achieve without collapsing depending on the soil material. In SSSPAM diffusive erosion E_d is calculated by,

$$E_d = \begin{cases} DS & for\ S - \dfrac{DS}{X^3} < S_{th} \\ (S - S_{th})X^3 & for\ S - \dfrac{DS}{X^3} \geq S_{th} \end{cases} \tag{5}$$

where D (m^3 s^{-1} m^{-1} width) is diffusivity, S is slope and X (m) is the DEM resolution. The particle size distribution of the diffused material was simulated using a simple size selective approach where the smallest particles in the soil surface are removed first.

2.3 Size selective deposition

Sediment deposition occurs when the sediment load carried by the water flow id greater than the transport capacity of the flow. SSSPAM is capable of tracking the mass and the particle size distribution of all the sediments eroded from upstream pixels and use this information to determine the mass and the particle size distribution of the material that needs to be deposited at a particular pixel. In order to calculate the PSD of the deposited material a quantity called the critical immersion depth is defined as shown in Figure 5.

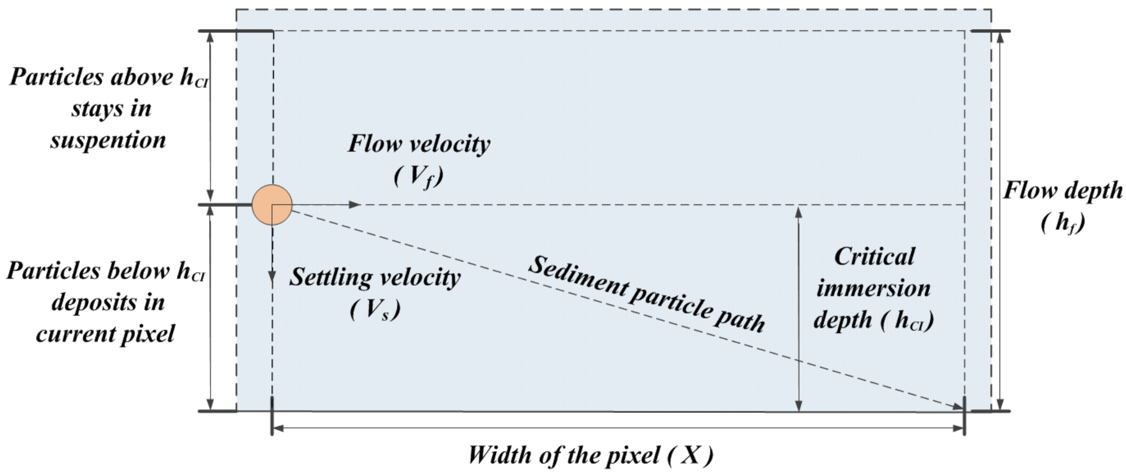

Figure 5 Determination of critical immersion depth of a sediment particle.

Critical immersion depth is referred to vertical distance a particle will fall through the water column with the settling velocity while moving the horizontal distance of pixel width with the flow velocity at the pixel assuming all the sediment particles are distributed equally throughout the water column at a pixel. Critical immersion depth $h_{ct(z)}$ is given by,

$$h_{ct_{(z)}} = \frac{X}{V_f} V_z \tag{6}$$

Where X is the pixel width, V_z is the settling velocity of the particle size class and V_f is the fluid flow velocity.

Depending on the position of the sediment particle entering into the pixel with respect to critical immersion depth, whether or not that particle will deposit in that pixel can be determined. Particles entering to the pixel below the critical immersion depth will settle within the current pixel, while particles entering above the critical immersion depth will stay in suspension and exit the current pixel. The critical immersion depth is greater for larger (or denser) particles and less for smaller (or less dense) particles. For sediment particles in larger size classes, the critical immersion depth can be larger than the flow depth H_f(m) (thickness of the water column). That means all the particles in that particle size class will settle in the pixel. Using the critical immersion depth and the flow depth we can define the elements $J_{z,z}$ of the deposition transition matrix $\mathbf{J}$ in following manner.

$$J_{z,z} = \begin{cases} \dfrac{h_{ct_{(z)}}}{H_f} & for\ H_f \geq h_{ct_{(z)}} \\ 1 & for\ H_f < h_{ct_{(z)}} \end{cases} \tag{7}$$

Using the deposition transition matrix the PSD of the deposited material is calculated. Further details of the formulation and implementation of the deposition module in SSSPAM can be found in Welivitiya (2017) and Welivitiya, Willgoose, and Hancock (2019).

2.4 Weathering

Weathering is the general term used to describe all the processes which cause rocks or rock fragments to disintegrate or to be altered through physical or chemical means (Strahler & Strahler, 2006). Currently SSSPAM only considers physical weathering for the breakdown of the surface armour layer and the subsurface soil layers where mass in conserved. Mass reduction mechanisms such as chemical dissolution are not considered because of their complex interactions with soil.

The weathering module of SSSPAM consists of two components. They are (1) the weathering geometry for the grading of the daughter particles and (2) the weathering rate for the different soil layers which determines the rate at which the parent material is weathered. The weathering rate of each soil layer typically (though not always) depends on the depth below the soil surface.

2.4.1 Weathering mechanism

The geometry of the products of physical weathering is modelled in SSSPAM using a fragmentation mechanism. The fragmentation model determines the geometry of the weathered particles. If a spherical parent particle of diameter d (m) brakes into a daughter particle with diameters d_1 (m) accounting for α fraction and n-1 daughter particles with diameter d_2 (m) (Figure 6), the sizes of the daughter particles can be determined in terms of the parent particle diameter as,

$$d_1 = \alpha^{\frac{1}{3}}d \quad (8)$$

$$d_2 = \left(\frac{1-\alpha}{n-1}\right)^{\frac{1}{3}} d \quad (9)$$

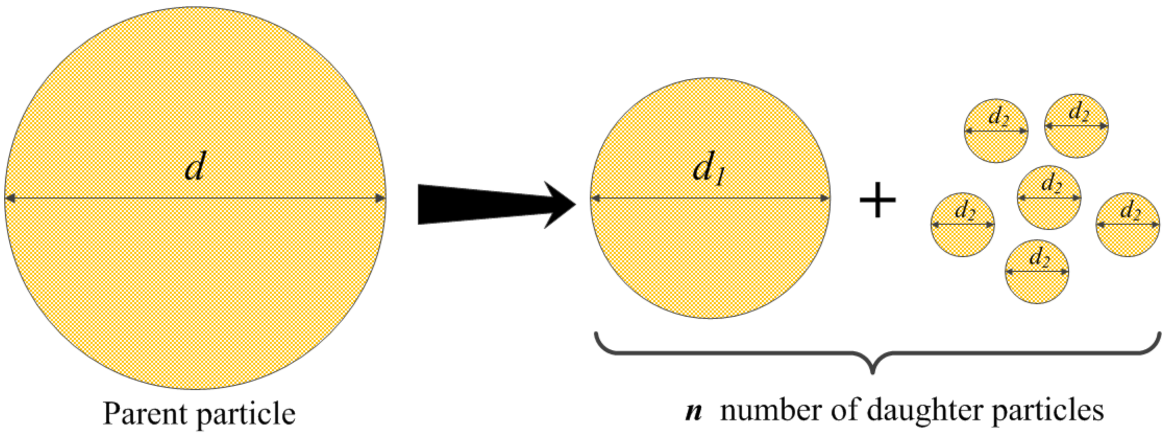

Figure 6 Weathering mechanism used in SSSPAM.

By changing the α fraction value and the number of daughters n SSSPAM is capable of simulating various fracture geometries such as symmetric fragmentation, asymmetric fragmentation, and granular disintegration (Wells, Willgoose, & Hancock, 2008). For instance α =0.5, n=2 represents symmetric fragmentation with two daughter particles, α =0.99, n=11 represents a fracture mechanism resembling granular disintegration where a large daughter retains 99% of the parent particle volume and 10 smaller daughters have 1% of the parent volume collectively.

2.4.2 Depth dependent weathering functions (DDWF)

To characterize the weathering rate with soil depth, depth-dependent weathering functions are used. in SSSPAM several DDWF's are available to choose. They are (1) exponential decline (called exponential in Figure 7) (Humphreys & Wilkinson, 2007) and (2) humped exponential decline (called humped exponential in Figure 7) (Ahnert, 1977; Minasny & McBratney, 2006). The base weathering rate of w_0 is modified by the depth ependent function value at the soil depth to generate the actual weathering rate of the soil layer. In the exponential, the weathering rate is highest at the soil surface and declines exponentially with depth. The rationale underpinning this function is that the surface soil layer (surface armour layer) is subjected to high rates of weathering because it is closer to the surface where wetting and drying, and temperature fluctuations are greatest. The humped function has the maximum weathering rate at a finite depth below the surface instead of at the surface and then declines exponentially below that depth. The rationale for this is that, in some regions there is evidence that the weathering rate is highest at the water table surface which leads to a humped function.

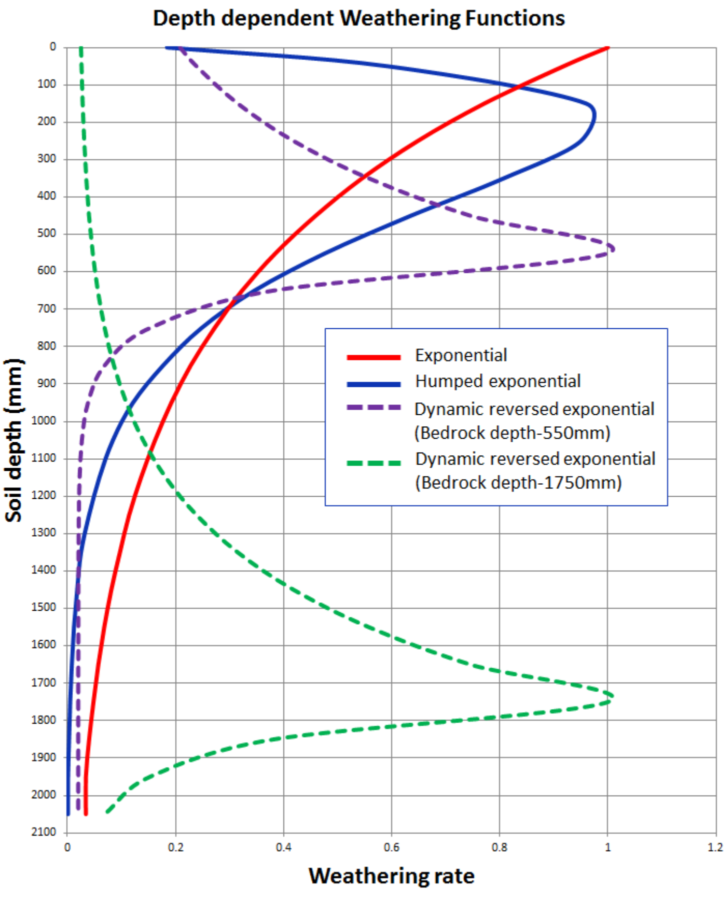

Figure 7 Graphical representation of depth dependent weathering functions used in SSSPAM.

In addition to these functions another theoretical depth dependent weathering function called the dynamic reversed exponential function was also incorporated into SSSPAM modelling framework. In this function the highest weathering rate is located at the soil-bedrock interface and exponentially decreases upwards toward the surface and downwards into the underlying bedrock. Unlike the exponential and humped functions the depth of the peak weathering rate in the dynamic reversed exponential function moves up and down with the increase and decrease in depth of the soil-bedrock interface. The rationale of this function is that at the soil-bedrock interface the bedrock material may be relatively rapidly transformed from bedrock to soil.

In the exponential function the weathering rate of a layer h (m) below the soil surface w_h is given by,

$$w_h^{exp} = w_0 \beta e^{(-\delta_1 h)} \tag{10}$$

where, δ_1 is the depth scaling factor and β is a constant defining the maximum weathering rate.

In the humped exponential function the weathering rate of a layer h (m) below the soil surface w_h is given by,

$$w_h^{hum} = w_0 P_0 \left[\frac{e^{(-\delta_2 h + P_a)} - e^{(-\delta_3 h)}}{M_f} \right] \tag{11}$$

where P_0 and P_a are the maximum weathering rate and the steady state weathering rate respectively, δ_2 and δ_3 are constants used to characterise the shape of the function, and M_f is the maximum weathering rate at the peak of the hump which is used to normalize the function.

In the dynamic reversed exponential function, the weathering rate of a layer h (m) below the soil surface w_h is given by,

$$w_h^{drev} = \begin{cases} w_0\left(1 - \lambda\left[1 - e^{-\delta_4 (H-h)}\right]\right) & for\ h \le H \\ w_0\left(1 - \lambda\left[1 - e^{-\delta_5 (h-H)}\right]\right) & for\ h > H \end{cases} \tag{12}$$

where *H* (m) is the depth down to the soil-bedrock interface from the surface which is calculated from the soil grading distribution at each iteration during the simulation.

3 Model Parameters

The following section describes the model input parameters that can be input by the user depending on the simulation requirement. The parameters in **bold text** are the most important parameters that require the user's special attention. Other parameters can be left as is or changed depending on the circumstances and knowladge.

3.1 Erosion parameters

Potential fluvial erosion rate calculation : equation (1) The parameters in this section require site specific calibration which can be done using field data, flume experiments or transforming existing erosion parameters from the SIBERIA model.	
Discharge Exponent (α_1)	Exponent which relates the discharge rate to erosion rate. Literature suggest this value ranges from 0.1 to 4.
Slope Exponent (α_2)	Exponent which relates the local slope to erosion rate. Literature suggests this value ranges from 0.1 to 4.
Erodibility (e)	Erodibility parameter representing how easily a particle from the surface could be entrained in the overland water flow. Depending of the material, this parameter can have a very broad range from a small fraction to many thousands.
Threshold entrainment diameter (TED) calculation: equation (2) Size selective armouring matrix (**A**) calculation: equation (4) Parameters in this section were originally calculated from the available historical field data collected from the erosion test plots located on trial rehabilitated landform	

(TLF) at the Ranger mine site by Hancock, Lowry, and Saynor (2016). If no runoff-erosion data with particle size distribution (PSD) of the eroded material is available default parameter values already filled in SSSPAM GUI can be left as is. If (PSD) of the eroded material is available these parameters can be calibrated for that specific site using a custom Monte Carlo simulation employing SSSPAM.	
Threshold coefficient (C_{th})	Linear scale factor needed to calculate TED which relates to parameter K of equation (1). Default value : 0.3
Manning's coefficient (n)	Manning coefficient is required to calculate TED which relates to parameter K of equation (1) Default value: 0.1
Mean Diameter exponent (m)	The exponent value relating the likelihood of particle entrainment through overland flow to the particle size. Default value: 0.173
Soil grading exponent (v)	The exponent value relating the likelihood of particle entrainment through overland flow to the material availability on the surface layer. Default value: 1.3
<u>Soil diffusion : equation (5)</u> The diffusion parameter maybe calculated from the long term field data observations or use a typical value until reasonable geomorphological development is achieved through trial and error. The Threshold Slope can be determined by the examination of the sidewalls of gullies of the site to identify the maximum slope.	
Diffusion (D)	Coefficient of diffusion for sediment transport. In SSSPAM, process rates are typically given in per second basis. Range: 10^{-9} to 10^{-11} .
Diffusion threshold slope (S_{th})	The threshold slope is the maximum slope any pixel in the DEM could have. It is mainly used to simulate bank collapse of deep gullies. Typically a value of 1 which represent a maximum slope of 45^0 can be used. If No diffusion threshold slope needs to be considered (i.e No bank

	collapse of gullies) use the value of 0 to deactivate this functionality.

3.2 Weathering parameters

Weathering mechanism: equations (8)**,** (9)	
Number of fractions (N)	The number of daughter particle produced after fracturing of a single parent particle. (For symmetric fragmentation mechanism N=2)
Largest fraction (α)	Volume fraction of the largest daughter particle relative to parent particle (Symmetric fragmentation α=0.5)
Depth dependent weathering functions: equations (10),(11),(12)	
Weathering rate (w_0)	Weathering rate of soil was calibrated from: Wells T, Willgoose GR, Hancock GR. 2008. Modeling weathering pathways and processes of the fragmentation of salt weathered quartz-chlorite schist. Journal of Geophysical Research-Earth Surface 113. DOI: F01014). **If no weathering is required set this value to 0.**
ex	These parameters are used to characterise the depth dependent weathering functions used in SSSPAM. these parameters are not used unless pedogenesis modelling is required.
$revex$	
P_0	
P_a	
δ_1	
δ_2	
M_f	

3.3 Physical constants.

Soil bulk density (ρ_s)	Bulk density of the soil material (kg/s/m^2)
Uplift mode	SSSPAM can model the uplift of the landform in two different method. These are **“Static”** and **“Dynamic”** uplift. In the static mode, the user can input a value such as regional uplift rate to simulate the uplift of the landform. If no uplift is necessary the user needs to select the “Static” uplift mode and set the Uplift rate parameter to 0. In the **“Dynamic”** uplift mode, SSSPAM calculates the total volume of material removed from the landform and add the same volume to the entire landform as a uniform uplift. In this method long term stable landforms with minimum erosion can be achieved starting from an existing engineered landform.
Uplift rate	Uplift rate of the landform. If no uplift is necessary the user should select “Static” uplift method and set the Uplift rate parameter to 0.
Fluid density (ρ_s)	Density of the erosive fluid (1000kg/m^3 for water)
Fluid viscosity (μ)	Dynamic viscosity of erosive fluid (1.002 kg/s/m^2 for water)
Gravitational acceleration (g)	Gravitational acceleration of earth.

3.4 Model run parameters.

Simulation length	Length of the required simulation in years.
LEM time step per year	The number of iterations the model should be run per year. For example, if the simulation needs to be run at daily time steps, 365 should

	be entered as **"LEM time step per year". A special consideration needs to be given if the user is using "Time series" input rainfall mode. The LEM time step per year value needs to be the same as the frequency of the rainfall time series data. For example, if the user is using a daily time series rainfall file the LEM time step per year needs to be set to 365. If monthly rainfall time series is being used, the value needs to be set to 12.**
Number of sub surface layers	Number of subsurface layers which needs to simulate soil profile evolution. Use 1 if no subsurface simulation is required.
Depth of armour (surface) layer	Depth of surface soil layer which erosion and deposition occur (mm). Needs to be at least large as largest particle size in the surface grading distribution.
Depth of a sub-surface layer	Depth of sub-surface soil layers (mm). Needs to be at least the depth of surface armour layer.
Output interval	Yearly frequency which data needs to be saved to the hard drive of the computer. Typically given in years. For example if the user is running the simulation at yearly time steps, and require output data every 10 years, LEM time step per year=1 Output interval=10 This number can be a fraction given that the LEM time step per year >1. The minimum value for Output interval parameter would be 1/ LEM time step per year. For example if the user requires monthly results while running SSSPAM at daily time step, then LEM time step per year=365

	Output interval=1/12 (0.0834)
Output mode	SSSPAM is able to output data in two output modes. In **“Elevation and surface only”** mode, SSSPAM creates folders for elevation data, sediment output data and surface soil layer, and saves the required data in each folder. However the results of sub-surface layers are not saved. The data saved in this output mode is adequate for most of the applications concerning landform evolution and erosion prediction. If detailed study of the soil profile development is required the user should select the **“All layers mode”**. In this mode, in addition to the folders mentioned earlier, additional folders are created for each sub-surface soil layer and soil grading data of each sub-surface soil layer is saved in each folder. However this mode requires considerably more computer storage space compared to **“Elevation and surface only**” mode.
Weathering function	Depth dependent weathering function which needs to be used to simulate soil profile evolution.

3.5 Input data

DEM file	Location of the ASCII text (*.txt, *.asc) file containing the Digital Elevation Model of the landform (use the “Browse” button to navigate to the file). The ASCII file generated from GIS software such as ArcGIS can be directly used as the DEM file for SSSPAM simulations. The structure of the ASCII text file is shown below.

Example DEM ASCII file:

```
site5_clip.txt - Notepad
File  Edit  Format  View  Help
ncols         362
nrows         346
xllcorner     622273.53
yllcorner     7538015.58
cellsize      0.5
NODATA_value  -9999
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-9999 -9999 -9999 -9999 -9999
```

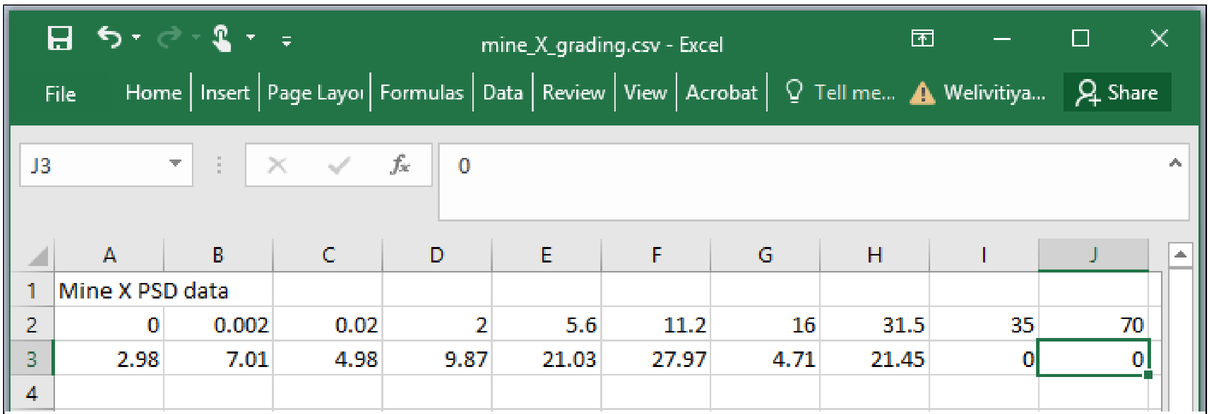
In this ASCII text file the first 6 rows contain the spatial and other information regrding the data contained in the file. **"ncols"** and **"nrows"** represent the number of columns and rows in the data array.

"xllcorner" and **"yllcorner"** is the spatial coordinates of the top-left corner of the data array according to the spatial coordinate system used to generate the ASCII file. **"cellsize"** is the resolution of the DEM and **"NODATA_VALUE"** is the value assigned to the pixels which fall outside the DEM boundry. (i.e filler pixels used to create a rectangular or square array from a landform with irregular boundry)

From the 7th row onverds, elevation data rows of the DEM array is recorded.

DEM resolution X and Y	These represent the resolution of the DEM in the two cardinal directions in meters. Typically

	resolution of the DEM in both directions are the same. If the ASCII DEM file provided as the DEM file contains correct **“cellsize”** information, these fields are automatically filled through the GUI. If they lack the required information or they are not correct to the knowledge of the user, they needs to be filled manually.
Surface and Sub-surface grading files	Location of the CSV (*.csv) files containing the soil particle size distribution to be used as the surface grading and sub-surface grading (use the “Browse” buttons to navigate to the files). If the simulation is carried out on a landform constructed with homogeneous material such as a mine dump site landform without a cap, the same grading file can be used to characterize both surface and sub-surface grading. If a different capping material is considered, two separate files can be used to represent the grading difference between the capping material and construction material. **The grading fractions in the grading file is given in percentages and the sum of all the grading values should account for exactly 100%. When using two separate files for surface and sub-surface gradings, make sure that both of them have the same grading distribution classes.** The structure of the soil grading CSV file is given below.
Example grading CSV file :	



	A	B	C	D	E	F	G	H	I	J
1	Mine X PSD data									
2	0	0.002	0.02	2	5.6	11.2	16	31.5	35	70
3	2.98	7.01	4.98	9.87	21.03	27.97	4.71	21.45	0	0
4										

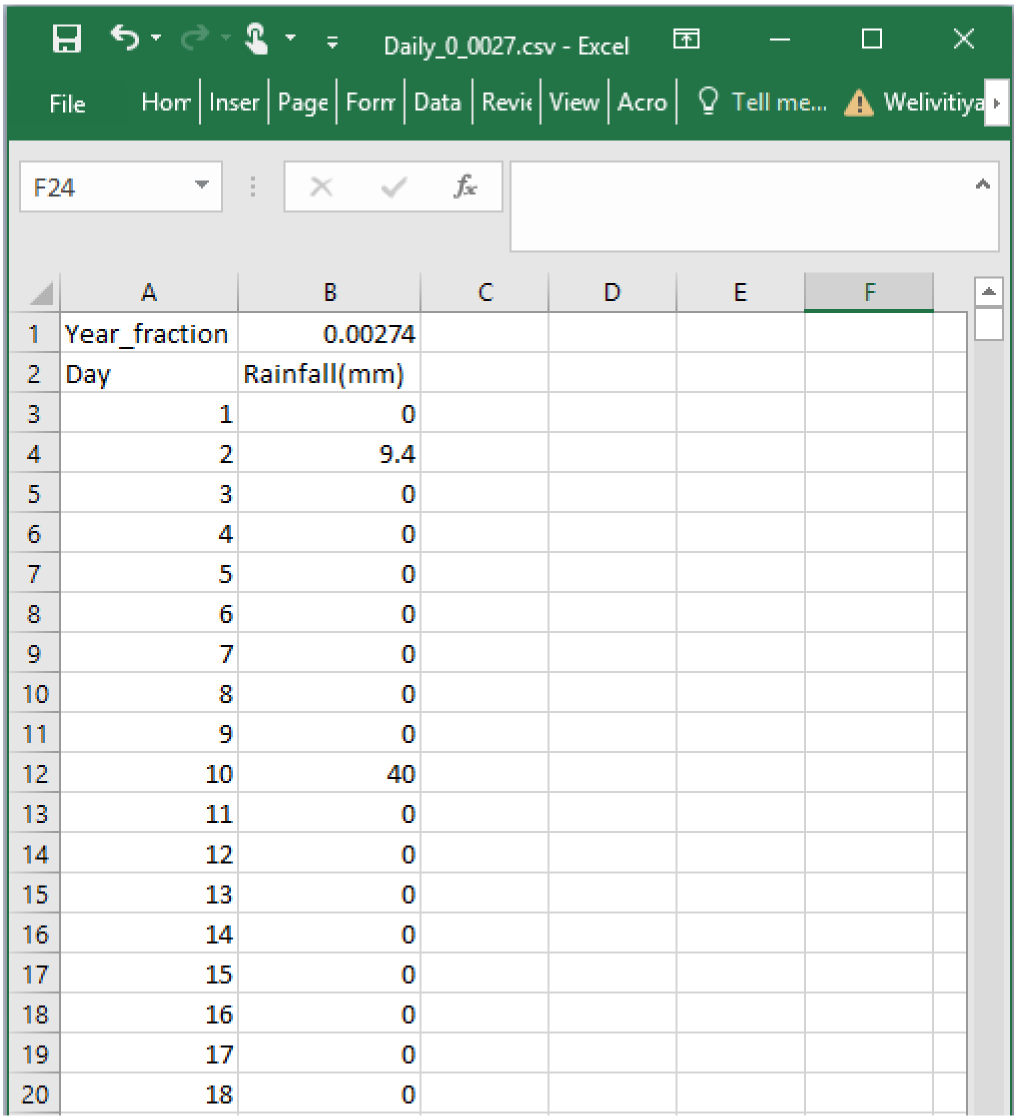
In the grading CSV file, first cell is dedicated to a descriptor of the grading data. The second row represents the grading distribution classes in millimetres (mm) and the 3rd row represents the grading distribution in percentages. **As mentioned earlier the total sum of the grading distribution percentages should account for exactly 100%. Also, if two grading distribution files are used, both of them should have the same grading distribution classes. i.e the second row should be identical.**

Input Rainfall	SSSPAM is able to use annual average rainfall or a variable rainfall time series. If the **"Annual average"** option is selected**,** the user needs to input the annual average rainfall value in millimetres in the **"Average rainfall"** text field (i.e 1400). If the "**Time series"** rainfall option is selected the user needs to input the path of the"**Rainfall time series file".** (Use the "Browse" button to navigate to the file). **If this option is selected the user must ensure to use the correct "LEM time step per year" value. This value needs to be the same as the frequency of the rainfall time series data. For example, if the user is using a daily time series rainfall file, the LEM time step per year needs to be**

set to 365. If monthly rainfall time series is being used, the value needs to be set to 12.

The structure of the rainfall time series file CSV file is given below.

Example rainfall time series CSV file :



	A	B	C	D	E	F
1	Year_fraction	0.00274				
2	Day	Rainfall(mm)				
3	1	0				
4	2	9.4				
5	3	0				
6	4	0				
7	5	0				
8	6	0				
9	7	0				
10	8	0				
11	9	0				
12	10	40				
13	11	0				
14	12	0				
15	13	0				
16	14	0				
17	15	0				
18	16	0				
19	17	0				
20	18	0				

In the rainfall time series CSV file, the first row shows the time step of the time series as a fraction of a year. In this example since we are using daily time steps it is 1/365≈0.00274. Second row is the descriptor for the time step.

Onwards from the 3rd row, the rainfall data is recorded as the time step number and the rainfall during the time step.

SSSPAM is able to use rainfall time series data of certain length to run the simulation well beyond the available rainfall data. For example, imagine we

have a daily rainfall time series for 10 years with 3650 individual rainfall entries. If the simulation needs to be run for 100 years, the user still can use the 10 year daily rainfall time series. For the 100 year simulation SSSPAM creates an internal rainfall time series of 100 years by putting the available 10 year data set end to end.	
Results folder	Folder where the results of the simulation needs to be saved.
Custom folder ID	An identifying text or number combination to aid in discriminating between different simulations. SSSPAM uses date and time at which the simulation was started to create a unique folder and save the simulation data. "**Custom folder ID"** modifies this folder name with user defined text.

4 SSSPAM file and folder structure

At each simulation, SSSPAM creates a folder to save the simulation data inside the **"Results folder"** location provided by the user. SSSPAM uses the current date and time together with **"Custom folder ID"** provided by the user to create a unique folder every time a simulation is run. This method avoids data replacement in already concluded simulations. An example of a results folder name created by SSSPAM is shown below in Figure 8.

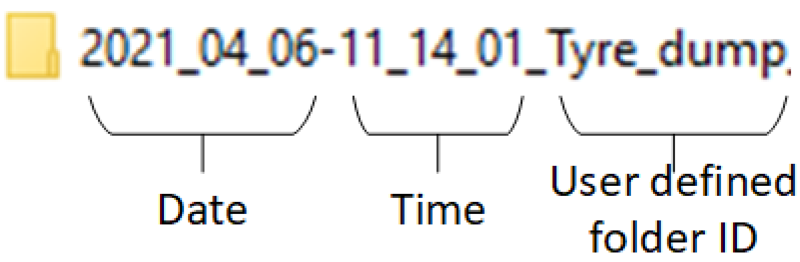


Figure 8. Results folder created by SSSPAM.

Within the created results folder SSSPAM creates a number of different sub-folders to save different types of data. There are some folders used for testing of SSSPAM which the user can ignore. A brief description of the important folders which the user needs to be aware of are given below.

1) **metadata**

This folder contains the parameters used to run the simulation as well as a copy of the last internal data files generated by SSSPAM during its simulations. These data files can be used to reinitiate SSSPAM and continue a simulation that has been abruptly terminated. The most important file inside this folder is the **“All_parameters.json”** file which contain all the parameters and file paths of the input data files used to initiate the simulation.

2) **Elevation_values**

This folder contains the elevation data of the simulation outputs as 2-dimensional numpy arrays with the extension .npy. Each entry in this file represents the elevation value of a single pixel.

3) **cumulative_sediment_values**

Files in this folder contain the sediment output mass leaving the landform from catchment outlets. The files are saved as 3-dimensional numpy arrays. Here the 3rd dimension is used to represent the grading distribution of the output sediments.

4) **layer0_grading_values**

Files in this folder contains the soil grading information of the landform surface layer as 3-dimensional numpy arrays. Here also the 3rd dimension is used to represent the grading distribution of each pixel.

5) **layer(n)_grading_values** (where n goes from 1 to the number of subsurface layers given by the user)

If the user selected the **“All layers”** output mode, SSSPAM creates individual folders to hold the soil grading data of each subsurface layer. The file type and the structure is same as the structure of surface layer soil grading files.

5 Running the SSSPAM model simulation

The SSSPAM model can be run by opening the SSSPAM desktop shortcut or opening the “NEW_SSSPAM.exe” executable file from the root folder where SSSPAM was installed. Once opened you will see the SSSPAM GUI interface.

5.1 New model run with new parameters

1) Edit the parameters and make sure to select the required files using the GUI.
2) Use the **“Save parameters”** button to save the parameters to the internal parameter file **(very important)**.
   Note:-If there are any inconsistencies with the parameters or the data files you provided, error messages will be given explaining the error. Correct these errors and retry to save the data. If all the parameters and data files are ok, a message will be displayed informing that the parameters have been saved.
3) Click the button **“Run SSSPAM from start”** to start the simulation.

A command prompt will appear and information about simulation progress is displayed in the command prompt.

5.2 Import parameters from a previous run

In some instances the user may need to perform additional simulations with slightly modified parameters or input data sets. For example, running the same simulation with a different surface grading file to see how different capping material can influence the landform evolution. In such cases to do a fresh run, the user will have to manually input the same parameters of the previous simulation except for the surface grading file location. Instead the SSSPAM GUI has the ability to load the parameters from the previous simulation, so the user can just change the required fields.

1) Click the **“Load existing parameters”** button.
2) In the previously run model results folder, navigate into the “metadata” folder and select the **“All_parameters.json”** file and click open.
   Note:- if there are any inconsistencies with the loaded parameters or the file locations, (for example: a grading file used in the previous simulation, no

longer exists in the same location) an error message will appear to explain the issue.

3) Modify the parameters as you wish and rectify any issues identified by the SSSPAM GUI.

   Note:- Although SSSPAM creates a unique results folder using the current time for each simulation, it is highly recommended that the user change the "**Custom folder ID"** parameter to a different value to distinguish easily between the 2 simulations.

4) Use the **"Save parameters"** button to save the parameters to the internal parameter file **(very important)**. if any error messages occur rectify the issues and retry saving the parameters.

5) Click the button **"Run SSSPAM from start"** to start the simulation.

A command prompt will appear and information about simulation progress is displayed in the command prompt.

5.3 Continue finished or stopped simulation from the last results data

In some instances a simulation that has been concluded or a simulation that has been abruptly discontinued due to an incident such as a power failure maybe needed to be continued further. In such a situation SSSPAM is able to load the parameters and the last internal datasets from file and continue the simulation from where it was terminated. To achieve this task,

1) Click the **"Continue SSSPAM from existing results"** button.
2) In the previously run model results folder, navigate into the "metadata" folder and select the **"All_parameters.json"** file and click open.
3) Modify the parameters in the new window (such as **"Simulation end")** as you wish.
4) Click the button **"Save parameters and continue SSSPAM from existing results"** on the new window to continue the simulation.

A command prompt will appear and information about simulation progress is displayed in the command prompt. When the simulation is continued, the new data is saved in the same folders as the previous simulation.

6 Using SSSPAM data analysis software

The SSSPAM model saves all its data including the elevation and soil grading data of all the soil layers as Python specific files (namely numpy type files with the extension npy). So regular users with limited knowledge of Python and its various modules will be unable to access the data for any analysis purpose. The SSSPAM data analysis software is capable converting all the Python specific data into ASCII or CSV data files which can be opened and analysed using various commercially available software. In addition, the SSSPAM data analysis software also has the ability to visualise the geomorphology and soil grading information as 3-dimensional plots. It also have the ability to plot the cross-sections of selected areas of the landform and visualize them as 2-dimensional plots.

The SSSPAM data analysis software is equipped with a GUI with 4 separate functions. They are,

1) Plot geomorphic data
2) Plot soil data
3) Plot cross-sections
4) Convert data.

6.1 Plot geomorphic data

This module generates a 3-dimensional plot of the landform using a file from the “**Elevation_values”** folder of a simulation chosen by the user. It also generates erosion-deposition 3-dimensional plot as well.

Once the “**Plot geomorphic data”** button is clicked a new sub-window appears where the user needs to select the elevation file they wish to plot and provide some display parameters. These parameters are used to setup the virtual camera to capture the scene of the landform. These parameters are

- **DEM resolution**

The resolution of the DEM. Typically SSSPAM data analysis software loads this value from the parameter file available in the **metadata** folder. The user only needs to manipulate this parameter if the value loaded by the system is erroneous.

- **Display elevation**

This parameter determines at which angle the camera should be set relative to the virtual horizon. A typical value of 60 (60^0) can be used here. Depending on the aesthetics of the plot, the user can change this value and achieve a better result.

- **Display azimuth**

This parameter determines the angular position of the virtual camera measured clockwise from virtual north. The azimuth value can be set as any number between 0 to 360. Depending on the aesthetics of the plot, the user can change this value and achieve a better result.

- **Display distance**

This parameter determines how far away the virtual camera needs to be placed relative to the landform. This value depends on the size of the landform. For small landforms a smaller value can be set for **"Display distance"** which will capture the entire landform in the scene. If the landform plot exceeds the scene boundary this value needs ne increased.

- **Vertical exaggeration**

In order to display some large landforms while emphasising their geomorphological features, the vertical elevation scale needs to be exaggerated. Using this parameter the user can input a number so that the elevation values will be multiplied by the given number to achieve the desired exaggeration.

In addition to the parameters mentioned above, the user can choose whether to flip the DEM horizontally (flip left-right). This function also solely depend on the aesthetics of the plot. Although the user can set **Display elevation, Display azimuth** and **Display distance** parameters in the data input window, the same parameters can be interactively changed once the plot is generated. The use can use mouse clicks and movement to change the orientation of the displayed landform to their liking.

6.2 Plot soil data

This module generates surface d_{50} , profile d_{50} and soil depth plots draped over a 3-dimensional plot of the landform. It uses the elevation data and the soil grading data to calculate and generate the required plots. If the SSSPAM simulation was run using the option **"Elevation and Surface only"** where the data on subsurface soil layers are not saved, the module plots only the surface d_{50}.

When the **"Plot soil data"** button is clicked, a new sub-window identical to the sub-window displayed for "**Plot geomorphic data"** module appears and the user needs to select the relevant elevation file and provide the parameter values same as above.

6.3 Plot cross-sections

This module interactively plots cross-sections of different locations of the landform chosen by the user. Once the **"Plot cross-sections"** button is clicked, a sub-window appears where the user just needs to brows to the DEM data file available in "**Elevation_values"** folder. Once the "**plot"** button is clicked, the system generates a 2-dimensional color-coded plot of the landform. Then the user can select 2 points on this 2-dimensional plot by clicking on it. Using the 2 points as reference the software draws a line between the selected points and draws the cross-section elevation in a different plot. Here the cross-section of the initial landform (landform at time 0) which falls on the same line is also plotted in the same cross-section plot to easily identify regions of erosion and deposition. If the subsurface soil data is available the software also plots the soil profile of the same cross-section as well.

6.4 Converting Python specific file types to ASCII or CSV files.

As mentioned earlier, SSSPAM saves its data as 2-dimensional or 3-dimensional numpy files which only can be accessed with Python subroutines. This module of the SSSPAM data analysis software converts all these relevant files into 2-dimensional text files in ASCII or CSV format.

Once clicked, this button opens a sub-window where the user can select the location of the DEM file which needs to be converted as well as a combo box where the user can select the output file type as CSV or ASCII. Once the **“Convert”** button is clicked the module creates a folder named after the selected file type (CSV or ASCII) and creates the same folder structure available in the SSSPAM simulation root folder. Then all the files in the subfolders in the SSSPAM simulation root folder are converted to 2-dimensional CSV or ASCII files according to the user’s preference.

In this conversion, the 3 dimensional numpy array files containing the soil grading data (surface and sub-surface) are also converted to 2-dimensional text files. Here the soil grading is used to calculate the corresponding d_{50} value and the 2-dimensional text files are generated using these d_{50} values.

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