LaharZ

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Contents

1 Introduction

LaharZ is an open source tool which can be used to model various flow hazards, most significantly lahars, based on a digital elevation model (DEM). From the DEM, LaharZ creates a stream file (which defines stream thalwegs), a flow direction file, an energy cone based on a height/length (H/L) ration, a set of initiation points (which can be edited) and a set of flows based on a range of volumes.

Stream and flow files created on any appropriate GIS system can be accepted instead of those generated and the resulting flows can similarly be displayed on any GIS system. However, LaharZ has been written and tested using QGIS and this guide will be based on QGIS[1].

The graphics produced can be displayed on any visualisation tool (including QGIS's 3D mapping tool). However, LaharZ has been written and tested using Paraview for 3D graphics and this guide will be based on Paraview[2].

The programme is based on Schilling, S.P., 1998 [1].

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[1] Version 3.34.10
[2] Version 5.13.0 RC1

2 Modelling Lahars

For full details, see Schilling, S.P., 1998 [1].

Material deposits occur around a volcano due to volcanic activity as ash fall, pyroclastic flows and earthquake induced debris flows. Deposited material will fall down steep slopes due to gravity and accumulate when the slope becomes less steep. Water, either from rainfall, melted glaciers or even collapsed volcanic lakes then mobilises the deposited material according to the topology in existing streams and gullies.

Figure 1 Material in a ravine ready to be mobilised

The point where material accumulates can be determined theoretically as the point where the ground surface meets a line from the apex of the volcano with an angle of angle $\tan^{-1}(H/L)$ against the horizontal, where H is the vertical height and L is the distance to the normal. H/L is known as the H/L ratio.

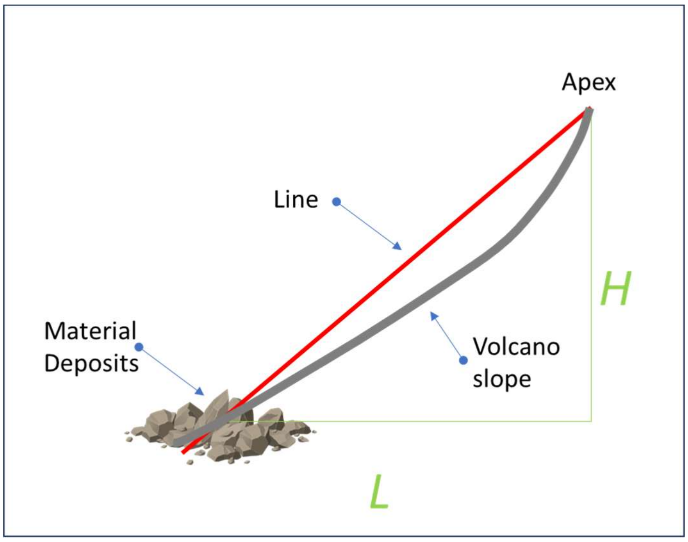

Figure 2 H/L Ratio

In three dimensions, the ‘line’ forms a cone around the apex of the volcano, known as the energy cone, and where the energy cone line meets the surface, this is the energy cone line.

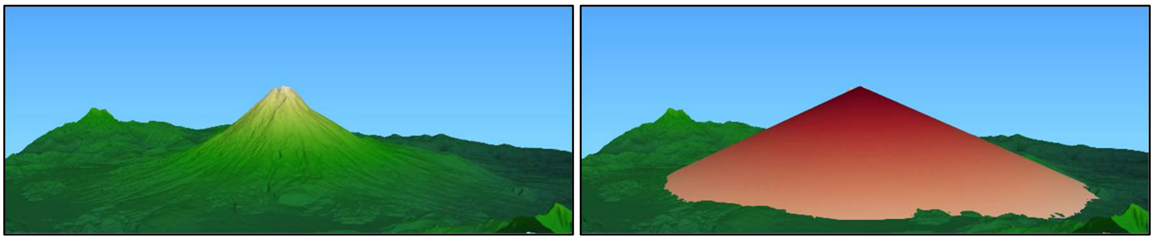

Figure 3 Volcanic cone; volcanic cone with energy cone; all in 3D

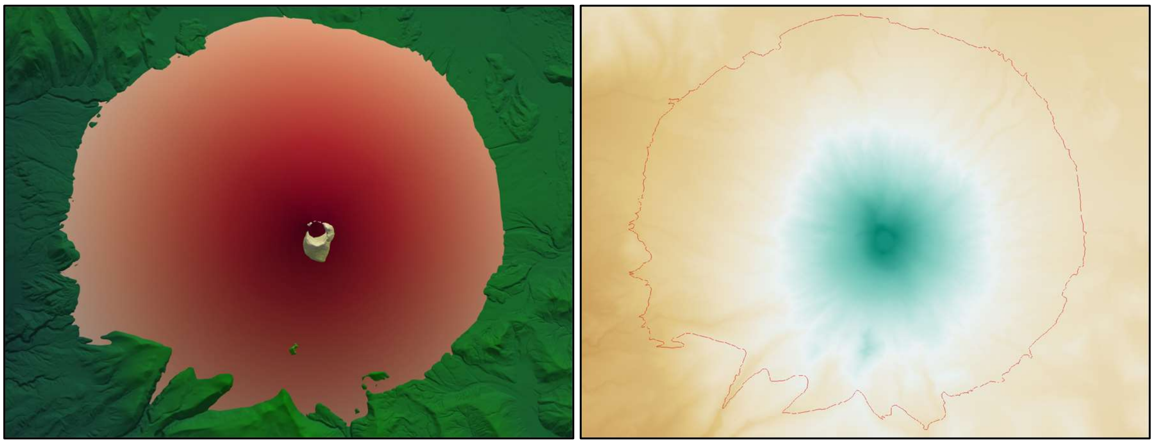

Figure 4 Vertical view of the energy cone (3D) and of the energy cone line (2D)

Water will flow down the sides of the volcano with the slope and topology, forming streams in gullies. Where these streams intersect with the energy cone line, a lahar can initiate and these points are known as Initiation Points.

The centre point of a stream, the thalweg, can be determined and hence, where the energy cone line meets the thalweg, the initiation points can be determined.

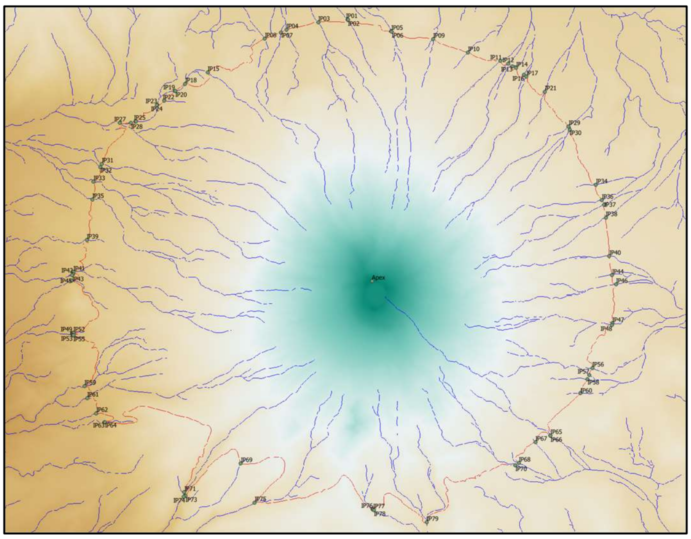

Figure 5 Energy cone line with streams and initiation points

With a classic conical volcano, this method for determining initiation points is a reasonable approach, but with volcanoes which have more complex topography or calderas, some manipulation is necessary. Adjustments include different H/L ratios; adjusting the threshold of what defines a stream; raising the height of the apex of the energy cone (eg to manage calderas); and moving or deleting the calculated initiation points.

Determining the volume of material mobilised is more difficult. Typically a set of different volumes are modelled to give a range of potential outcomes.

Lahars can be modelled through the following statistical relationships:

$$A = 0.05\, V^{\frac{2}{3}}$$

$$B = 200\, V^{\frac{2}{3}}$$

Where A is the cross sectional area of a lahar at any individual point on the flow, B is the planimetric area of the entire flow and V is the volume of material mobilised (m^3). As the cross sectional area at any point is related to the overall volume, we can calculate the inundation at any point. As the entire planimetric area is related to the overall volume, we can determine when the lahar will stop.

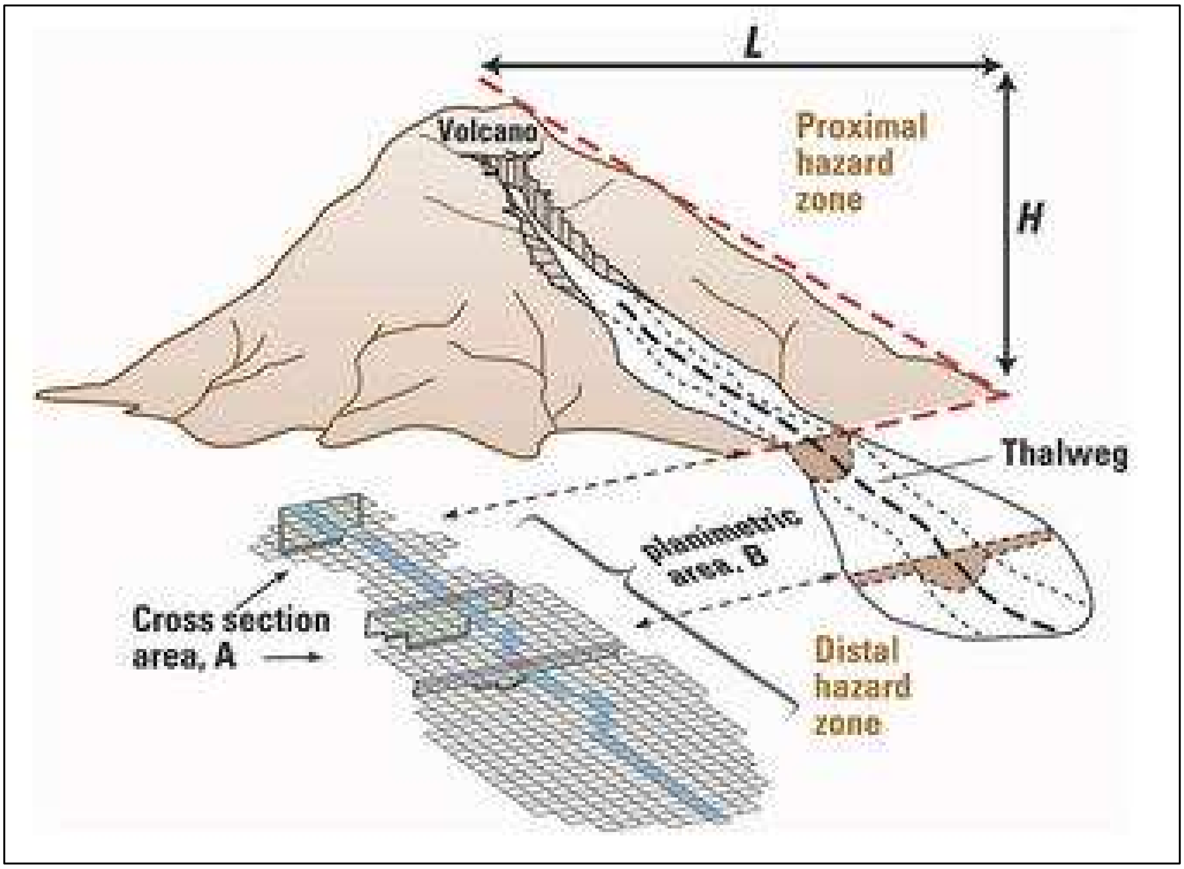

Figure 6 H/L Ratio. From Schilling, S.P., 1998 [1]

3 Setup

The current build runs on python[3] and is available through Conda.

3.1 Create an environment

Create a new environment and activate it with:

- **`conda create --name laharz-env-name`**
- **`conda activate laharz-env-name`**

Note that you can call the environment any name you please (ie not necessarily **`laharz-env-name`**).

3.2 Install Laharz

To install LaharZ from Conda use:

- **`conda install -c keith1815 -c conda-forge laharz`**

This should work for most users (and Apple iOS) but see below for alternatives if you have issues[4].

3.3 Running LaharZ

This will install LaharZ as a package in your environment. To run LaharZ use the command:

- **`laharz`**[5]

LaharZ will execute in your current working directory. To allow multiple scenarios to be managed easily, each scenario should be contained in a separate sub directory. On executing LaharZ, it will first prompt for a sub directory. It expects to find its input files in that directory and creates its output in the same directory.

In Linux you will have to use XMing to display the screens.

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[3] Python 3.12 and 3.13; probably earlier versions

[4] The installation should use the following channels, in order: **keith1815, conda-forge, defaults**
`Conda config --show channels` will show you the 'default' order of your channels
`Conda config --prepend channels conda-forge` will add conda-forge channels to the top of your list of channels
`Conda config --remove channels conda-forge` will remove conda-forge channels from your list of channels

So, in theory you could do:

```
Conda config --prepend channels conda-forge
Conda config --prepend channels keith1815
Conda install laharz
```

[5] Alternatively **`python -m laharz`** or **`python3 -m laharz`**

3.4 Alterative installation instructions

Installation using Conda is not always consistent. If the instructions above are not successful, an alternative to try is:

- **`conda install-c conda-forge -c keith1815 -c defaults laharz=2.1.4`**

Usually installation issues relate to Conda installing the wrong versions of dependent packages. To display the packages in your environment use:

- **`conda list`**

The main dependent packages (and version numbers) are:

- python =3.12
- numpy =1.26.4
- shapely =2.0.3
- geopandas =1.0.1
- gdal = 3.9.3
- rasterio =1.3.9
- pillow =10.2.0
- scipy =1.12.0
- richdem = 2.3.0

If you do not have these versions (at least) you may have issues. These version numbers are current; newer versions will probably be fine; recent older versions will probably be fine. There are other key packages, but they will be installed as dependencies of the above (eg GDAL).

Packages can be reinstalled follows:

- **`conda install <package name>`**

or by using:

- **`conda install <package name> -c conda-forge`**

to use the conda-forge channel. <package name> is the name of the package you wish to replace. See below for precise installation commands for each package.

Sometimes install doesn't replace the package and you may have to remove the package first with:

- **`conda remove <package name>`**

Conda remove and install may not work, or cause other issues within your environment. It may be better to create a new environment and install each package individually – ie:

- `conda install -c conda-forge shapely>=2.0.3`
- `conda install -c conda-forge geopandas>=1.0.1`
- `conda install -c conda-forge gdal>=3.9.3`
- `conda install -c conda-forge rasterio>=1.3.9`
- `conda install scipy>=1.12.0`
- `conda install numpy>=1.26.4`
- `conda install -c conda-forge pillow>=10.2.0`
- `conda install -c conda-forge richdem>=2.3.0`

Before trying:

- `conda install -c keith1815 laharz`

If you still have problems, you can manually download the source package from GitHub.

Create a new environment and download the dependent packages individually as above. Download the source code from: https://github.com/Keith1815/laharz/blob/main/src/laharz/laharz.py.

You can then run LaharZ using as follows:

- `python laharz.py`

Depending on your configuration you may have to use:

- `python3 laharz.py`

3.5 Other installation issues

3.5.1 GDAL Errors

Some users get this error message:

from rasterio._version import gdal_version, get_geos_version, get_proj_version
ImportError: DLL load failed while importing _version: The specified procedure could not be found.

This seems to relate to conflicts between rasterio and gdal. This can be caused by mixing pip and conda installations methods and it is advisable to use Conda alone. It is also possible that the issue is caused by the QGIS installation which also creates a version of GDAL which conflicts. See: https://github.com/conda-forge/rasterio-feedstock/issues/250

3.5.2 SSL Error

Some users get an error message relating to SSL:

Conda SSLError: OpenSSL appears to be unavailable on this machine. OpenSSL is required to download and install packages.

To resolve:

- Navigate to the location where you've installed anaconda to the directory ..\anaconda3\Library\bin. Eg. c:users\keith\anaconda3\library\bin]search
- Copy following dll files:
    - libcrypto-1_1-x64.dll
    - libssl-1_1-x64.dll
- paste to anaconda3\DLLs
- then restart your pc.

See: https://github.com/conda/conda/issues/11982

3.5.3 Pyproj issues

The PROJ database is based on the EPSG database. With each release, there is a good chance that there are database updates. If you have multiple versions of PROJ installed on your systems and the search path for the data directory becomes mixed up, you may see an error message like: SQLite error on SELECT. This is likely due to a version of PROJ attempting to use an incompatible database.

See Gotchas/FAQ - pyproj 3.6.1 documentation (pyproj4.github.io)

4 Operating Procedure

4.1 Create Sub Directory

From the directory you are running LaharZ, create a sub directory (eg *your-sub-directory*) and put your DEM file in the subdirectory.

4.2 Initiate LaharZ

On running LaharZ you will see the screen below.

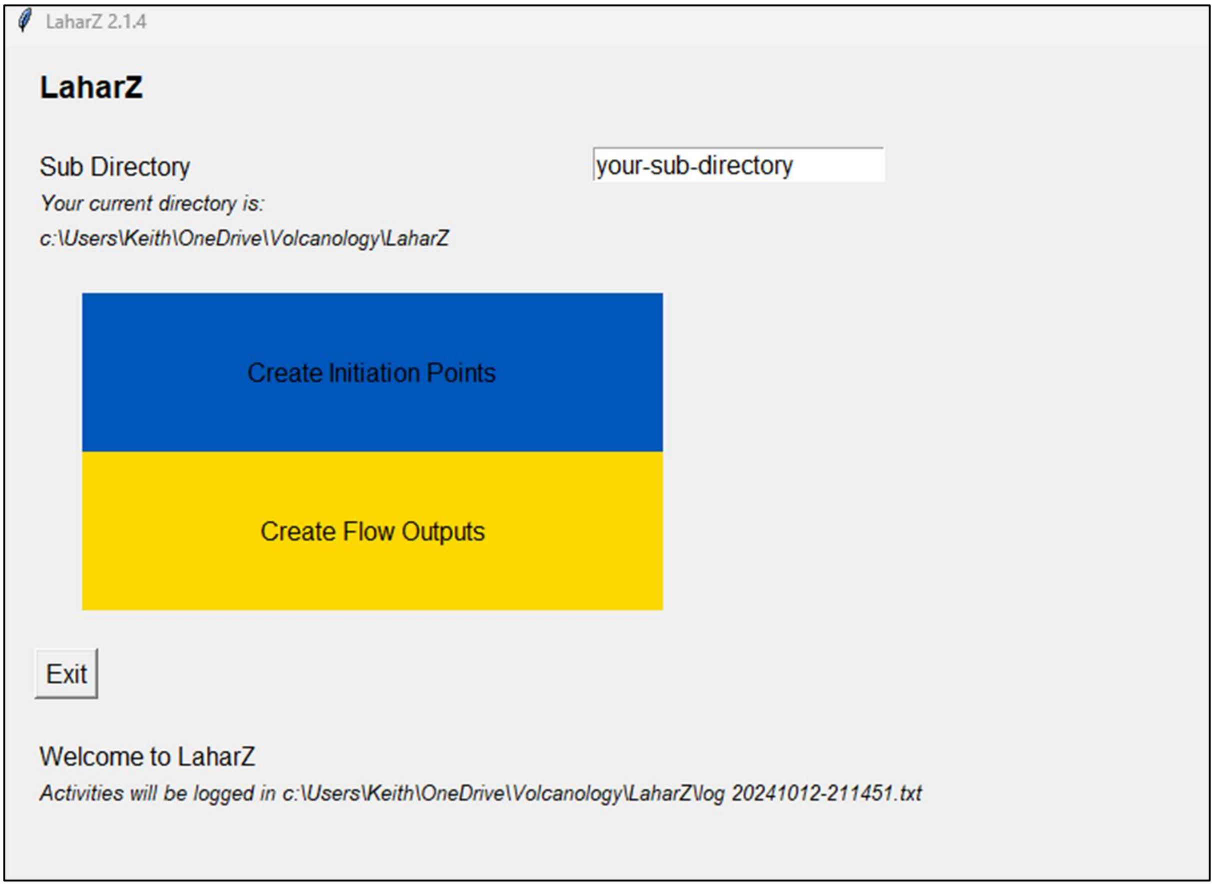


Figure 7 LaharZ: initial screen

1. Enter your subdirectory (eg *your-sub-directory*). The current working directory in which you are running LaharZ is shown below the entry field.
2. Choose either:
    a. Create Initiation Points (Blue Tile)
    b. Create Flow Outputs (Yellow Tile)

    Normally these are done in sequence, but one the initiation points have been created, it is possible to execute ‘Create Flow Outputs’ multiple times with different scenarios.

    Note that LaharZ logs all events while you use it in a text log file as indicated on the screen.

4.3 LaharZ – Create Initiation Points

The next stage is to create the initiation points. We shall start with the simplest method where LaharZ creates the stream and flow files. The initiation points will be generated by LaharZ as the points where the streams intersect the energy cone. The energy cone is an imaginary cone, usually placed on the apex of the volcano, where the gradient of the surface of the cone is referred to as the H/L Ratio (Height/Length Ratio, the gradient of a line segment).

We have to decide where the apex of the cone should be placed. LaharZ offers different methods to do this. Again, we shall start with the simplest method where the apex of the cone is placed on the surface at a specific longitude and latitude. After pressing the blue **Create Initiation Points** tile you will see the screen below.

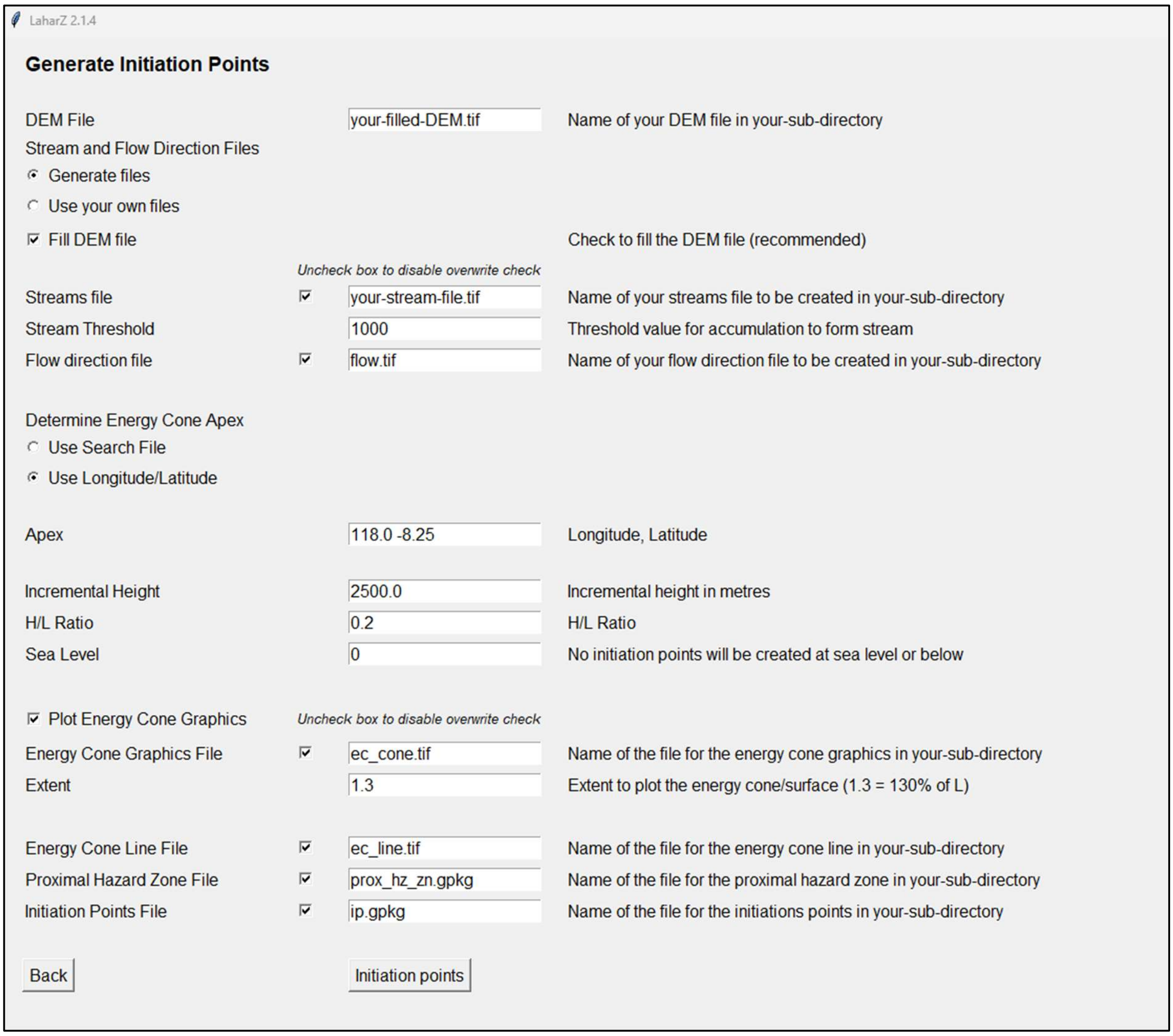


Figure 8 Generate Initiation points

3. Enter your **DEM File** which should be available in *your-sub-directory*.
4. Select **Generate files** so that LaharZ will create the stream and flow direction files

5. Check Fill DEM file. If selected, this fills the DEM so that streams are continuous. This should normally be selected.
6. Enter a name for your **Streams File** which will be created in *your-sub-directory*.
7. Enter a value for the **Streams Threshold**. This is used the determine if enough points flow into a point to make it a stream. A larger number will have less detailed streams; a smaller number will have more detail
8. Enter a name for your **Flow Direction File** which will be created in *your-sub-directory*.

The stream and flow direction files are created using Rich DEM [4]. If selected, the DEM is filled using epsilon filling. Flows (and therefore streams) are calculated using a convergent, deterministic flow method (D8).

9. Choose how to **Determine** the **Energy Cone Apex**. In this case, chose **Use Longitude/Latitude.**
10. Enter the **Apex** coordinates (longitude, latitude).
11. Enter an **Incremental Height.** If working with a caldera, the apex of the energy will have to be raised above the height of the surface at the 'apex' of the volcano.
12. Enter the **H/L Ratio.** This is limited to values between 0.1 and 0.3. See section 7 if you need to use values outside this range.
13. Enter the **Sea Level.** No initiation points will be created at or below this height
14. If you wish to plot **Energy Cone Graphics,** select this option. This will create a raster tif file of the energy cone.
15. Enter the **Energy Cone Graphics File**. This is the name of the tif file which will be created in *your-sub-directory*. Uncheck the box to disable the dialogue box asking for confirmation before overwriting an existing file.
16. Enter the **Extent** of the energy cone. This limits the radius of the energy cone as a proport of the maximum value of L.
17. Enter the **Energy Cone Line File**. If entered, this will create a raster tif file of the energy cone line (ie the line where the energy cone meets the surface) in *your-sub-directory*. Uncheck the box to disable the dialogue box asking for confirmation before overwriting an existing file
18. Enter the **Proximal Hazard Zone File**. If entered, this will create a vector file (.gpkg) of the proximal hazard zone(ie the area enclosed by the energy cone line) in *your-sub-directory*. Uncheck the box to disable the dialogue box asking for confirmation before overwriting an existing file
19. Enter the **Initiation Points File.** This will create a geopackage file (.gpkg) with the initiation points which can be edited in QGIS. Uncheck the box to disable the dialogue box asking for confirmation before overwriting an existing file.
20. Press Initiation Points to continue

An example of initiation points and the energy cone line is shown below.

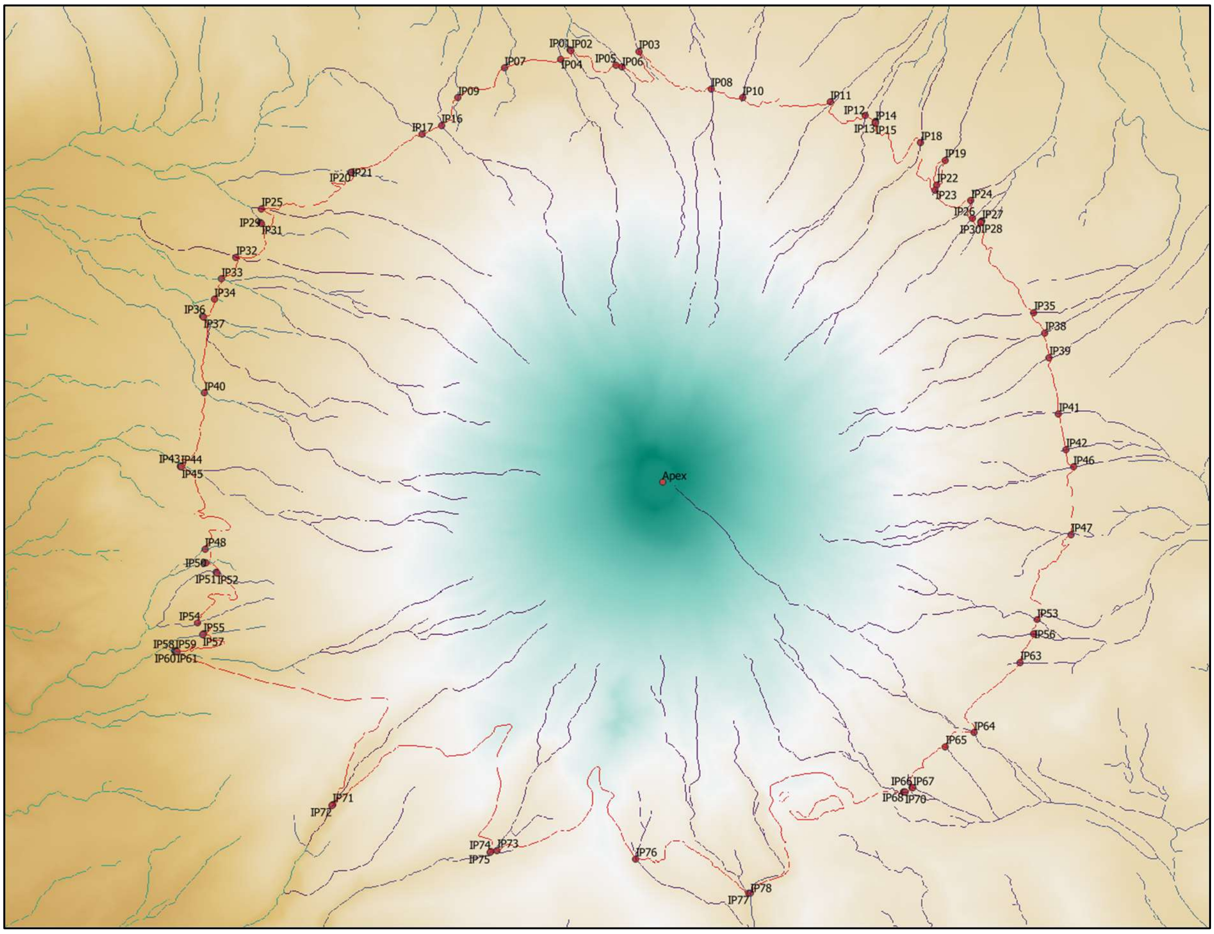


Figure 9 Initiation Points and Energy Cone Line

Instead of using LaharZ to generate your stream and flow direction files, you can use your own files (see 0 If you selected a flow output vector file, LaharZ will create a geopackage file with a layer for each volume/initiation point combination. See section 4.6 Working with the Flow Vector File.

Using QGIS to create stream and flow files).

Additionally LaharZ can create a Search File which can be used to determine the apex of the energy cone. The search file contains a Search Area and a Centre Point. You have the choice of using the highest point in your Search Area, the centre of your Search Area or the Centre Point as the Apex of the Energy Cone. The Search File, containing the Search Area and the Centre Point, is created as follows:

21. Choose how to **Determine the Energy Cone Apex**. In this case, chose **Use Search File** which will display these options:

Figure 10 Search file options

Enter the **Search File** and press **New Search File**. Uncheck the box to disable the dialogue box asking for confirmation before overwriting an existing file. LaharZ then displays:

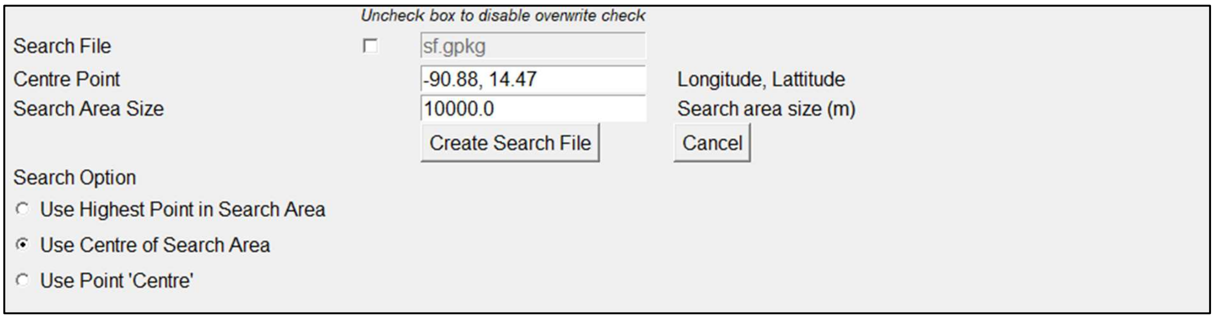


Figure 11 Creating a new search file

22. Enter the **Centre Point** coordinates (longitude, latitude) – this is the centre of the search area.
23. Enter the **Search Area Size**. The search area is a square with sides which have the length specified.
24. Press **Create Search File** to create the search file. This will create a geopackage file (.gpkg) with the search area and the centre point which can be edited in QGIS (see section 0.5.2 Working with points in a geopackage file). An example of the search file is shown below:

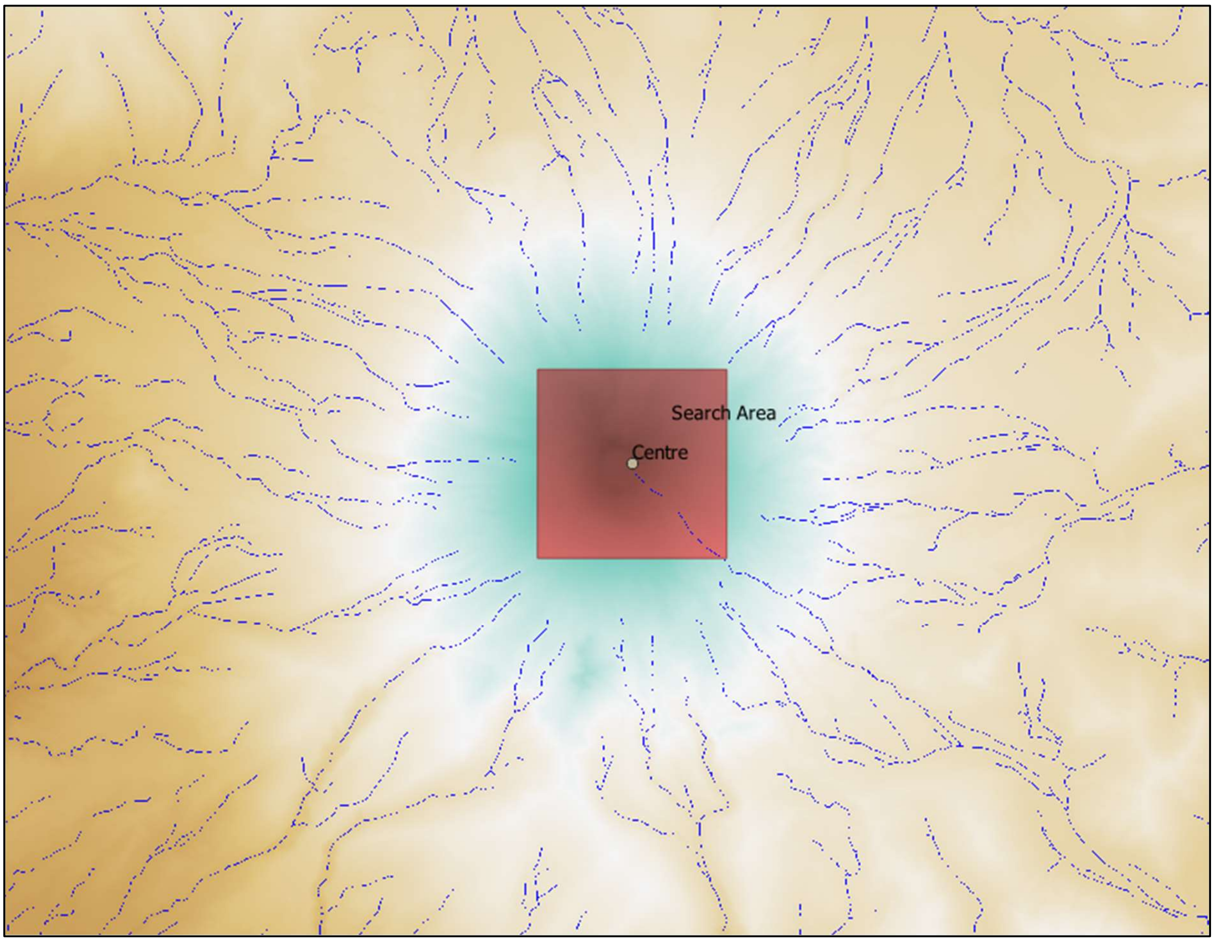


Figure 12 Search file in QGIS

25. Choose one of the three **Search Options:**
    a. **Use Highest Point in the Search Area** – useful when working with a conical volcano
    b. **Use Centre of the Search Area** – useful when working with a caldera, where the search area can be edited to match the caldera rim (see below). Note that the 'centre' is actually the centre of a rectangular bounding box of the search area polygon
    c. **Use Point 'Centre'** –useful when you want to use a specific point and edit it as such in the search file

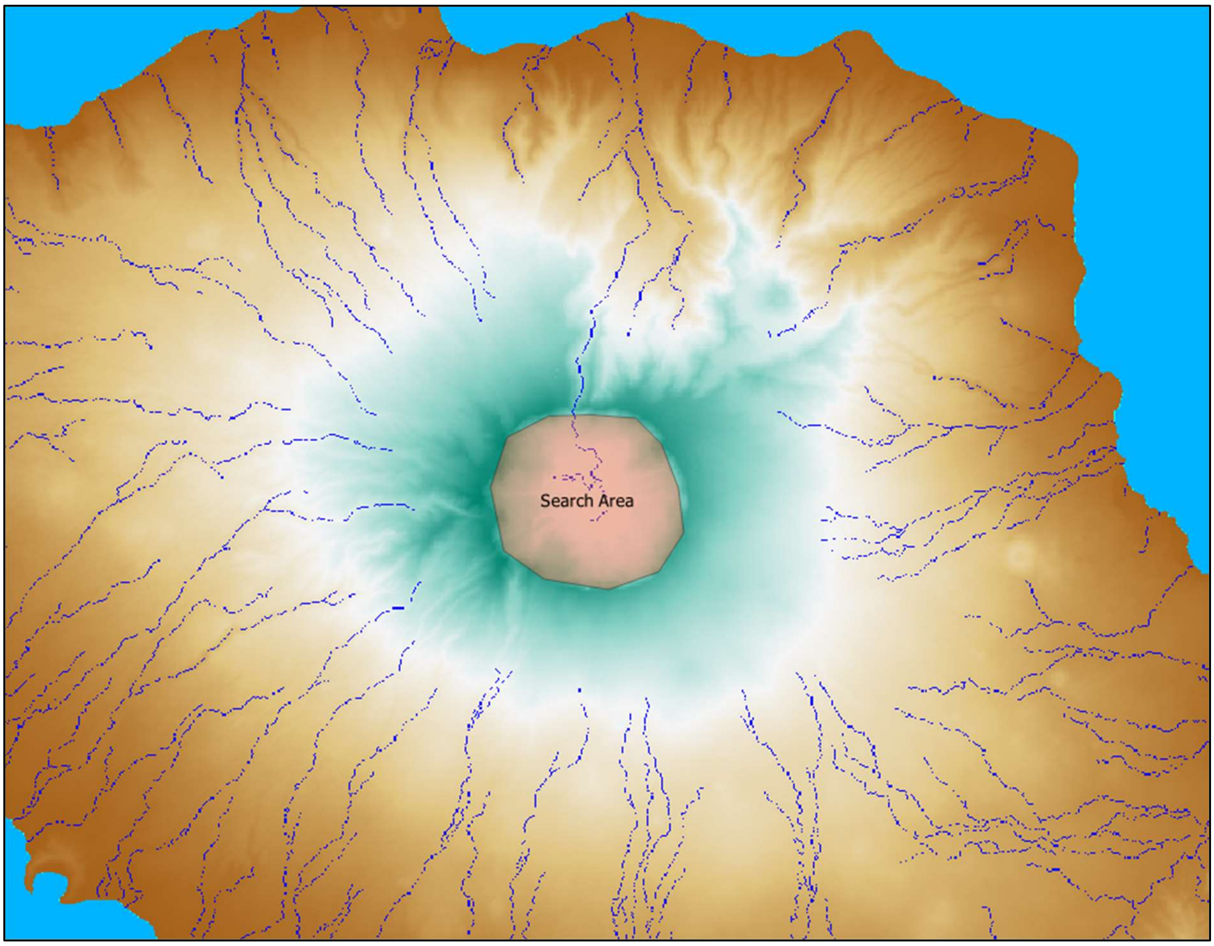


Figure 13 Search area edited to fit rim of a caldera

26. All other options are as stated previously.

The use of the energy cone to determine the initiation points is, of course, a theoretical approach. In many cases, practical experience will determine the initiation points. LaharZ can support by proposing a set of initiation points which then can be edited to reflect real life experience of where flows originate.

4.4 LaharZ – Create Flow Outputs

The next stage is to create the flow outputs. These will be generated by LaharZ from a set of volumes and the previously defined initiation points. It is possible to use different flow scenarios - eg Lahars, Debris flows and Pyroclastic flows. After pressing the yellow **Create Flow Outputs** tile you will see the screen below:

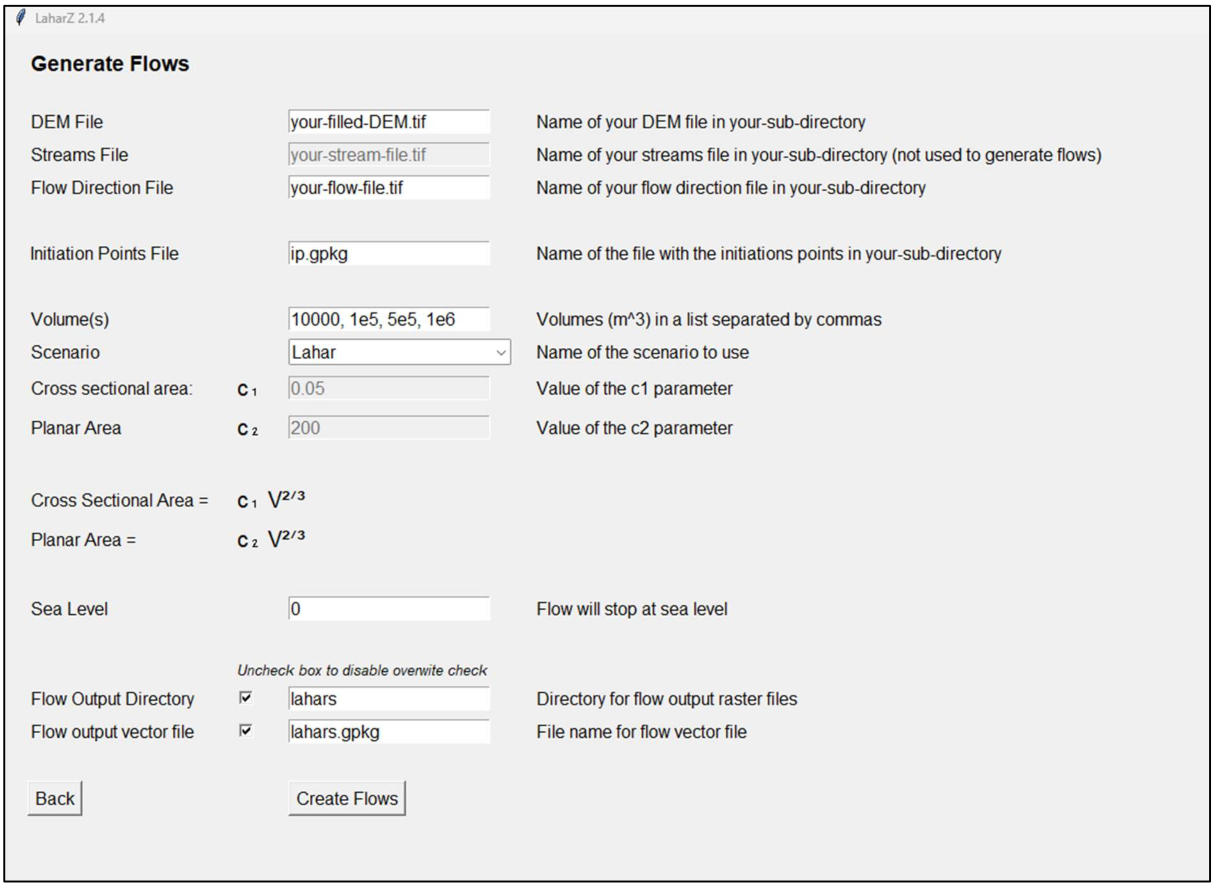


Figure 14 Generate flows

27. Enter your **DEM File**. This should be the same DEM you entered in step 3 which should be available in *your-sub-directory*. This will default to the DEM you used to create the initiation points.
28. The **Streams File** you used the create the initiation points is shown, but this is not used to create the flows, so this is for reference only and is greyed out. It should be the streams file you created in step 6 which should be available in *your-sub-directory*.

Enter your **Flow Direction File**. This should be the flow direction file you created in step 8 which should be available in *your-sub-directory*. If you created your own flow direction file (see 0 If you selected a flow output vector file, LaharZ will create a geopackage file with a layer for each volume/initiation point combination. See section 4.6 Working with the Flow Vector File.

29. Using QGIS to create stream and flow files) then enter it here.

30. Enter your **Initiation Points File**. This should be the initiation points you defined in step 19, and may have subsequently edited, which should be available in *your-sub-directory*. This will default to the initiation points file you used to create the initiation points.
31. Enter the **Volume(s)** for the flow. This is in m^3 and can consist of multiple values separated by commas. Scientific notation is accepted (eg 1000 can be represented by 1e3).
32. Enter the **Scenario** you wish to use. Select from LaharZ, Debris, Pyroclastic or Custom. See section 370 if you wish to have other options.
33. The **Cross Sectional Area** proportionality co-efficient, c1, that relates to the scenario chosen is displayed. This is dependent on the scenario: it cannot be changed and is greyed out for standard options; if you select *Custom* as your scenario, the value can be edited. Standard values are from Schilling, S.P., 1998 [1], Griswold, J.P., and Iverson, R.M., 2008 [2] and Widiwijayanti, C., Voight, B., Hidayat, D. et al, 2009 [3]
34. The **Planar Area** proportionality co-efficient, c2, that relates to the scenario chosen is displayed. This is dependent on the scenario: it cannot be changed and is greyed out for standard options; if you select *Custom* as your scenario, the value can be edited.
35. The governing equations for the **Cross Sectional Area** and the **Planar Area** are displayed for information.
36. Enter the **Sea Level**. The flows will automatically stop at sea level. Normally this would be set to zero but may have other applications eg flows running into lakes.
37. Enter the **Flow Output Directory**. This is where the raster flow output files will be created. If you chose to overwrite a current directory, all files in that directory will be deleted.
38. Enter the **Flow Output Vector File**. This is a file containing all the flows as vectors (.gkg file)

If you selected a Flow Output Directory (rasters), LaharZ will now create the following files in your directory:

- A tif file of a flow for each combination of initiation point and volume named as follows:
  <initiation point name>-V<volume>.tif – eg IP01-V1-00e3.tif. See below

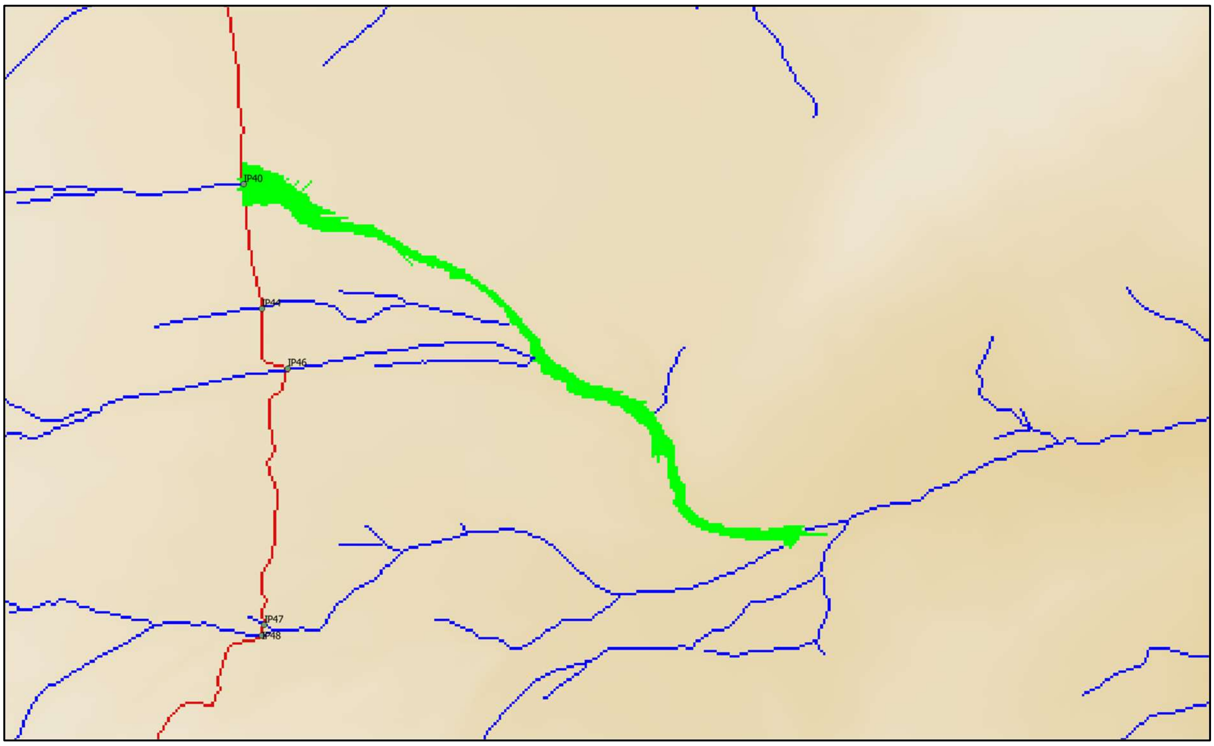


Figure 15 A single flow file

- A tif file for each volume which has the flows for every initiation point, where the raster pixels indicating the flow are numbered in sequence, which is named as follows: V<volume>.tif – eg V1-00e3.tif. This is useful to see, for a particular volume, all the flows and which initiation point they originate from

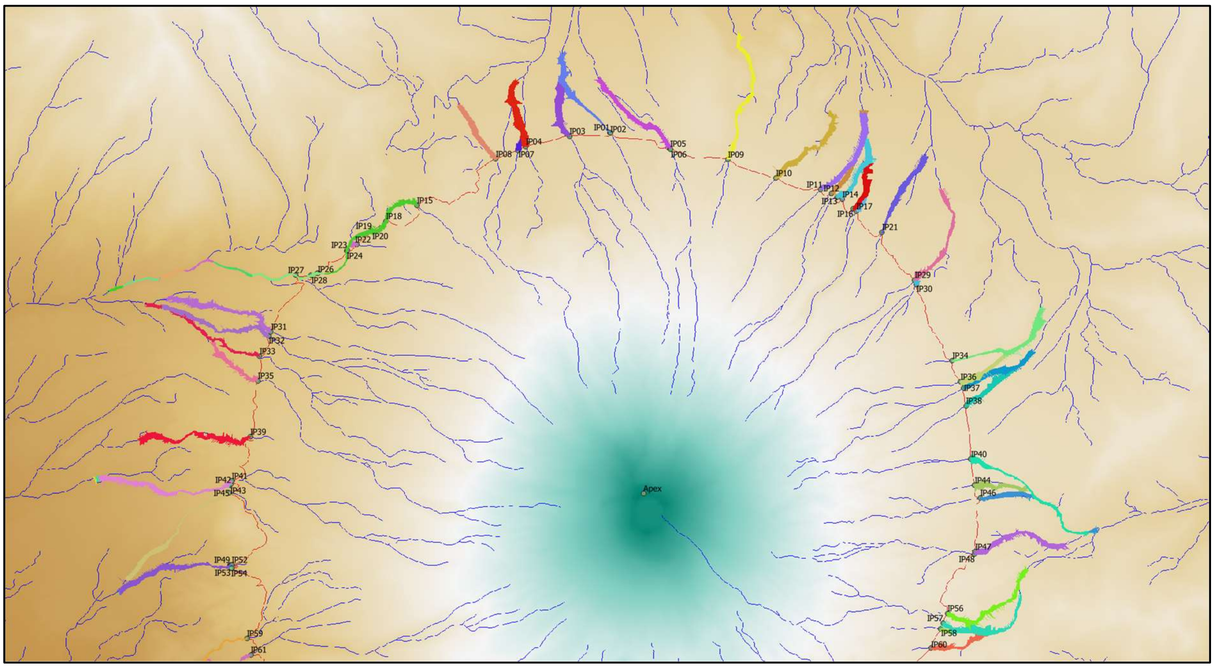


Figure 16 All flows for a particular volume

- A tif file for all volumes and initiation points, where the raster pixels indicating the flow are numbered in sequence for each volume, which is named Total.tif. This is useful to create an overall flow hazard map

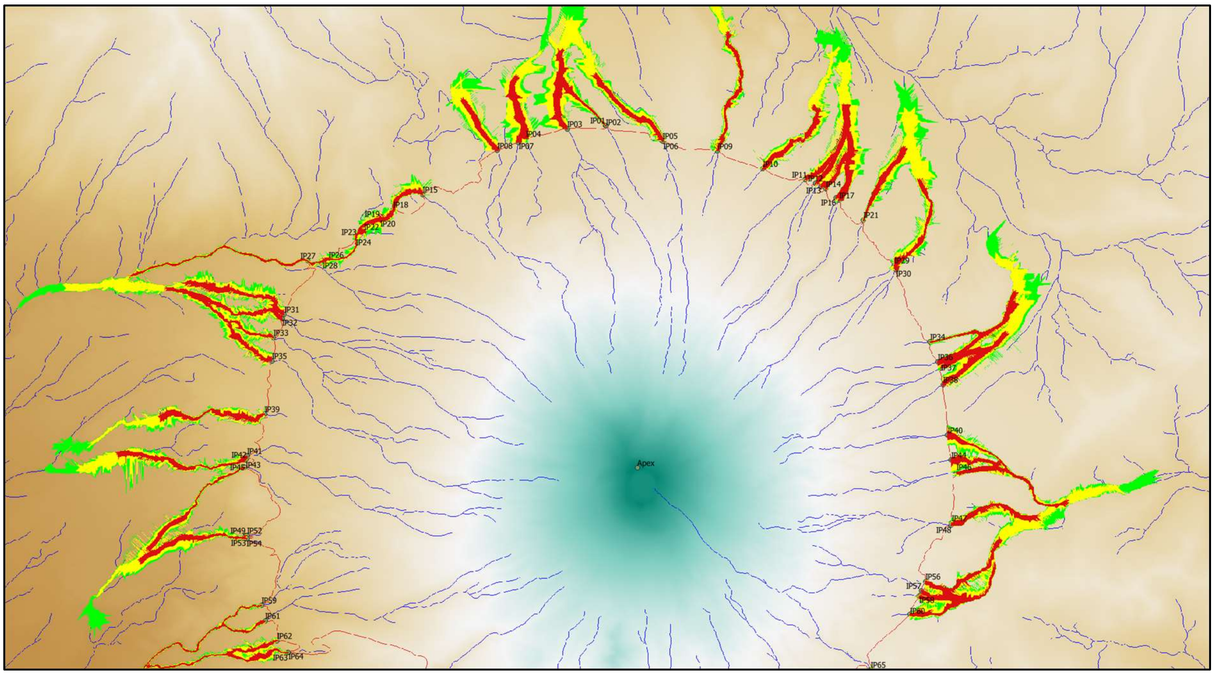


Figure 17 All flows for all volumes

If you selected a flow output vector file, LaharZ will create a geopackage file with a layer for each volume/initiation point combination. See section 4.6 Working with the Flow Vector File.

4.5 Using QGIS to create stream and flow files

You can also use any other stream and flow direction files. This section will detail how to create stream and flow direction files using QGIS.

39. Open QGIS and load the GRASS plug in (**Plug Ins/Manage and Install Plugins**).
    GRASS (Geographic Resources Analysis Support System) is an open source GIS with a wide array of useful GIS functions. These functions will be available in **Processing/Toolbox.**
40. Load a suitable DEM into QGIS (**Layer/Data Source Manager/Raster**).
41. If the DEM is large, use reduce the size of the file as larger files can take a long time to process and the outputs could be unnecessarily large. In the processing toolbox, use **GDAL/Raster/Extraction/Clip Raster by Extent** to reduce the size of the DEM file. This guide assumes GDAL was installed with QGIS.
42. Fill any holes in the raster file by using the GRASS tool r.fillnulls. In the processing toolbox, use **GRASS/Raster/r.fillnulls**. Use the default options with the exception of:
    a. Input raster layer to fill – use your DEM layer
    b. Interpolation method to use – select *bilinear*
    c. Filled – save to a file name of your choice – eg *your-filled-DEM.tif*.

43. Create the streams by using the GRASS stream extract tool. In the processing toolbox, use **GRASS/Raster/r.stream.extract**. Use the default options except for:
    a. Input map: elevation map – use your filled DEM layer eg *your-filled-DEM.tif*
    b. Minimum flow accumulation for streams – experiment with this value. A larger number gives less stream resolution (and hence less initiation points); a smaller one gives more stream detail (and hence more initiation points). Try *3000* to begin with
    c. Unique stream ids (raster) – save to a file – eg *your-stream-file.tif*
    d. Unique stream ids (vector) – skip output
    e. Flow Direction – save to a file – eg *your-flow-file.tif*.

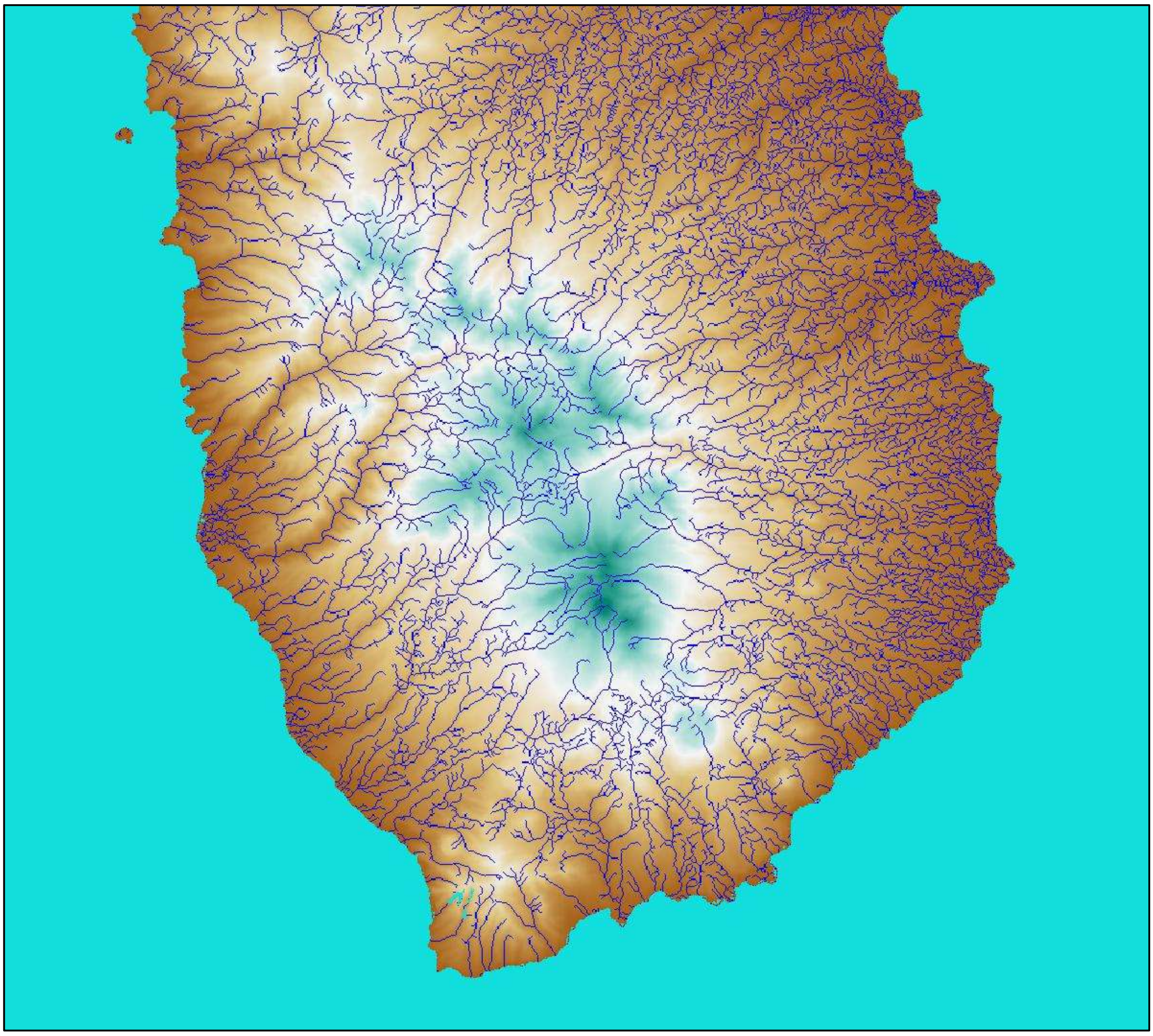


Figure 18 Filled DEM with streams

44. Optional: The stream raster numbers the streams (ie the pixels in each stream segment have a different number). When visualized, this results in multiple colours for the stream segments. To have just one value, and hence one colour, we can set all the pixels that have a stream number to 1. Select **Raster/Raster Calculator** and:
    a. Output layer set to a raster name of your choice (eg *Your-simplestreams.tif*)

b. An expressions such as ("Stream@1">0)*1 + ("Stream@1"<=0)*0 :ie where the stream value is greater than 0, set it to 1; where the stream value is less than or equal to zero, set it to zero.

45. Initiate LaharZ as in section 4.2
46. Pressing the blue **Create Initiation Points** tile
47. Select **Use your own files** so that you can enter the files. You will see the screen below

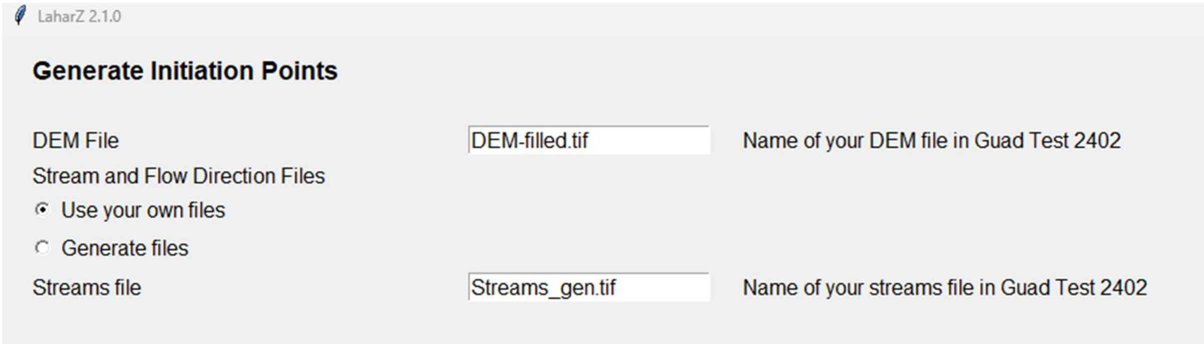


Figure 19 Generate initiation points

48. Enter a name for your **Streams File** which has been created in *your-sub-directory*. Note that you do not get asked for a Flow Direction file as it is not used to create the initiation points. You will be asked for it when you go to create the flows in section 4.4
49. Continue as per section 4.3

4.6 Working with the Flow Vector File in QGIS

LaharZ can create a geopackage file with a layer for each volume/initiation point combination which contains a polygon of the flow. Manipulating the layers is a little clumsy and uses a lot of computing power. It might be worth considering using the rasters instead.

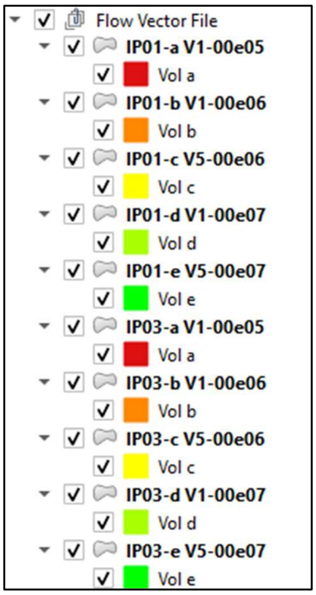
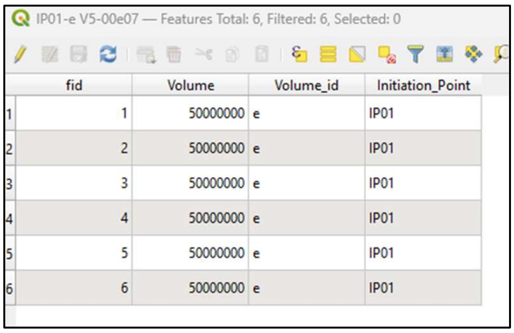


Figure 20 Flow vector file in the Layers Panel of QGIS

The layers are named: <initiation point name>-<volume_id> V<volume> – eg IP01-a V1-00e3. The volume_id is a letter corresponding to the volumes in order (ie ‘a’, ‘b’, ‘c’ etc.). Each polygon is named ‘Vol <volume_id> (see Figure 20).


IP01-e V5-00e07 — Features Total: 6, Filtered: 6, Selected: 0

	fid	Volume	Volume_id	Initiation_Point
1	1	50000000	e	IP01
2	2	50000000	e	IP01
3	3	50000000	e	IP01
4	4	50000000	e	IP01
5	5	50000000	e	IP01
6	6	50000000	e	IP01

Figure 21 Attribute table in QGIS

Each polygon can have multiple features (as pixels which are only diagonally attached are a separate feature within the polygon. Each feature has the attributes (as shown in Figure 21)

- fid (feature id) – a system generated sequential number
- Volume (the volume of the flow)
- Volume_id (a sequential letter designating the flow in order of size, ie ‘a’, ‘b’, ‘c’ etc.)
- Initiation_Point (the intitation point)

The volume_id is an important feature which forces QGIS to load the layers in the appropriate volume order to show the smaller flows above the larger flows.

It is useful to apply colour formatting to all flows of a particular volume. This is tedious to do manually but can be done more easily by setting rules as follows:

- Select the layer then menu options **Layer/Layer Properties** and **Symbology**

- Chose *Rule based* and create appropriate rules using the volume_id (see Figure 22 and Figure 23)
- Using **Layer/Copy Style** and **Layer/Paste Style** copy and paste the rule based style to all the required layers

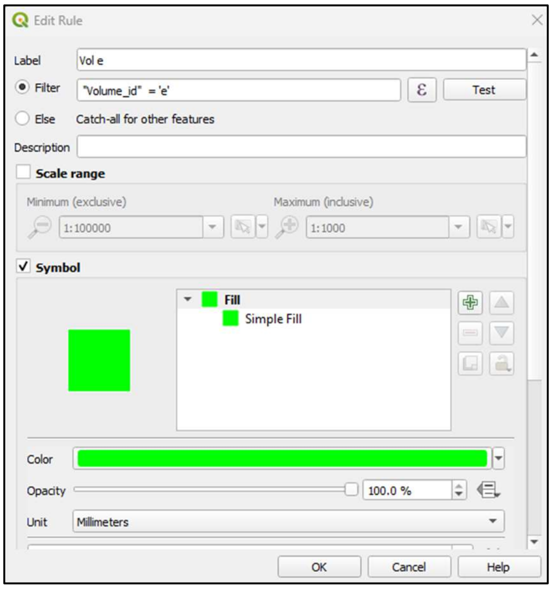


Figure 22 Creating formatting rules

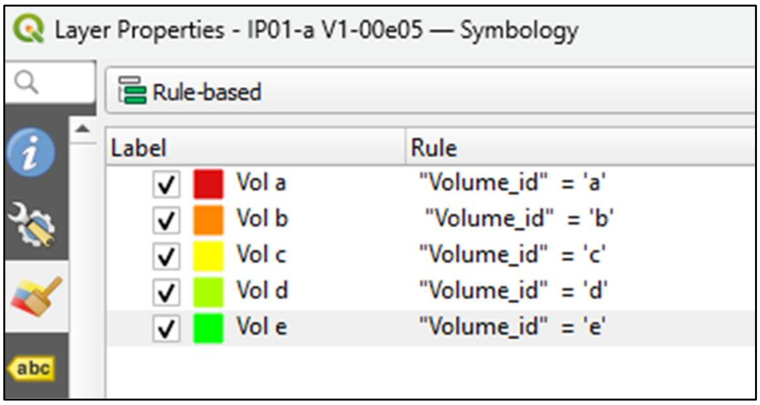


Figure 23 Rule based formatting

Filtering the layers (eg show only a particular volume) cannot be done in native QGIS but is possible with the plug in **FilterLayersAtOnce.**

To install the plugin, choose **Plugins/Manage and Install Plugins** and search for **FilterLayersAtOnce.**

To filter the layers:

- Select all the layers you wish to filter
- Select the **FilterLayersAtOnce** Tool 
- Enter the filter details as per Figure 24 and press **Filter Selected Layers**

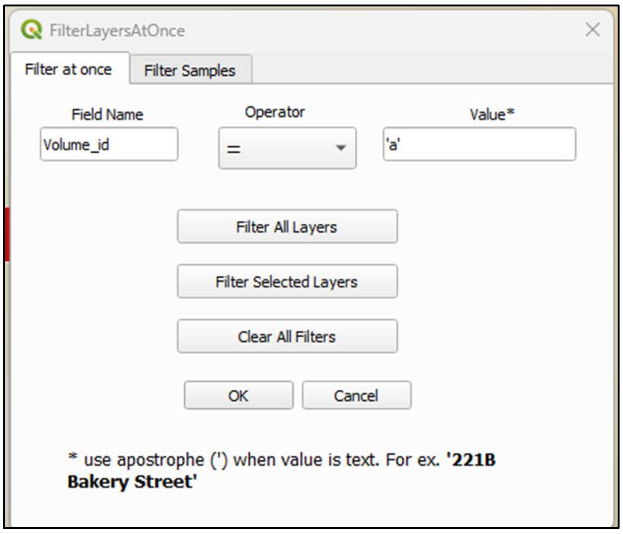


Figure 24 Filter Criteria

4.7 Parameters

LaharZ saves the values entered in a file **parameters.pickle** in *your-sub-directory.* This file can be deleted to restore defaults or copied to another sub directory if you wish to reuse the parameters.

4.8 Rectangular pixels

LaharZ will process DEM's with rectangular pixels (for example, STRM data for latitudes beyond 50°).

If you create your own files using QGIS, **GRASS/Raster/r.stream.extract** will create a .tif file with square pixels, with the square size set to the larger of the rectangular sides. When LaharZ processes a DEM file and a Streams file with different sized pixels, LaharZ will recast the DEM file (using GDAL Translate) to the pixel size of the Streams file. All further output will match the pixel size of the Streams file. The entered DEM file is not updated but the recast DEM will be available with the suffix '_c.tif'.

5 Editing files in QGIS

LaharZ creates two files (both geopackage files - .gpkg) where it is appropriate to edit in QGIS – the search file and the initiation points file. The search file consists of a search area (a polygon) and a centre point; the initiation points file just has a series of points for the initiation points and an apex point, showing the apex of the energy cone.

The additional files created by LaharZ are raster files (normally .tif files) which are not intended to be edited, but to be displayed only.

Hence this section will show how to display raster files in QGIS, open and label the geopackage files, edit and save points & polygons in the geopackage files.

QGIS can have issues if the files it is displaying are then updated in LaharZ. Restarting QGIS usually resolves any issues.

There are many ways to perform these operations. This guide tries to present the simplest methods, but better approaches probably exist. Please let me know.

5.1 Displaying raster files

Add a raster file as a layer in QGIS by **Layer/Data Source Manager/Raster**

The raster files created by LaharZ all have zero (nan) as the background value and integer values as follows:

- Energy cone line – pixels set to 1 for the pixels on the energy cone line
- Individual flow files – pixels set to 1 for pixels on the flow
- Volume flow files – pixels set to a sequence (1..n) corresponding to the number of initiation points
- Total flow file – pixels set to a sequence (1..n) corresponding to the number of volumes processed.

To display the rasters in QGIS, select the layer then menu options **Layer/Layer Properties** and **Symbology** . Then:

- For **Render Type** select *Paletted/Unique Values*
- Press **Classify**
- For each numeric value in the raster set the appropriate colour by right clicking on the colour associated with each value.

To display the DEM raster in QGIS, select the layer then menu options **Layer/Layer Properties** and **Symbology** . Then:

- For **Render Type** select *SingleBand pseudocolor*
- Choose an appropriate **Color Ramp**
- Set **Mode** to *Equal Interval*

- Set **Classes** to an appropriate value – eg *32*
- Press **Classify.**

If you wish to create a masking layer for the sea use menu option **Raster/Raster Calculator.** Then:

- In **Raster Bands**, select *your-dem-layer*
- Enter an expression like *("your-dem-layer@1"<=0) *1 + ("your-dem-layer@1">0) *0*
- Save as a .tif file and add it to your QGIS project. The pixels for the sea (ie height is <= 0) will be set to 1, the remaining pixels (land, ie height >0) will be set to zero.

5.2 Working with points in a geopackage file

Points are created in the search file (the centre of the search area, which can be used to define the apex of the energy cone) and in the initiation points file.

Add a geopackage file as a layer in QGIS by menu options **Layer/Data Source Manager/Vector.** (It is also possible to add the file as a geopackage layer, rather than a vector, but adding as a vector seems the most straightforward.)

To display the labels associated with the points, select the layer then menu options **Layer/Layer Properties.** Then:

- Select **Labels**
- In the first field select *Single Labels* from the drop down
- In the **Value** field select *index*.

To change the symbols and colours used for each point in QGIS, select the layer then menu options **Layer/Layer Properties** and **Symbology** :

- For **Render Type** select *Paletted/Unique Values*
- Press **Classify**
- For each numeric value in the raster set the appropriate colour by right clicking on the colour associated with each value.

To edit the position of the points, select the layer then menu options **Layer/Toggle Editing**. Then choose the **Vertex Tool** from the toolbar :

- To delete points, click and drag to select, then press delete. This will not delete them from the attribute table
- To move points, double click and drag
- To change the name of a point, select menu options **Layer/Open Attribute Table**. This will display a table of all the label names (in field index) which can be click on and edited directly

- To add points, select the **Add Point Feature** tool , and click on the map. You will also be able to add the label for the new point (in field **index**)
- To delete points using the **Vertex Tool**, click and drag to select, then press delete. This will not delete them from the attribute table
- To fully delete points, use the **Select Features Tool** to select, then press the **Delete** button . Points can also be deleted from the Attribute Table.

Save your edits by pressing the **Save Layer Edits** button .

In some cases, you may wish to have multiple executions to determine initiation points with different parameters and have multiple initiation point geopackages. These can be merged in a single file by selecting menu options **Vector/Data Management Tools/Merge Vector Layers**.

5.3 Working with polygons

Polygons are created in the search file (ie the search area) which can be used to define an area, the centre of which, or highest point within it, can be used to define the apex of the energy cone.

Add a geopackage file as a layer in QGIS by menu options **Layer/Data Source Manager/Vector.** When adding the search file, both the search area polygon and the centre point are added as separate layers in a single operation. The centre point can be edited as above (5.2 Working with points in a geopackage file).

To display the labels associated with the polygon, select the layer then menu options **Layer/Layer Properties.** Then:

- Select **Labels**
- In the first field select **Single Labels** from the drop down
- In the **Value** field select index

To change the symbols and colours used for the polygon in QGIS, select the layer then menu options **Layer/Layer Properties** and **Symbology** . It can be useful to change the opacity of the search area to see the DEM beneath it.

To edit the polygon, select the layer then menu options **Layer/Toggle Editing**. Then choose the **Vertex Tool** from the toolbar . Each vertex of the polygon will have a point highlighted; if you hover the cursor on the midpoint of any side of the polygon a new point will appear (as a cross) which can also be edited.

- To move existing points (on the vertices) double click and drag
- To add new points, hover the cursor on the midpoint of a line. A cross will appear which can be moved by double clicking to select it and a further click on the location where you want to position it
- To delete points, double click and hold on a point, then press delete

Save your edits by pressing the **Save Layer Edits** button.

Note that LaharZ expects the search area to be labelled ‘Search Area’ and the centre point to be labelled ‘Centre’. It won’t be able to determine the apex of the energy cone if these labels are changed.

6 Displaying graphics in Paraview

In Paraview, it is possible to create 3D visualisations any of the input and output files of Paraview. This section will outline how to create a 3D model of the surface, energy cone and flow files. The instructions are reasonably detailed but some familiarisation with Paraview is assumed.

6.1 Displaying the Surface

In Paraview, to load the DEM:

- Select menu options **File/Open** and open your filled DEM file (*your-filled-DEM.tif*). If prompted choose the GDAL Raster Reader rather than the TIFF series reader. This will display a 2D overview of the surface

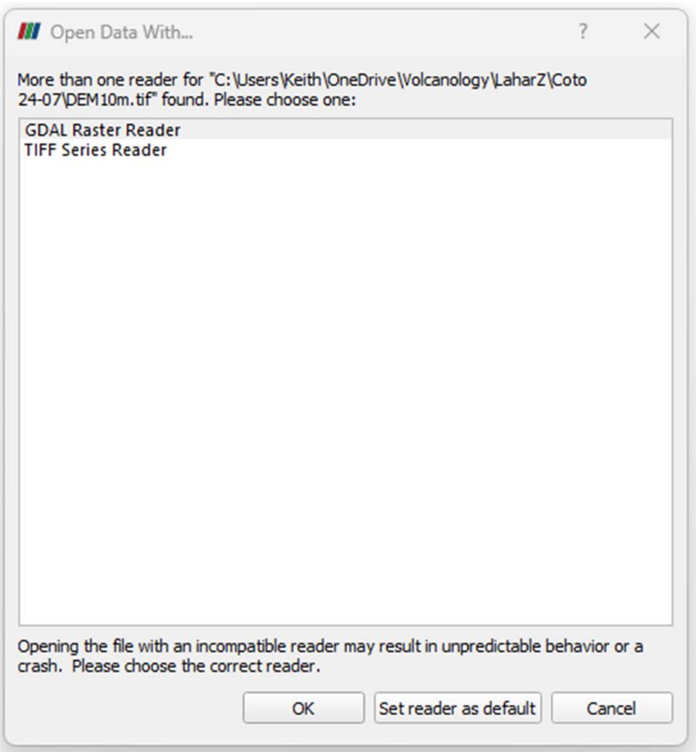


Figure 25 Selecting the reader in Paraview

- If you have an error Unhandled Bit per sample 64 then you are working with a 64 bit floating point file whereas Paraview will only handle 32 bit files. To convert, open the file in QGIS and in the processing toolbox, use **GDAL/Raster Conversion/Translate** to convert the file to a 32 bit floating point file

- If you have created your own filled DEM (*your-filled-DEM.tif*) file using the GRASS tool r.fullnulls, your filled DEM file can be a slightly different size to the original DEM file. Using the original DEM file can then cause issues in Paraview[6] as all the LaharZ output files are based on your filled DEM file (*your-filled-DEM.tif*). Its better to use your your filled DEM (*your-filled-DEM.tif*) file to avoid these issues
- Use the Convert Cell Data to Point Data filter to convert the cell data to point data. Select menu options **Filter/Alphabetical/Convert Cell Data to Point Data**. If the filters are greyed out, you may need to press **Apply** (on the LHS) while selecting *your-filled-DEM* in the pipeline browser
- Create a 3D representation of the surface by selecting menu options **Filter/Alphabetical/Warp by Scalar**. In the Properties tab, set an appropriate **Scale Factor**:

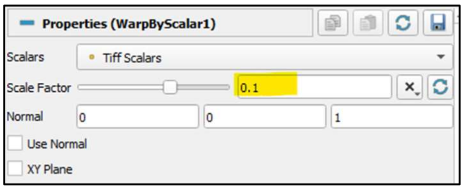


Figure 26 Setting the Warp by Scalar Scale in Paraview

- The image should now be visible in 3D and can be manipulated on the screen. You may need to set the interaction mode to 3D (from 2D) to see the image in 3

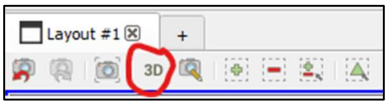


Figure 27 Changing to 3D view in Paraview

To colour the DEM:

- In the Properties tab, select the **Use Separate Color Map** button. This allows each component of the display to have their own colour settings

Figure 28 Using separate colour maps in Paraview

- In the **Properties** tab, select **Edit Color Map** button. This opens a new window on the RHS with the Color Map Editor

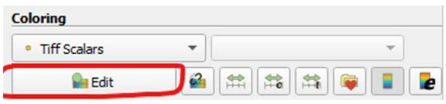


Figure 29 Editing colour maps in Paraview

- Either select a colour map from the default presets (1)

[6] When using the Append Attributes filter, Paraview expects the source files to have the same dimensions

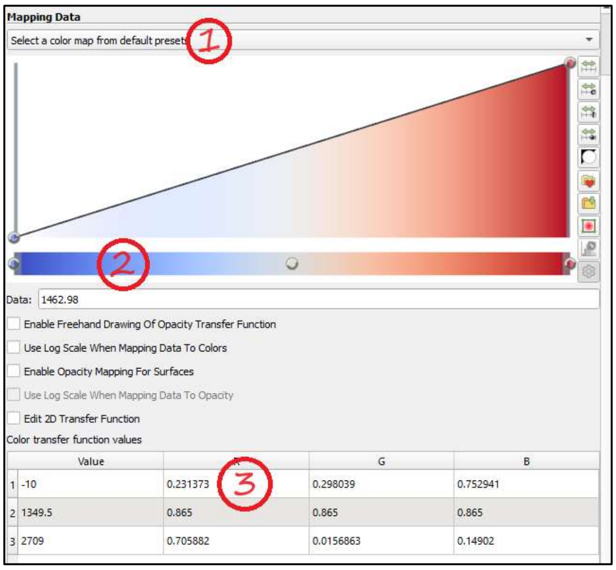


Figure 30 Colour map settings in Paraview

- Or add new points by clicking on the scale at (2) and then editing the colours in the table in (3) by double clicking on the values
- In the table (3) each point can have a different colour and all points between are interpolated. The colours are applied from the the point you add to the next point
- To display the sea, for example, add a point at 0 and a point at 0.1. Set a sea colour for all points to 0; set the land colour from 0.1
- Here is an example:

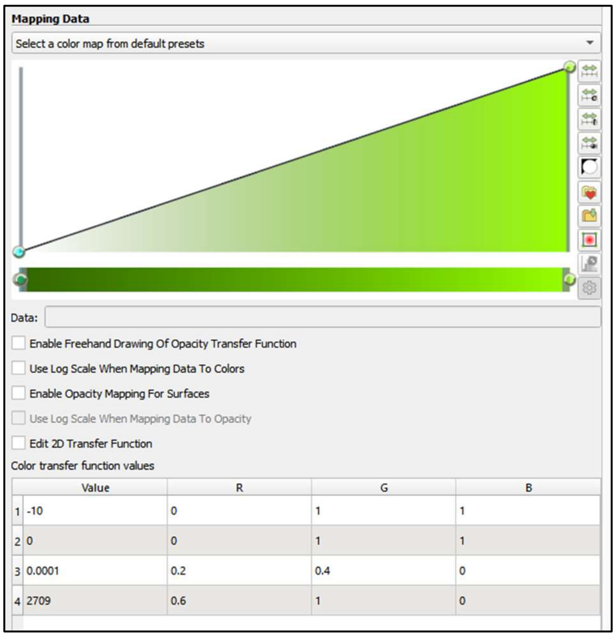


Figure 31 Example colour map settings

which results in:

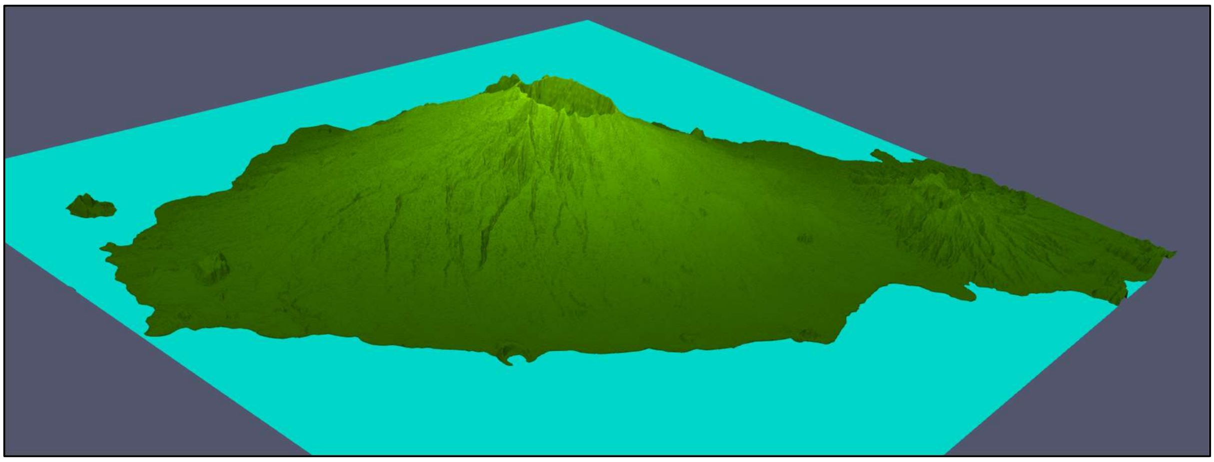


Figure 32 Example surface display

6.2 Displaying the Energy Cone

In Paraview, to load the Energy Cone, it is the same steps as above:

- Select menu options **File/Open** and open your energy cone file (your-energy_cone.tif).
- Select menu options **Filter/Alphabetical/Convert Cell Data to Point Dats**
- Create a 3D representation of the surface by selecting menu options **Filter/Alphabetical/Warp by Scalar**. Be sure to use the same scale factor as the DEM
- The image should now be visible in 3D and can be manipulated on the screen.

To colour the Energy Cone, again it is the same steps as above:

- In the Properties tab, select the **Use Separate Color Map** button. This is an important step – otherwise any changes you make will affect the surface display as well
- In the Properties tab, select **Edit Color Map** button
- Select a colour map from the default presets.

Example output below:

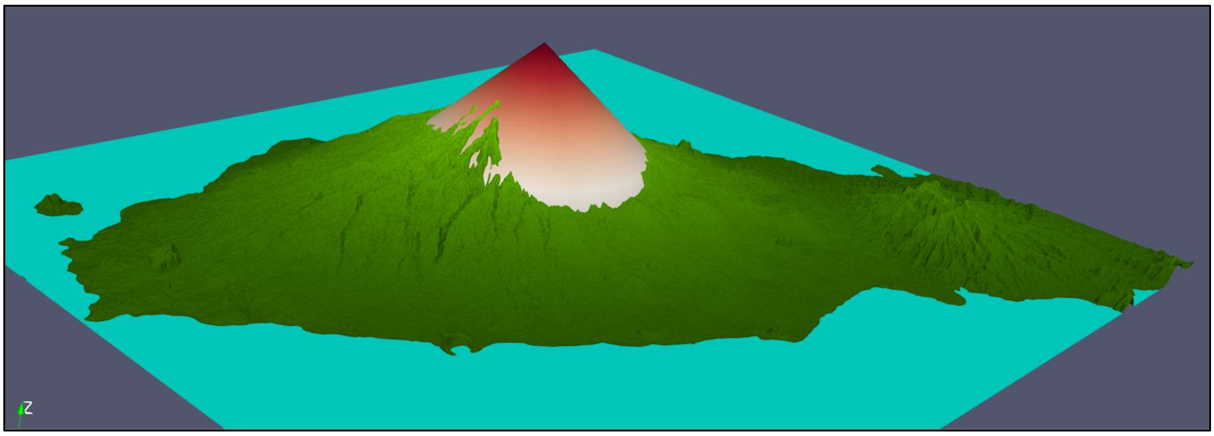


Figure 33 Example showing surface and energy cone

6.3 Displaying the Flows

In Paraview, to load the Flows, it is the same steps as above:

- Select menu options **File/Open** and open your flow file. In this case we use Total.tif
- Select menu options **Filter/Alphabetical/Convert Cell Data to Point Data**
- To display the flows we have to combine the flow data (from *Total.tif*) with the DEM data where we use the DEM for the height (z-dimension) and the flow data (*Total.tif*) for the colouring
- Select both the Convert Cell Data to Point Data filter for the DEM and the Convert Cell Data to Point Data filter for the flows in the pipeline browser on the LHS. Combine the date by selecting menu option **Filter/Alphabetical/Append Attributes**
- In the resulting pipeline browser entry (AppendAttributes 1), create a 3D representation of the surface by selecting menu options **Filter/Alphabetical/Warp by Scalar**. Use the same scale factor as the DEM. Set **Scalars** to *Elevation_input_1* and **Coloring** to *Elevation* (or the other way around, depending on the order you selected your DEM layer and your flow layer – it should be obvious if it's the wrong way round) – see below:

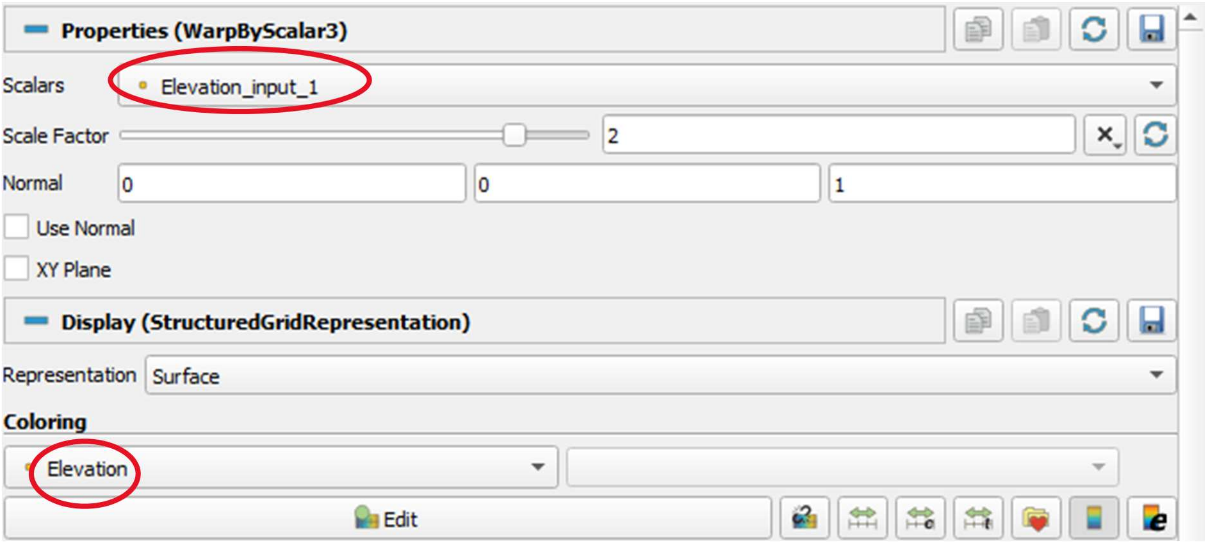


Figure 34 In the Warp by Scalar filter, setting different values to use for the z-scale and the colouring

- The image should now be visible in 3D and can be manipulated on the screen.

To colour the flows and produce a composite image we use categories rather than a colour ramp

- In the **Properties** tab, select the **Use Separate Color Map** button. Again, important step not to change the display configuration already entered for the surface and the energy cone
- In the **Properties** tab, select **Edit Color Map** button. In the window on the RHS, as shown below:
    - Select **Interpret Values as Categories** (1)
    - Select **NAN color opacity** to zero(2)
    - Double click on the colours (1..n) to change them (3)

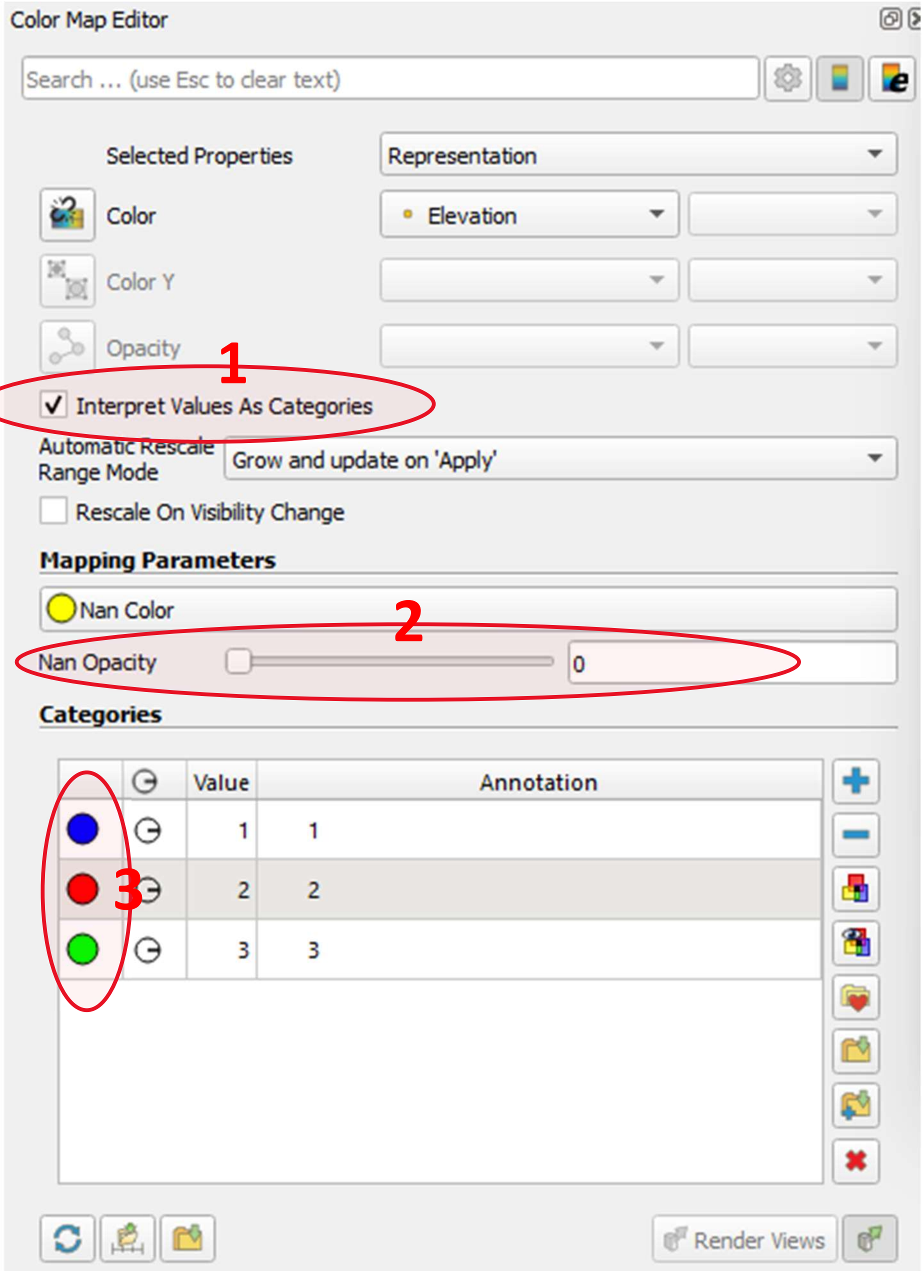


Figure 35 Setting category display values in Paraview

You should now have output similar to that shown below:

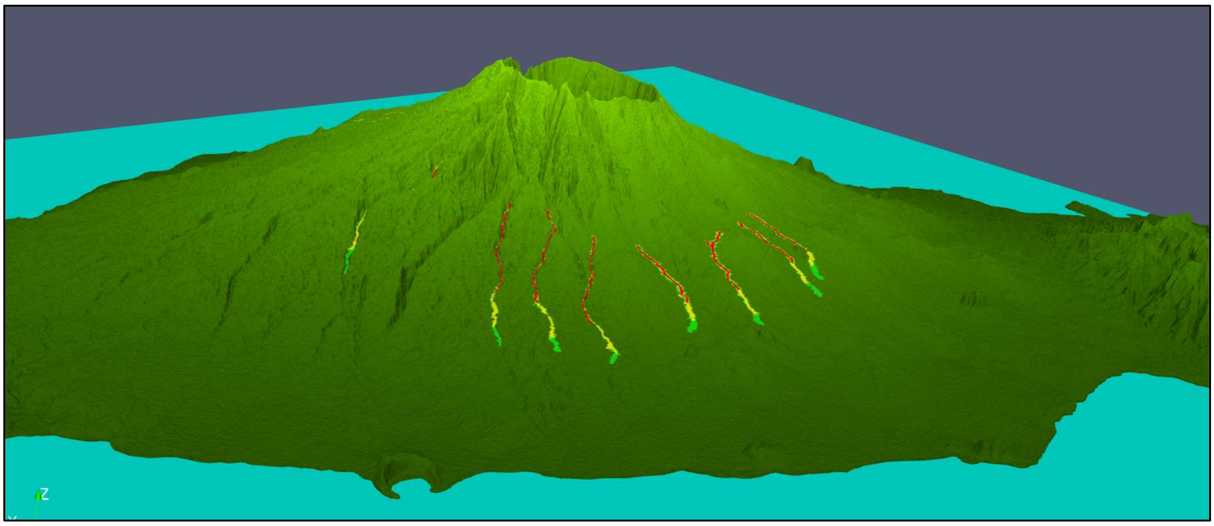


Figure 36 Example flow output in Paraview

7 Additional Parameters

You have access to a series or parameters within LaharZ which govern its operation and provide additional functionality. If you execute the following from a command line:

```
laharz maintain
```

you will see the following screen:

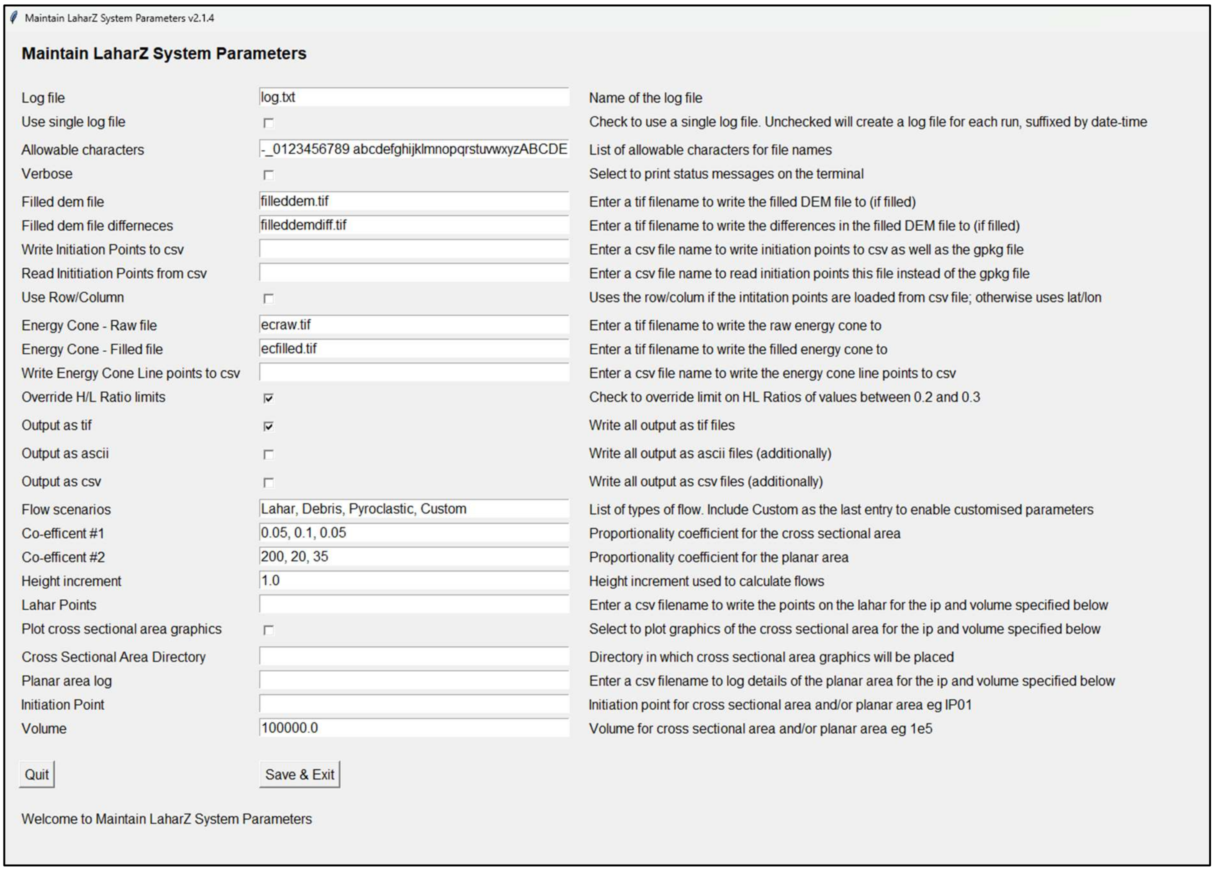


Figure 37 Maintain system Parameters screen

There is no need to change these for normal use. Some key points are outlined below.

Log file: every execution of LaharZ creates a log file. You can choose whether to **Use a Single File** which is overwritten each time, or have the log file name appended with the date and time of the start of execution to have different log files each time. The log files are stored in your current working directory.

Allowable characters: define which characters are allowed in filenames. They are somewhat OS dependent so the allowable values is quite limited. If you add characters which conflict with your OS file naming rules, the consequences are unpredictable.

Filled dem file: enter a tif file name to create a file of the filled DEM

Filled dem file differences: enter a tif file name to create a file of the differences between the filled DEM and the original DEM

Override H/L Ratio Limits: the H/L ratio is limited to values between 0.1 and 0.3. Check this box to remove the constraint.

Output as…: the files generated by LaharZ can be created in different formats. Note that if you don't select at least one format, you will not have any output.

Flow Scenarios: a list of scenarios which includes 'Custom'. If Custom is on this list, the user will be able to enter their own values for the proportionality co-efficients.

Co-efficient…: the proportionality co-efficients. There should be a corresponding number of co-efficients for each scenario (except Custom)

Height Increment: to calculate the cross section area, LaharZ raises the flow level by an increment on each iteration. The default value is 1m; smaller values (eg 0.1m) can be more precise, but slower

Lahar Points: specify a csv file and all points for the initiation point and volume (as specified above) will be written to that csv file in your working directory

Plot cross sectional area graphics: select to create cross section graphics. See below

Cross Sectional Area Directory: for a particular initiation point and a particular volume (specified below), so can create a series of images showing the cross section in each direction for each point in the flow. Specify the directory here where the images will be created. An example below.

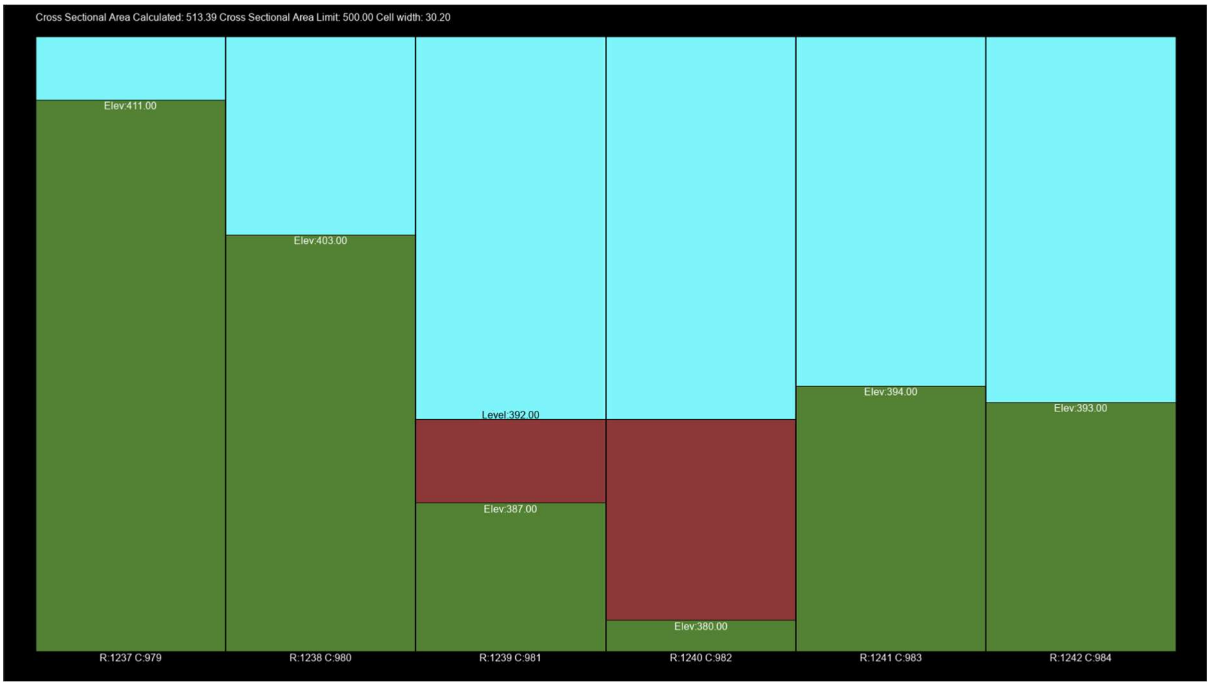


Figure 38 Image of a cross sectional area plot

Note there are no checks to test if any output files generated from the parameters above already exist. All files will be overwritten.

Planar area log: specify a csv file and a log will be created detailing how the planar area is calculated for the initiation point and volume (as specified above). It will be written to that csv file in your working directory

The system parameters are stored in a file **sys_parameters.pickle** in your sub directory. To restore the parameters to defaults, delete this file and run LaharZ.

8 And finally

Comments, suggestions, issues all welcome. Please report on GitHub to help track (https://github.com/Keith1815/LaharZ/issues).

9 Change Log

Version	Comment
1.0.0a	First release
1.0.1a	Updated release to match version 1.0.1 of LaharZ. Reference to installation guide otherwise no changes to documentation
1.0.2a	Updated to show how to install using conda
1.0.3a	No updates. Version incremented to match programme.
2.0.0a	Updated to support new version of LaharZ. This version has a simplified user interface, options to set the apex of the energy cone and add incremental height, and the ability to edit initiation points.
2.0.0b	Updated to include additional installation options and some typical installation issues
2.0.0.c	More details on implementation issues and potential resolutions
2.1.0.a	Updated to reflect changes in version 2.1.0. • Ability to create stream and flow files directly as well as using user provided files • Ability to process files when DEM has rectangular pixels (eg STRM data for latitudes beyond 50°) • Ability to process DEM and stream files when they have different pixel sizes by recasting the DEM • Added Sea Level to initiation points screen to prevent IPs being created under the sea level • For very small volumes, planar area was not being included in the totals if the cross sectional area threshold was breached in the first iteration: corrected • Tidied up the use of pyproj, projected and geographic crs's • Cleaner termination of lahars on edges of the map • Corrected some validation anomolies • Added dynamic font sizes on cross section area charts

2.1.1.a	Updated to reflect changes in version 2.1.1 • Correction of error in calculating planar volumes • Ability to log details of planar area calculations, selected in Maintain LaharZ System Parameters • Trapping of file locking errors when logging Lahar Points and Planar Area
2.1.2a	Updated to reflect changes in version 2.1.2 • Management of circular flows (particularly on edges)
2.1.3a	Updated to reflect changes in version 2.1.3 • Now manages where the edges are defined nonlinearly using no data. Primarily to support Mark Bemelmans work with the sandbox • Added option to fill the DEM (or not). Previously it was always filled • Added option in Maintain System Parameters so that the filled DEM can be written out and a file with the differences between the filled DEM and the original DEM • Updated section on creating graphics in Paraview to use the GDAL Raster Reader rather than the TIFF series reader
2.1.4a	Updated to reflect changes in version 2.1.4 • Added ability to create polygons for the proximal hazard area (filled energy cone) and the flows as geopackage files • Added horizontal scroll bars • Corrected issue with data types on custom coefficient values • Corrected data typing issue with inundation arrays • Ability to run laharz from a command rather than executing the python module • Geopandas dependency updated to 1.0.1. Some users having warning messages on earlier versions • Python version updated to 3.12
2.1.4b	Minor changes in the installation section
2.1.4c	Minor changes in the installation section. Clarifying channels.

10 References

1. Schilling, S.P., 1998, LaharZ—GIS Programs for automated mapping of lahar-inundation hazard zones: U.S. Geological Survey Open-File Report 98-638, 80 p.

2. Griswold, J.P., and Iverson, R.M., 2008, Mobility statistics and automated hazard mapping for debris flows and rock avalanches (ver. 1.1, April 2014): U.S. Geological Survey Scientific Investigations Report 2007-5276, 59 p.

3. Widiwijayanti, C., Voight, B., Hidayat, D. et al. Objective rapid delineation of areas at risk from block-and-ash pyroclastic flows and surges. Bull Volcanol 71, 687–703 (2009). https://doi.org/10.1007/s00445-008-0254-6

4. Barnes, Richard. 2016. RichDEM: Terrain Analysis Software. http://github.com/r-barnes/richdem