Ecosystem Services, part 3: Sediment Retention

The Science

- Underneath each InVEST model, there is a large literature and synthesized science
  - Here is a small excerpt related to sedimentation
- Too much content to cover here, but is in the extensive Users Guide
  - Instead, I will present a quick "stylized version" of what's being computed.

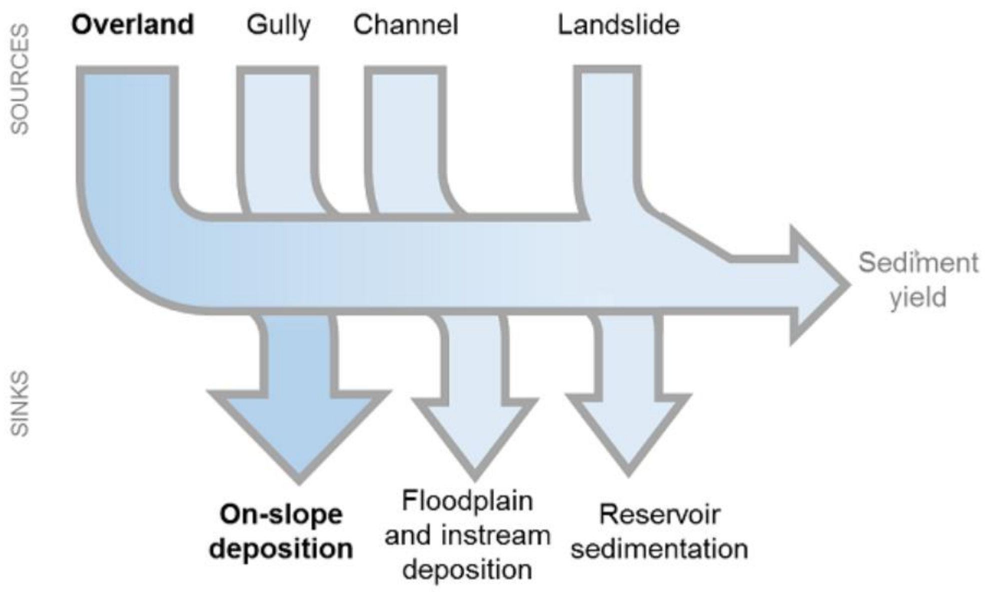


Figure 1. General catchment sediment budget. The relative size of the arrows changes depending on the environment. The InVEST model focuses on the overland sources and sinks, and does not include the others.

Annual Soil Loss

The amount of annual soil loss on pixel i, $usle_i$ (units: $tons \cdot ha^{-1}yr^{-1}$), is given by the Revised Universal Soil Loss Equation (RUSLE1 - Renard et al. 1997):

$$usle_i = R_i \cdot K_i \cdot LS_i \cdot C_i \cdot P_i, \tag{69}$$

where

- R_i is rainfall erosivity (units: $MJ \cdot mm(ha \cdot hr \cdot yr)^{-1}$),
- K_i is soil erodibility (units: $ton \cdot ha \cdot hr(MJ \cdot ha \cdot mm)^{-1}$),
- LS_i is a slope length-gradient factor (unitless)
- C_i is a cover-management factor (unitless)
- and P_i is a support practice factor (Renard et al., 1997). (cf. also in (Bhattarai and Dutta, 2006)). (unitless)

The LS_i factor is given from the method developed by Desmet and Govers (1996) for a two-dimensional surface:

$$LS_i = S_i \frac{(A_{i-in} + D^2)^{m+1} - A_{i-in}^{m+1}}{D^{m+2} \cdot x_i^m \cdot (22.13)^m} \tag{70}$$

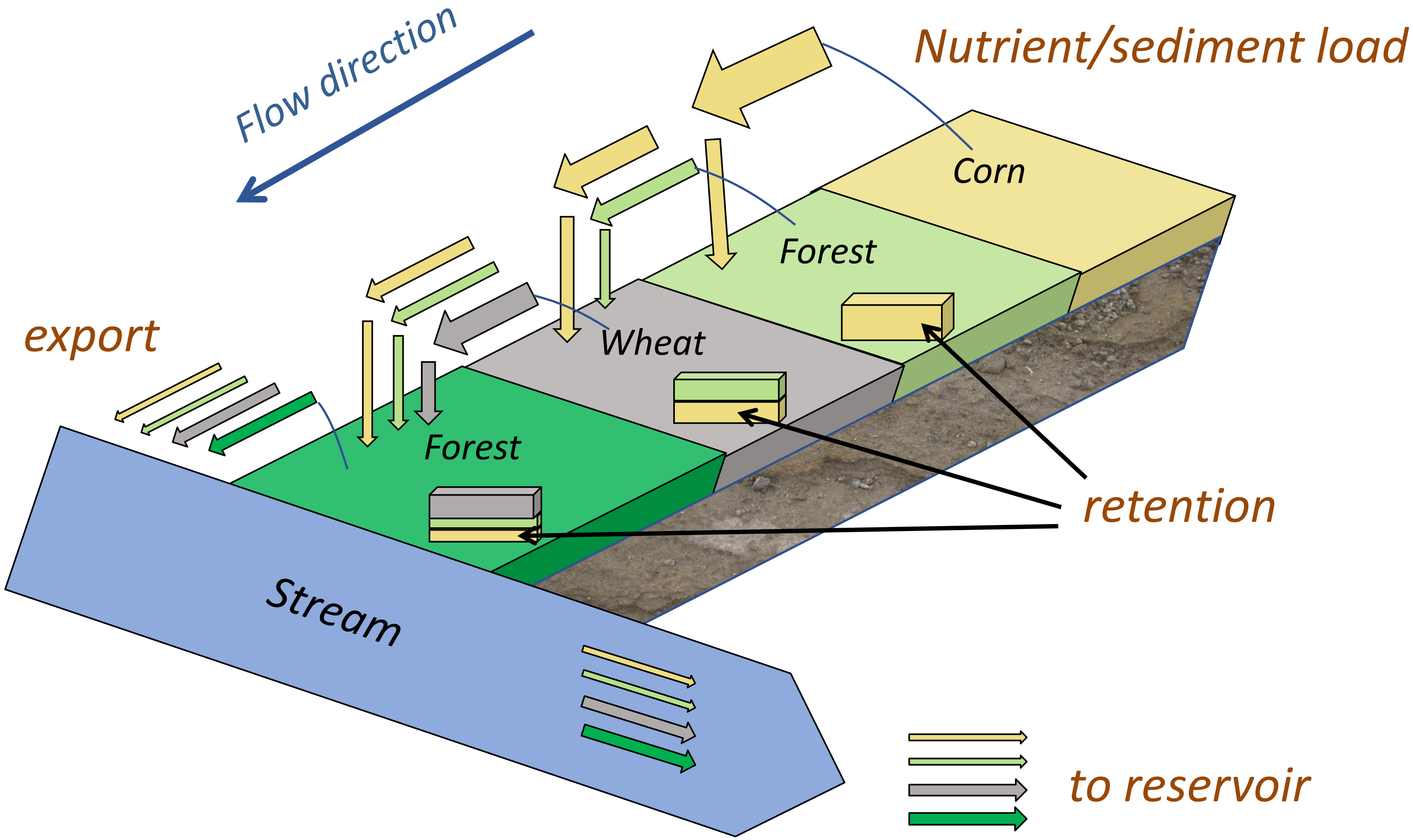
where

- S_i is the slope factor for grid cell i calculated as a function of slope. s is the percentage slope and θ is the slope in degrees (Renard et al. 1997):

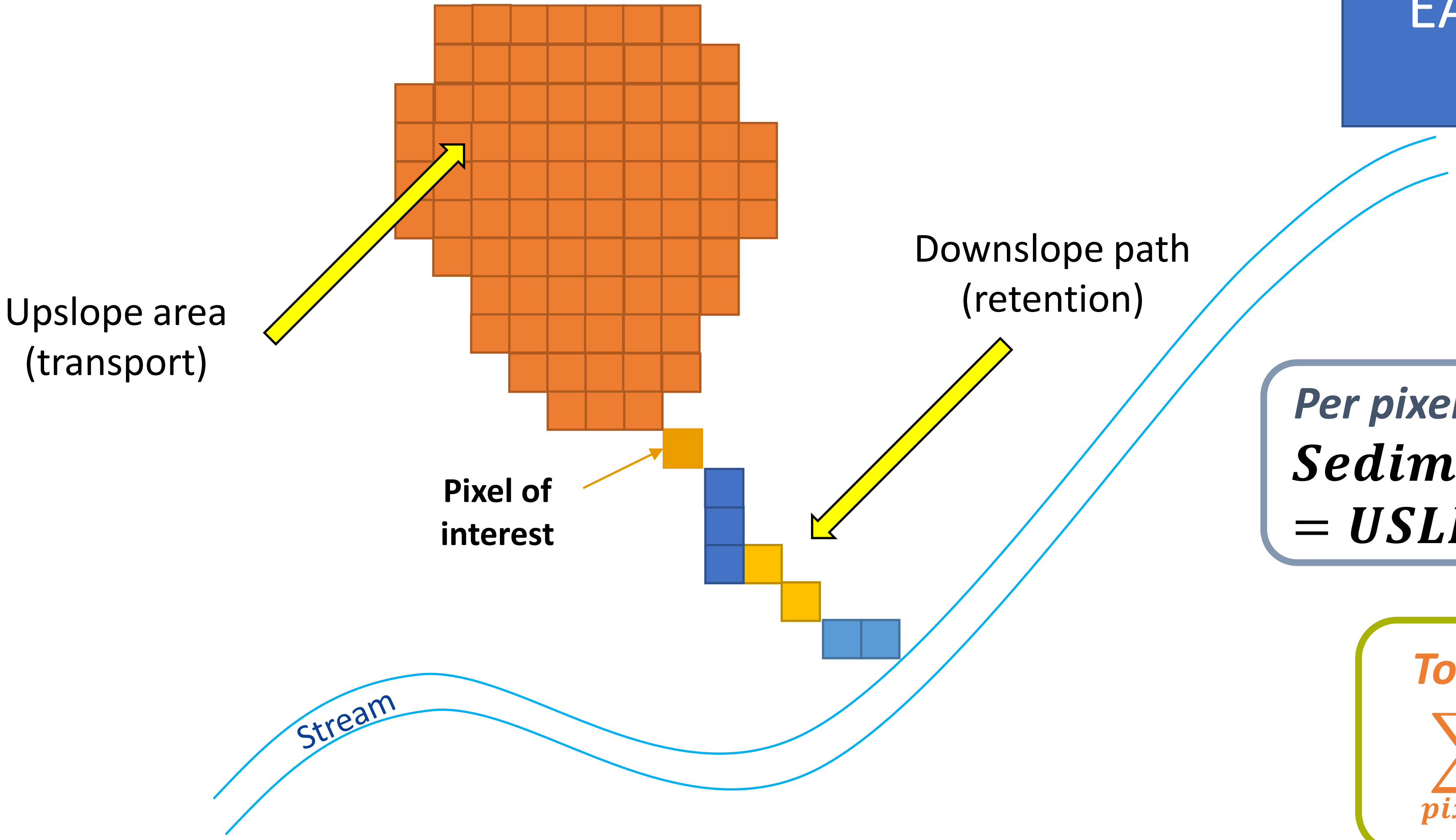
$$S = \begin{cases} 10.8 \cdot \sin(\theta) + 0.03, & \text{where \s} < 9\% \\ 16.8 \cdot \sin(\theta) - 0.50, & \text{where \s} \geq 9\% \end{cases}$$

- A_{i-in} is the contributing area (m^2) at the inlet of a grid cell which is computed from the Multiple-Flow Direction method
- D is the grid cell linear dimension (m)
- x_i is the mean of aspect weighted by proportional outflow from grid cell i determined by a Multiple-Flow Direction algorithm. It is calculated by

Sedimentation on a *very* simple LULC map



Transport/retention



This is calculated for EACH pixel on the landscape

Per pixel:

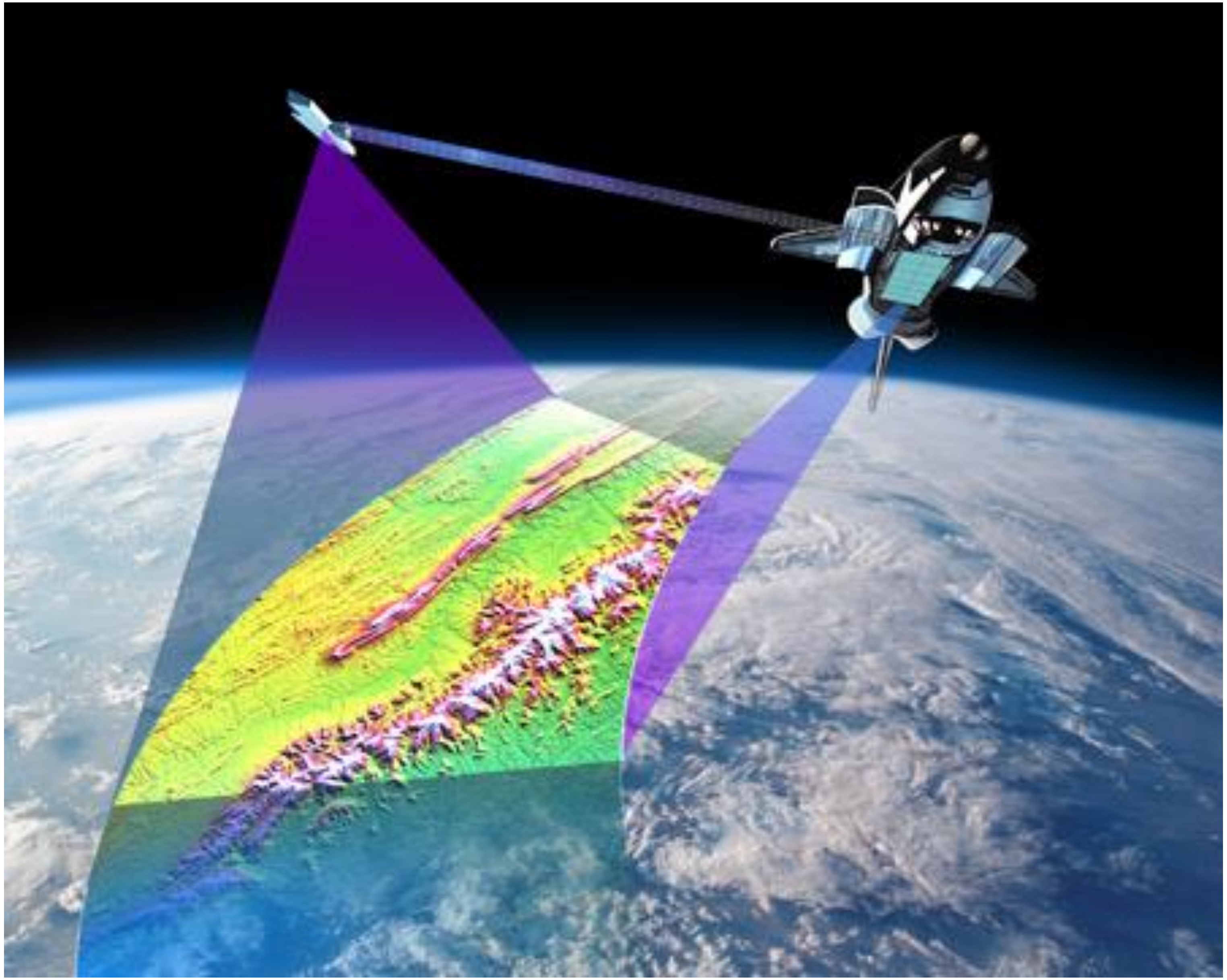
$$SedimentExport\ (ton/yr) = USLE \times SDR$$

Total export (ton/yr) =

$$\sum_{pixel} SedimentExport$$

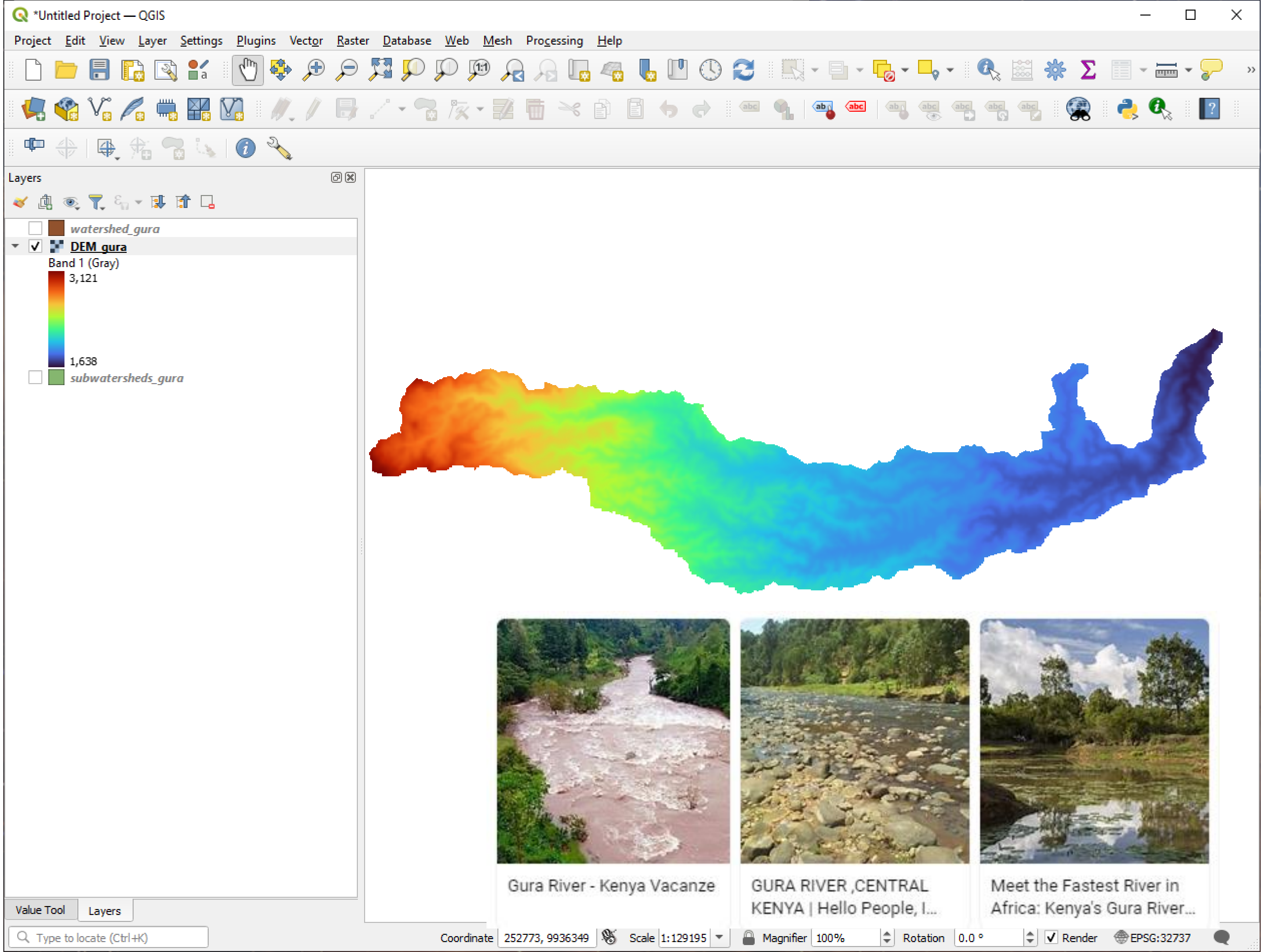
Hydrological routing depends on the topography of the area

- DEM: Digital Elevation model
- Literally from the Space Shuttle!
  - Basically shoots lasers at the same spot from two different directions to get a very precise elevation measurement.



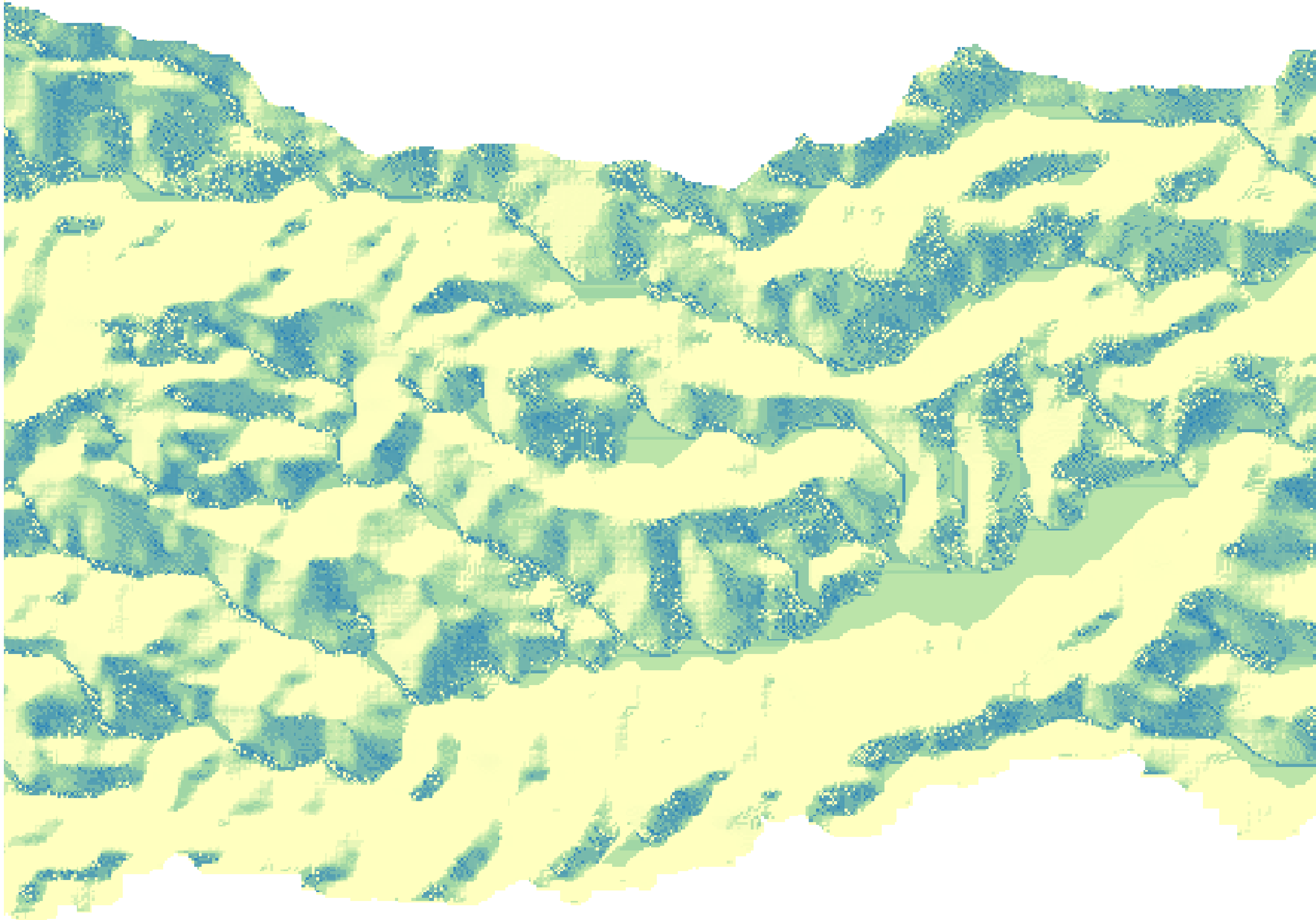
DEM of Gura

- The Gura is a critically important river in Kenya



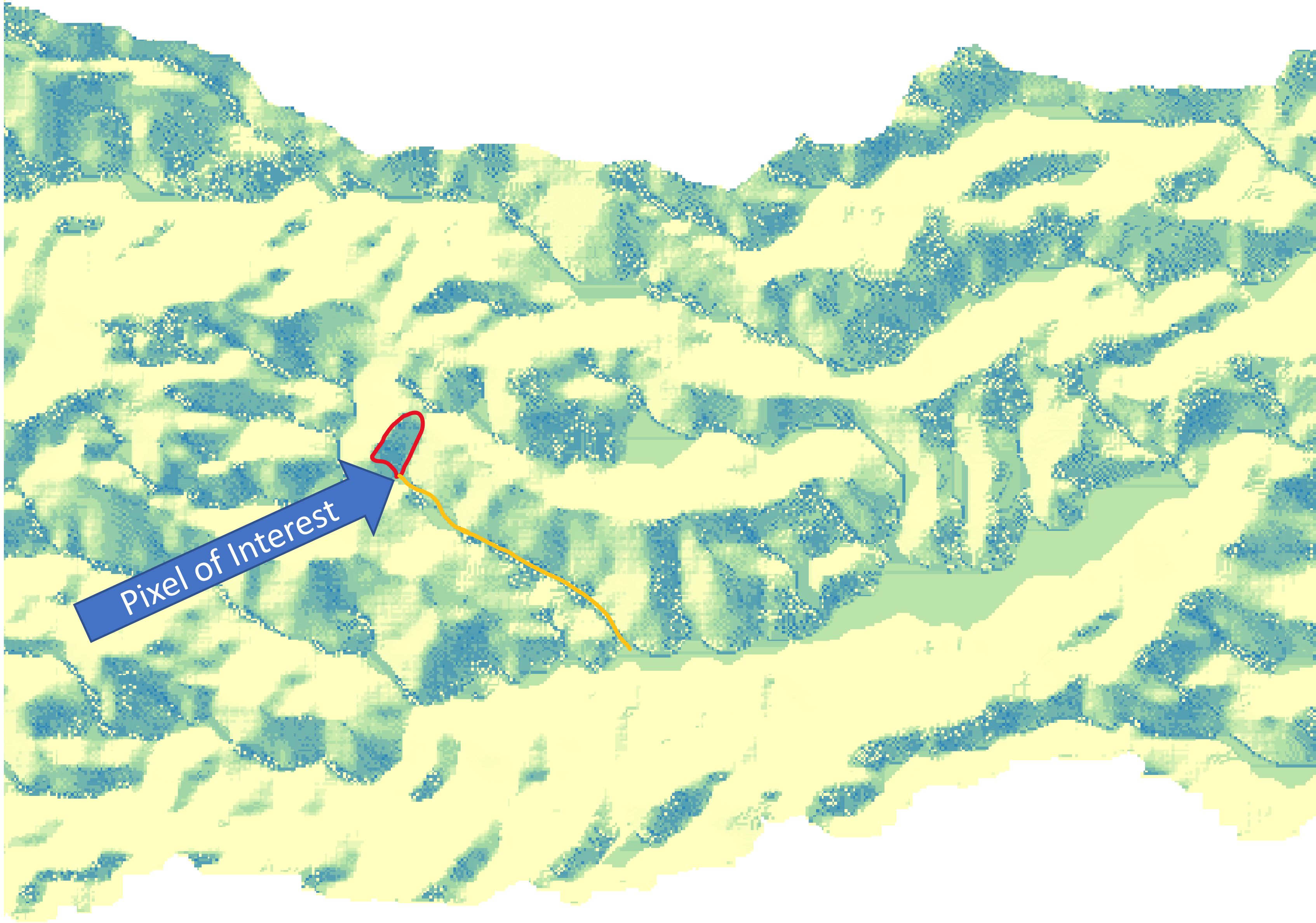
Flow direction

- Calculated from the DEM.
  - Color indicates which direction (in degrees) the water is flowing.



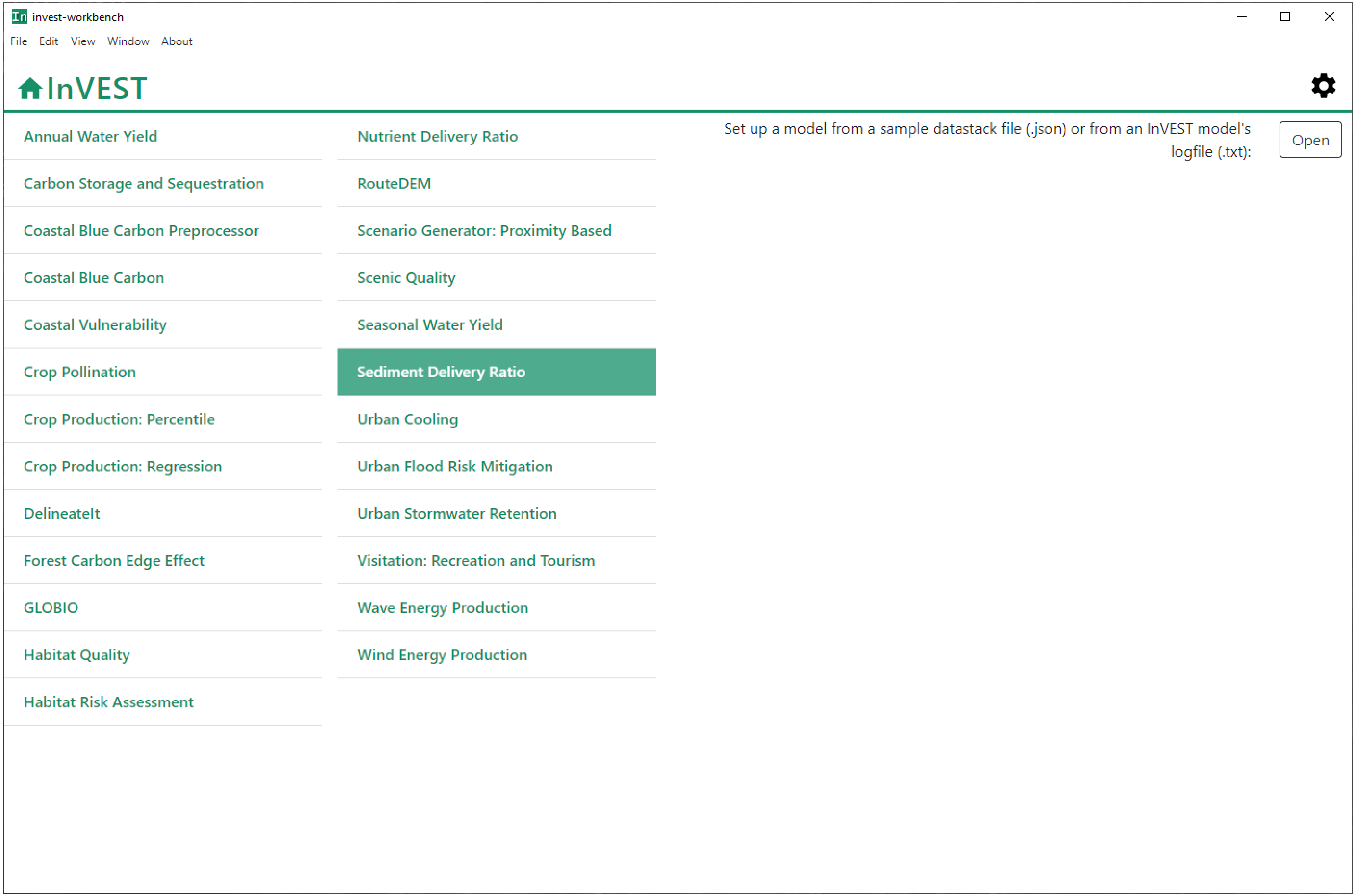
SDR calculation for one pixel of interest

- Red: Upslope area
- Yellow: downslope path
- Calculate this for ALL the pixels.

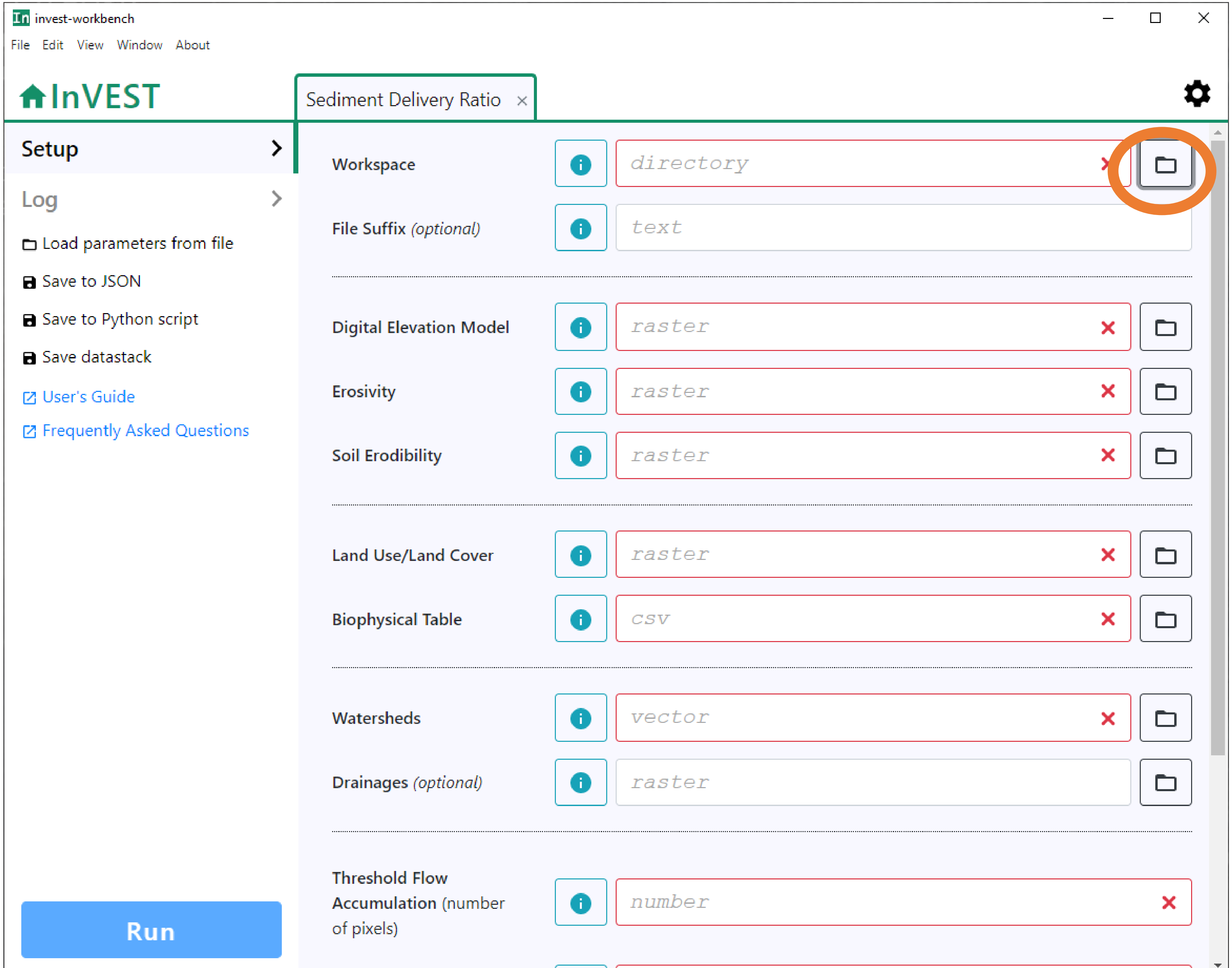


Running the InVEST SDR model

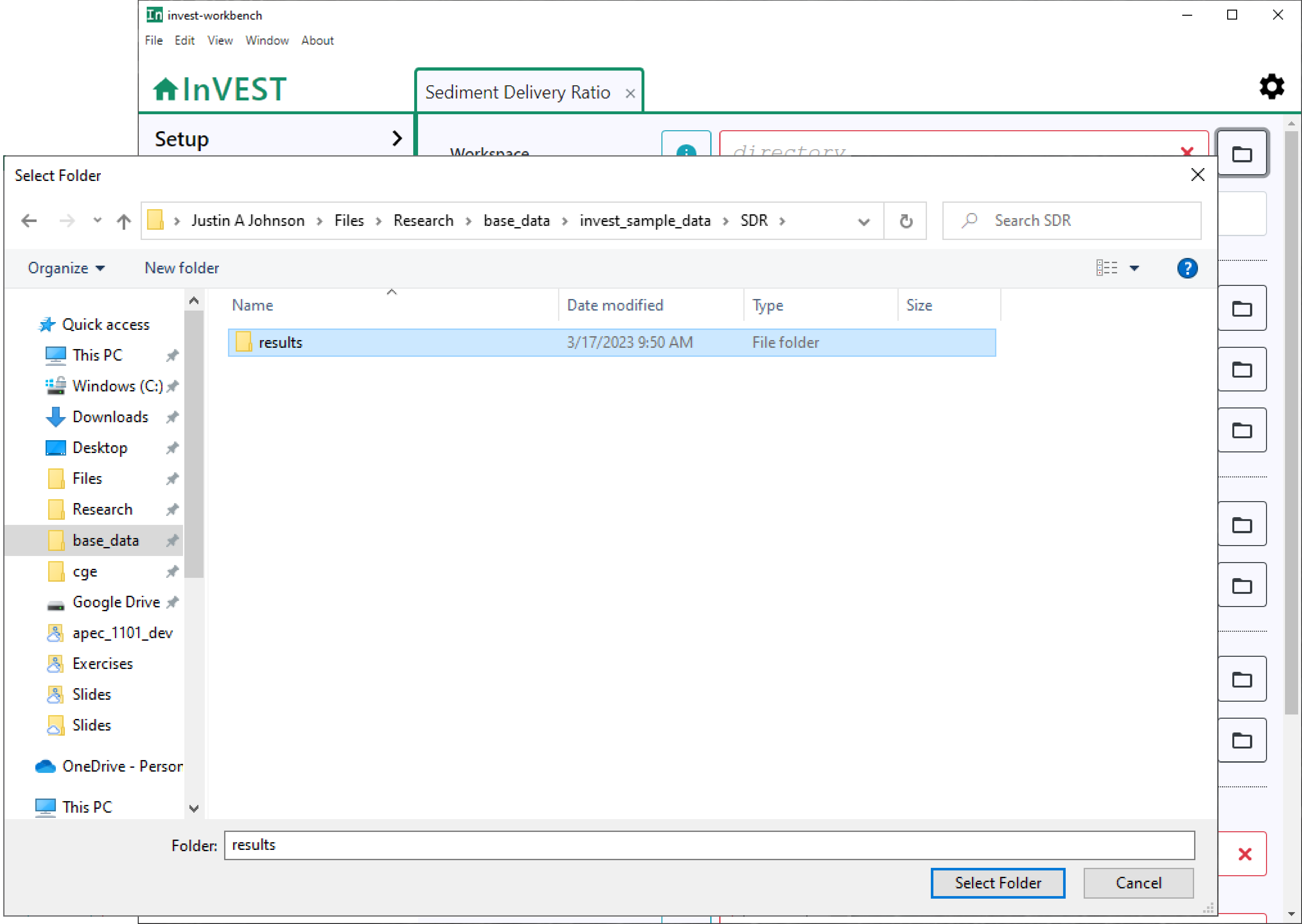
- Hit the "home" button to go back to the model selection screen.
- Select the Sediment Delivery Ratio model



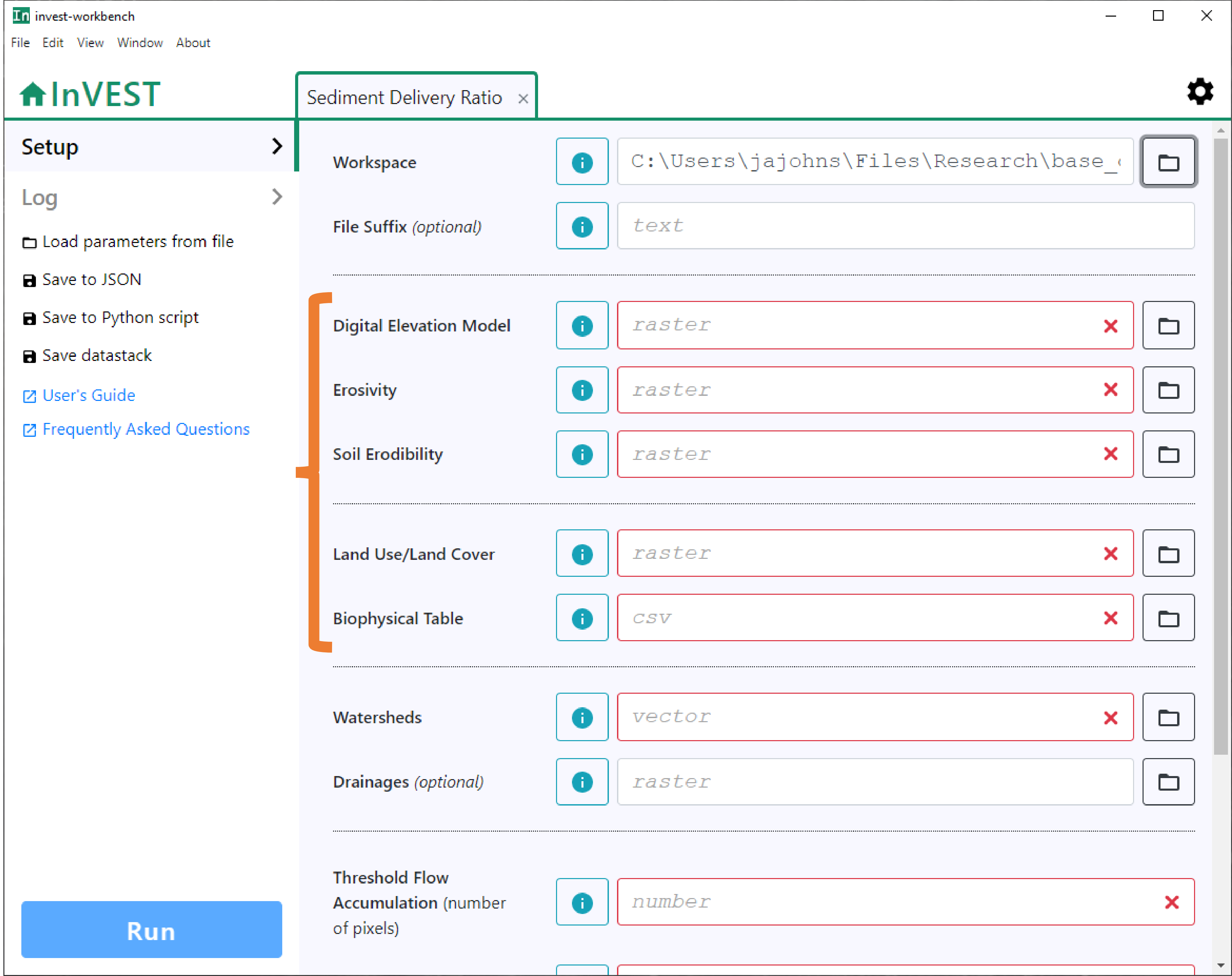
- Start by setting the Workspace folder



- Start by setting the Workspace folder
- Create a new folder in the SDR model called results.
- Select this folder as your Workspace



- Input the first five inputs.
- You can probably guess which is which by the file name.
  - Refer to the User's Guide link if you can't.



Erosivity

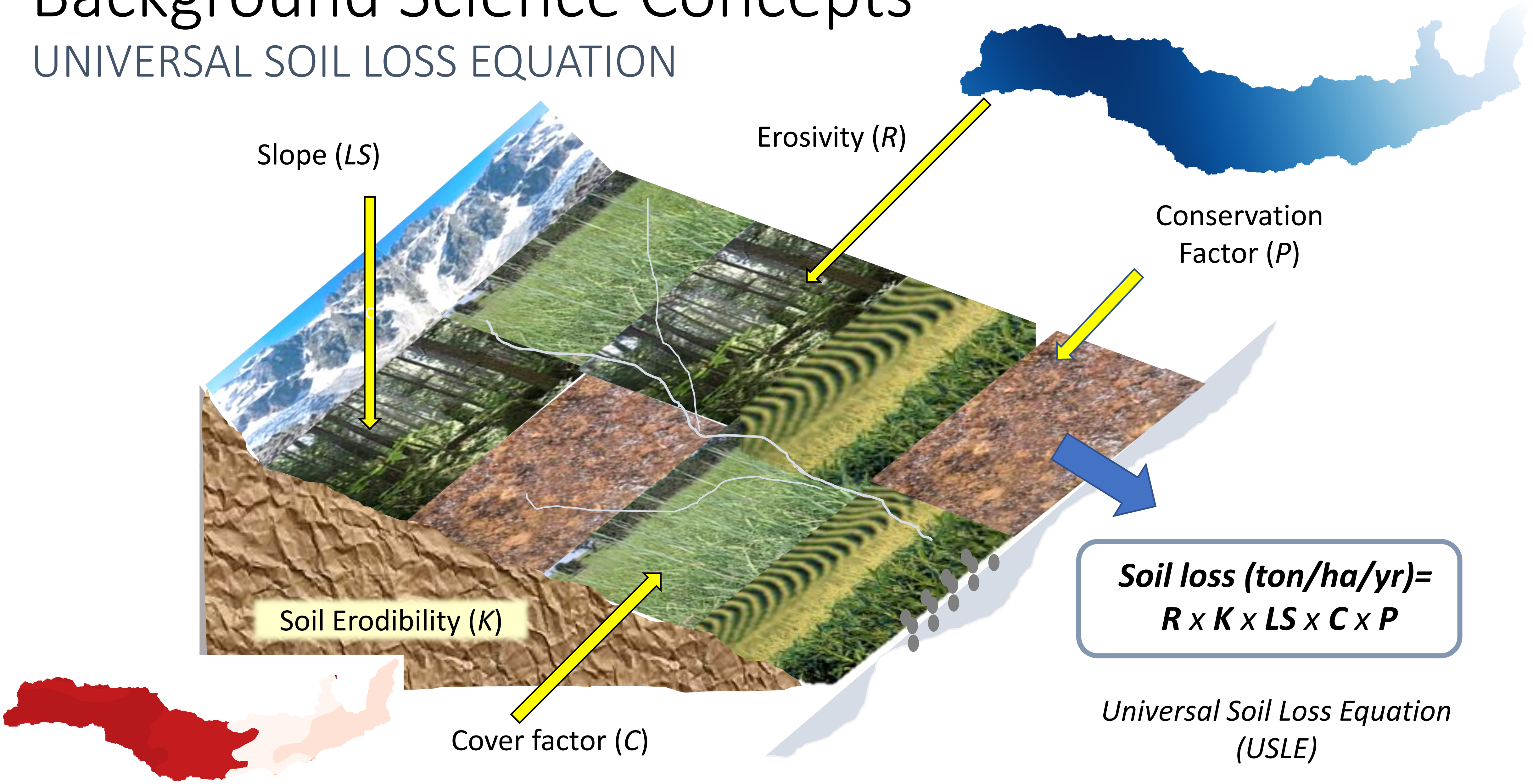
- Map of rainfall erosivity, reflecting the intensity and duration of rainfall in the area of interest.

Soil Erodibility

- Map of soil erodibility, the susceptibility of soil particles to detachment and transport by rainfall and runoff.

Background Science Concepts

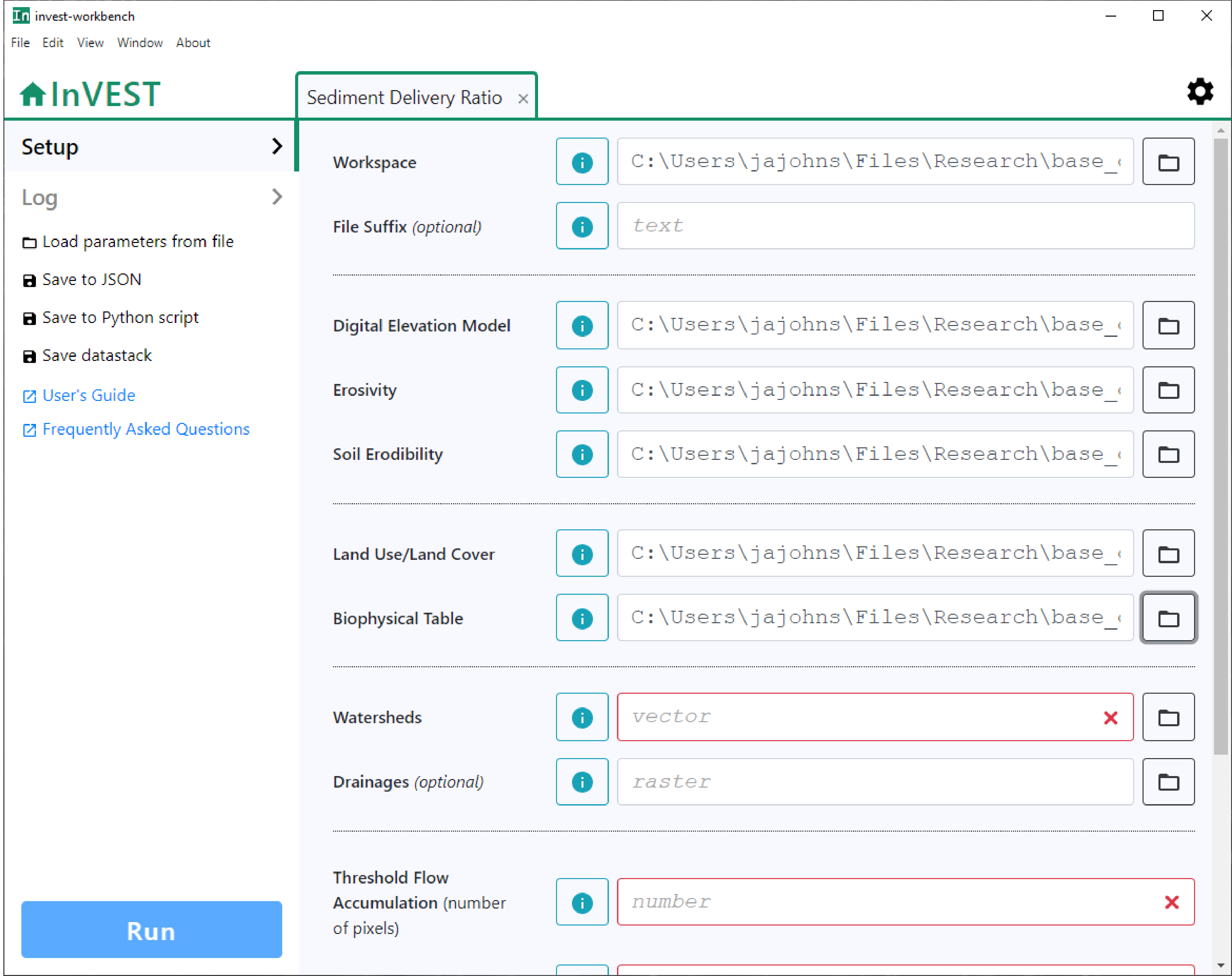
UNIVERSAL SOIL LOSS EQUATION



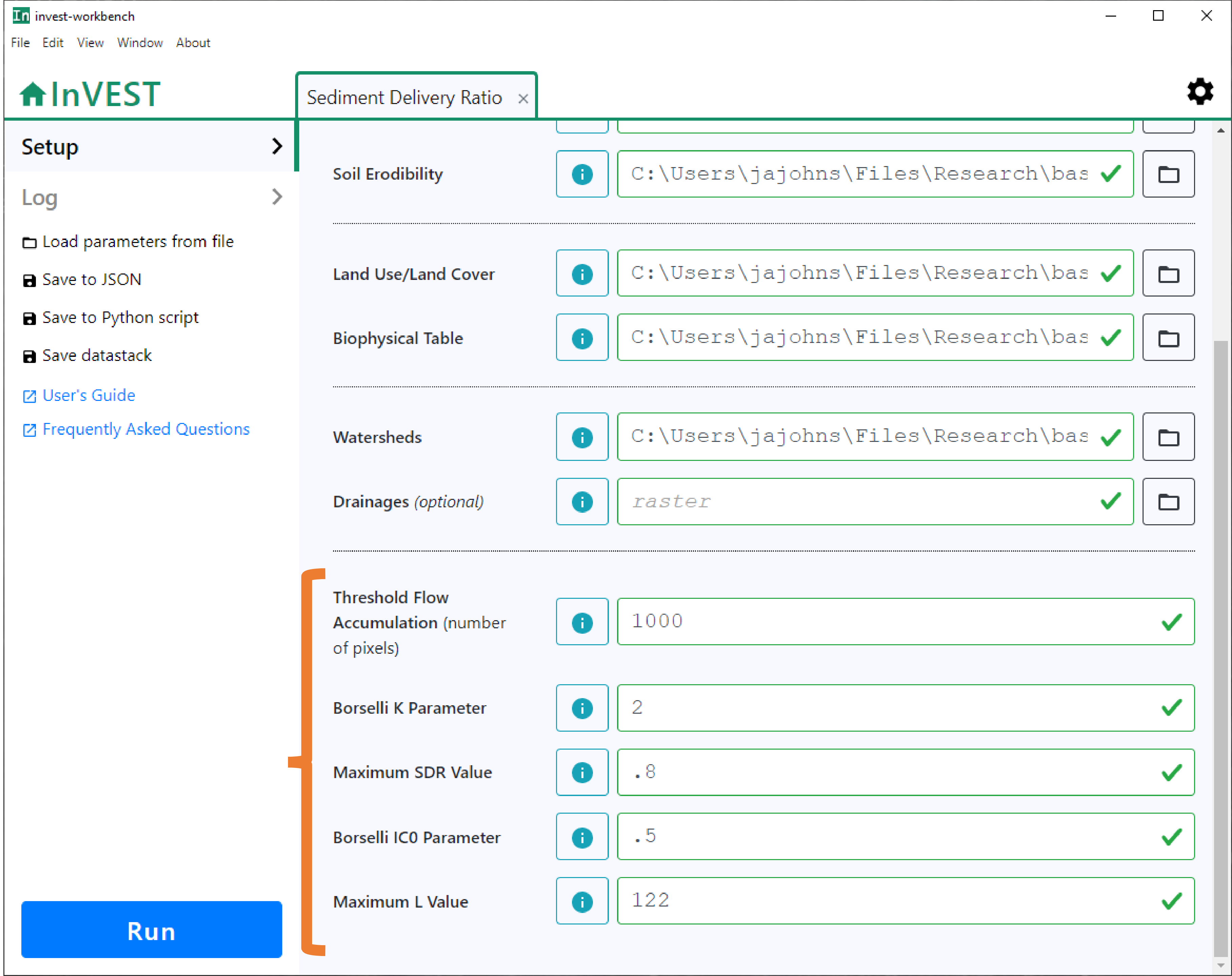
Soil loss (ton/ha/yr)=
R x K x LS x C x P

Universal Soil Loss Equation (USLE)

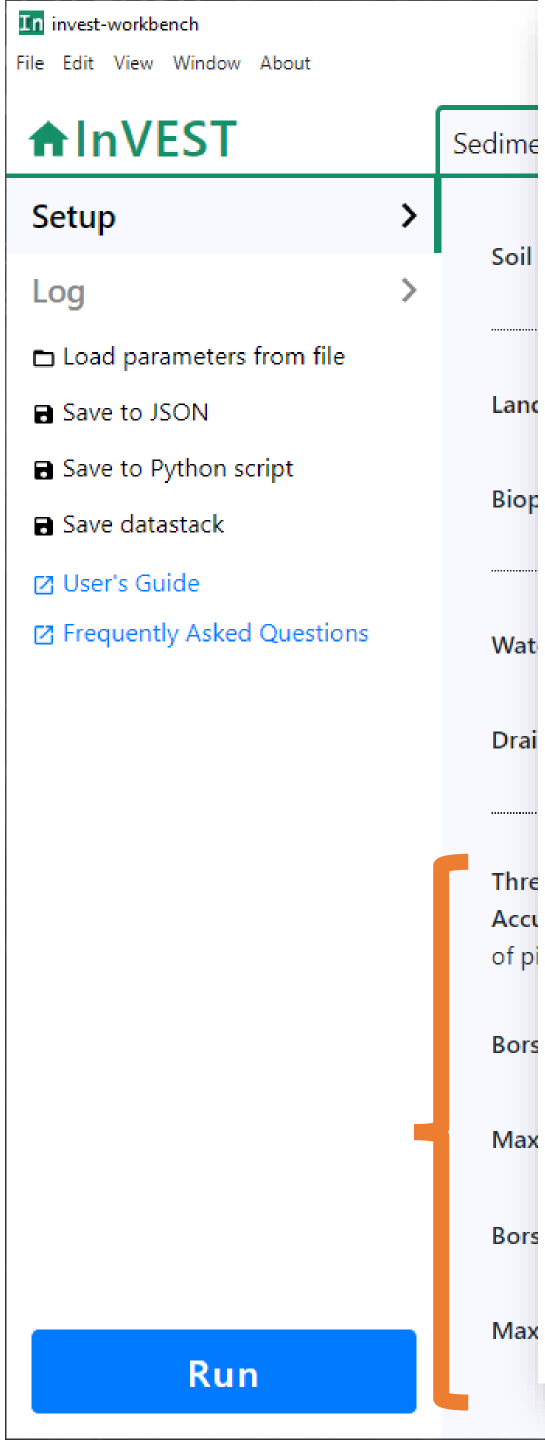
- Now enter the Watersheds input.
- We have two options.
    - “watershed_gura.shp”
    - “subwatershed_gura.shp”
- Notice that we have a new file type (.shp)
    - This is a Vector file, also called a Shapefile
        - Or sometimes Area of Interest (AOI) or just a Polygon.
- You can also add this to QGIS if you’d like to look at it.
- For now, select “watershed_gura.shp”

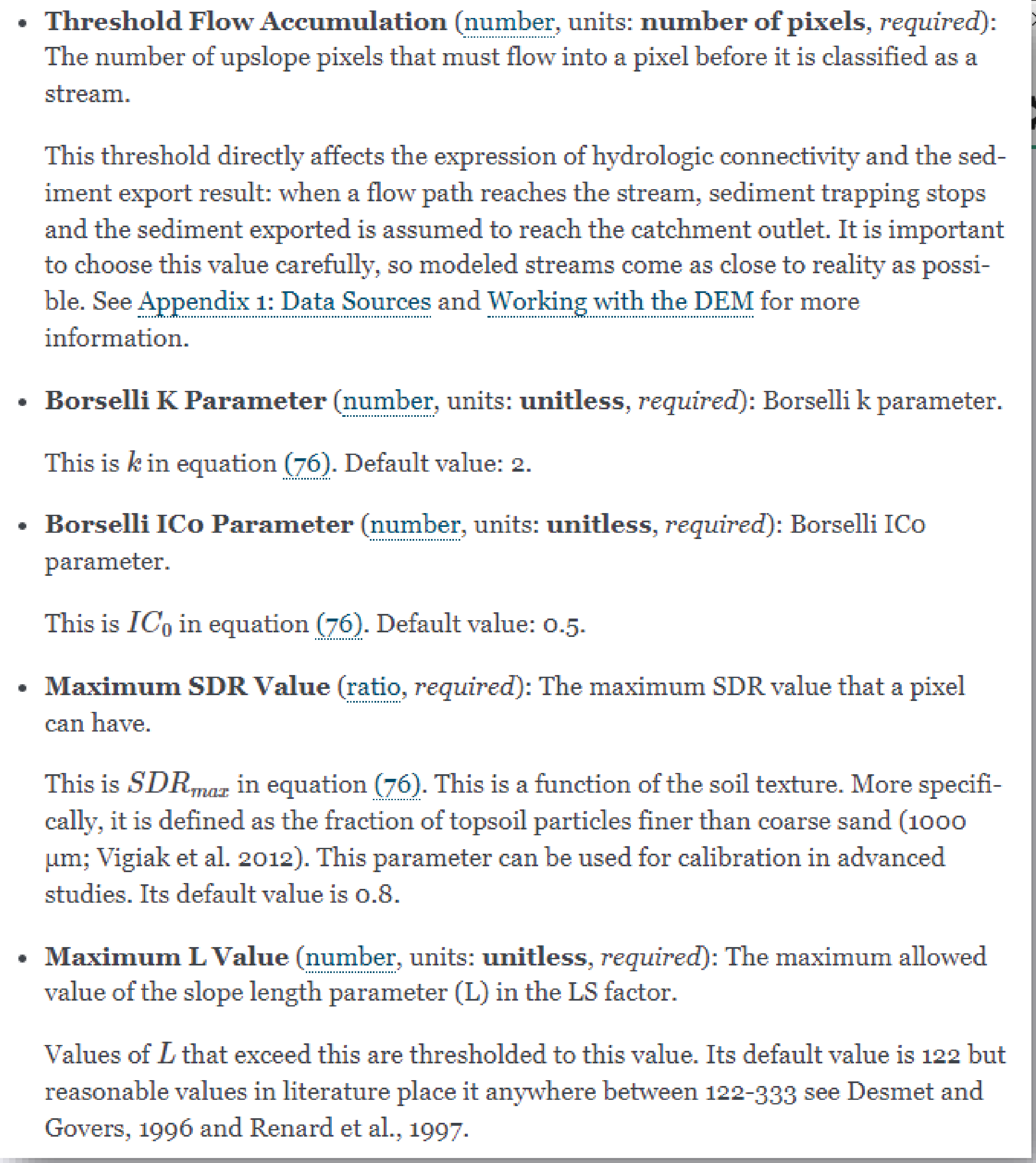


- Next, input the following “model parameters”
- Each of these values has important scientific context from Hydrology.
- For now, however, we are going to set them according to the Default Values reported in the InVEST User’s Guide



- Next, input the following "model parameters"
- Each of these values has important scientific context from Hydrology.
- For now, however, we are going to set them according to the Default Values reported in the InVEST User's Guide
  - Access the Users Guide with the info icon.
- One of the key reasons for InVEST's success is the thorough documentation it provides.





- **Threshold Flow Accumulation** (number, units: **number of pixels**, *required*): The number of upslope pixels that must flow into a pixel before it is classified as a stream.

  This threshold directly affects the expression of hydrologic connectivity and the sediment export result: when a flow path reaches the stream, sediment trapping stops and the sediment exported is assumed to reach the catchment outlet. It is important to choose this value carefully, so modeled streams come as close to reality as possible. See Appendix 1: Data Sources and Working with the DEM for more information.

- **Borselli K Parameter** (number, units: **unitless**, *required*): Borselli k parameter.

  This is k in equation (76). Default value: 2.

- **Borselli ICo Parameter** (number, units: **unitless**, *required*): Borselli ICo parameter.

  This is IC_0 in equation (76). Default value: 0.5.

- **Maximum SDR Value** (ratio, *required*): The maximum SDR value that a pixel can have.

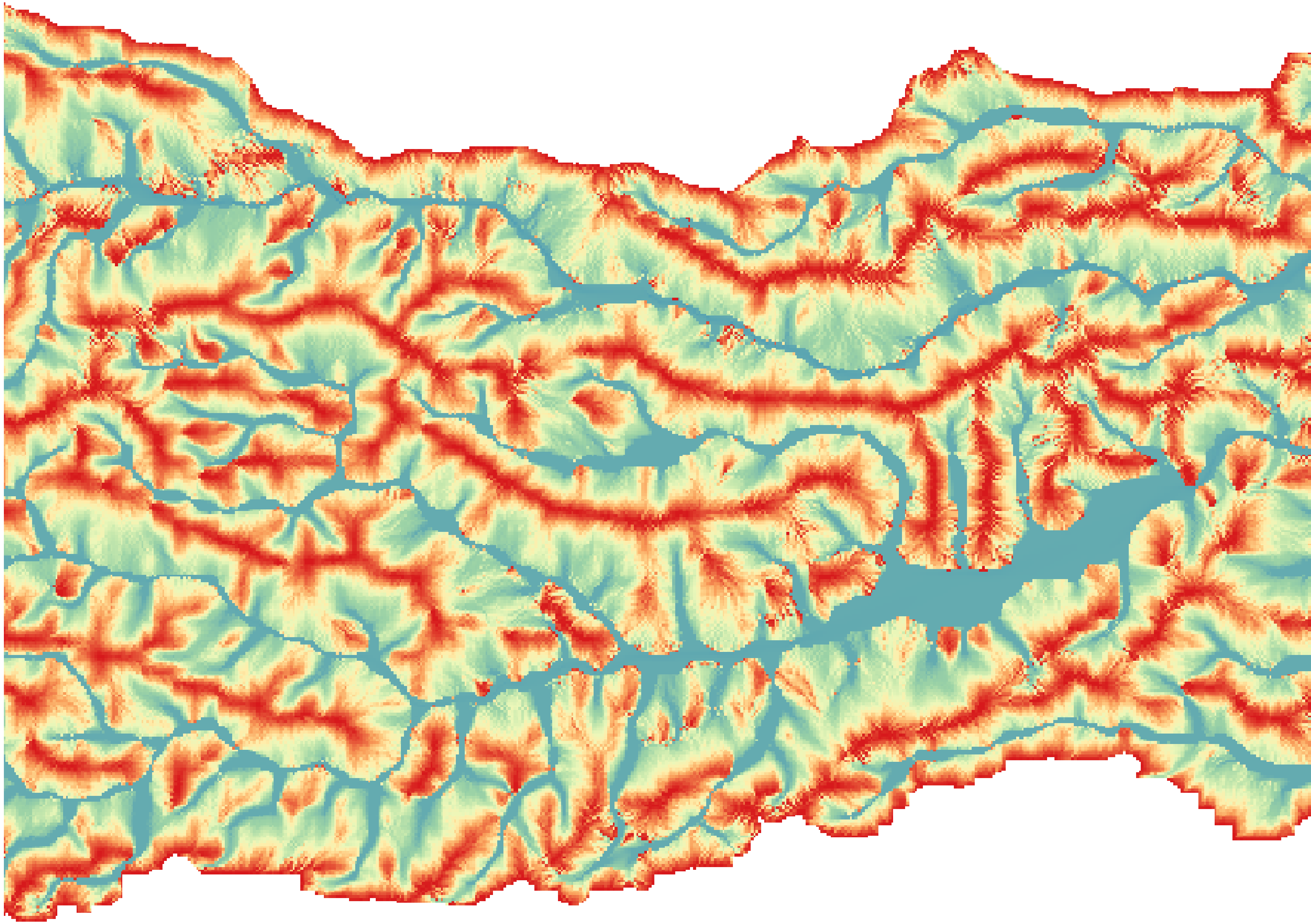
  This is SDR_{max} in equation (76). This is a function of the soil texture. More specifically, it is defined as the fraction of topsoil particles finer than coarse sand (1000 μm; Vigiak et al. 2012). This parameter can be used for calibration in advanced studies. Its default value is 0.8.

- **Maximum L Value** (number, units: **unitless**, *required*): The maximum allowed value of the slope length parameter (L) in the LS factor.

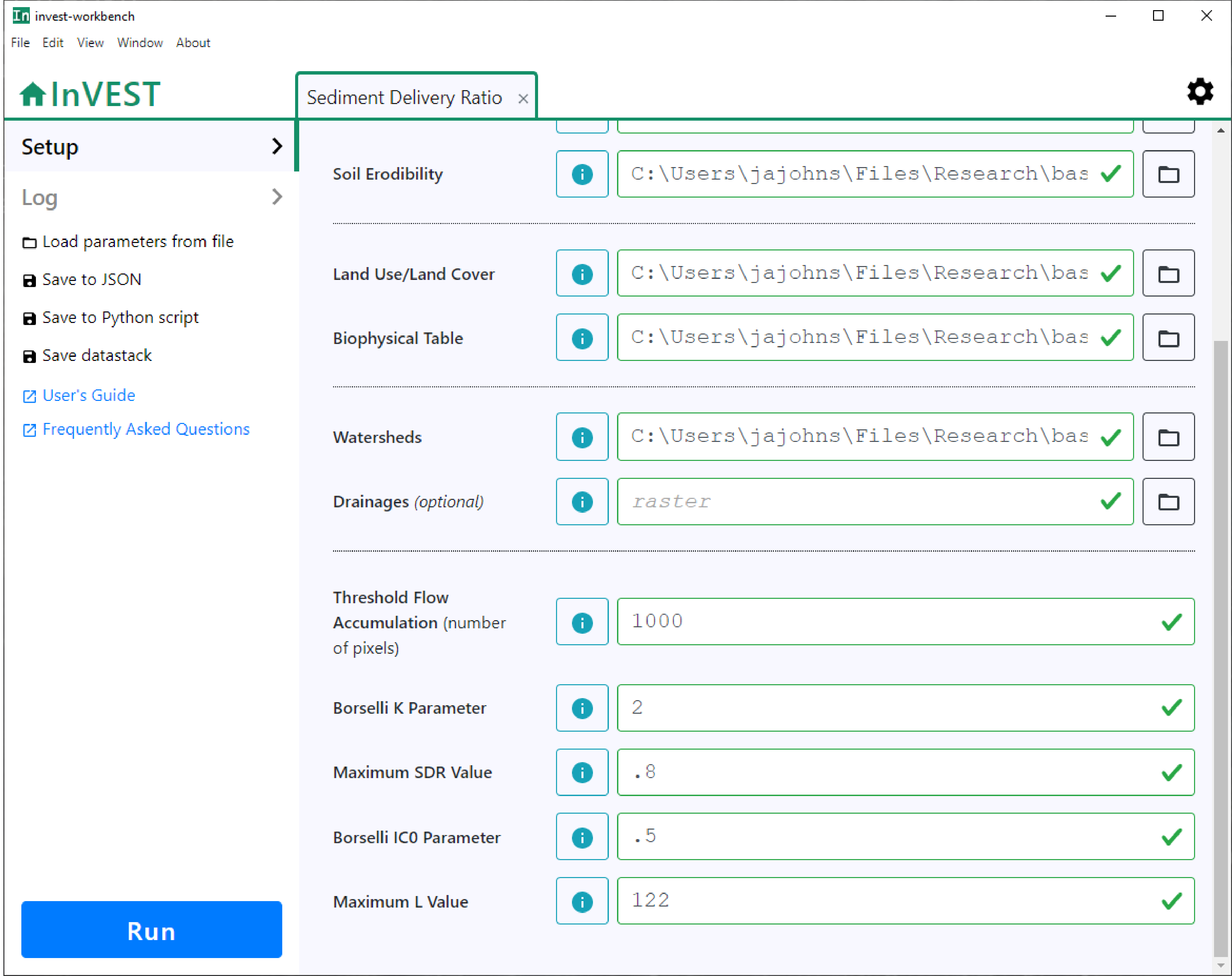
  Values of L that exceed this are thresholded to this value. Its default value is 122 but reasonable values in literature place it anywhere between 122-333 see Desmet and Govers, 1996 and Renard et al., 1997.

One key parameter: Flow accumulation

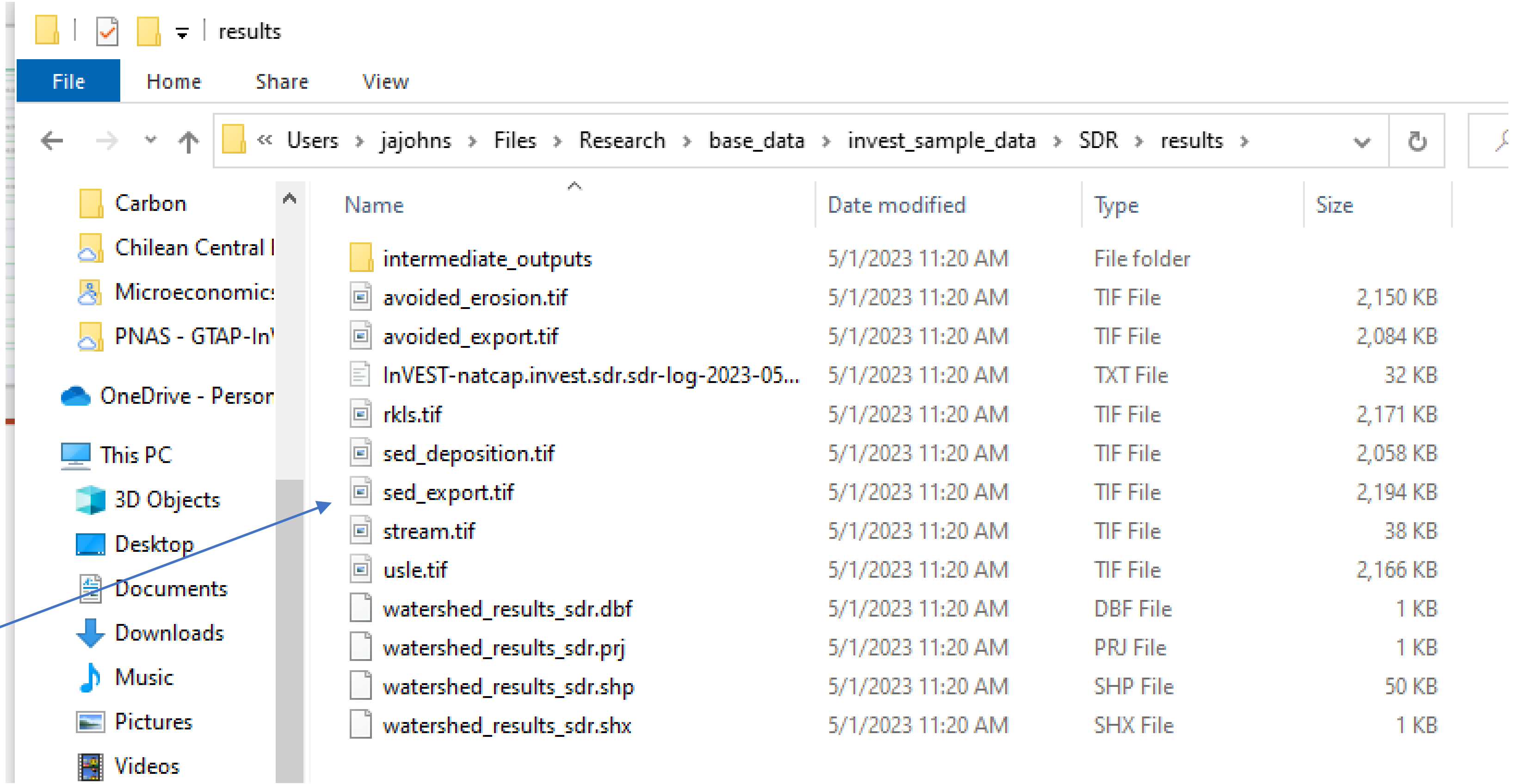
- Determines how much water must flow before we define it as a stream
- Here, red values show where little water has accumulated yet, but as it goes downhill, it eventually becomes a stream (blue)



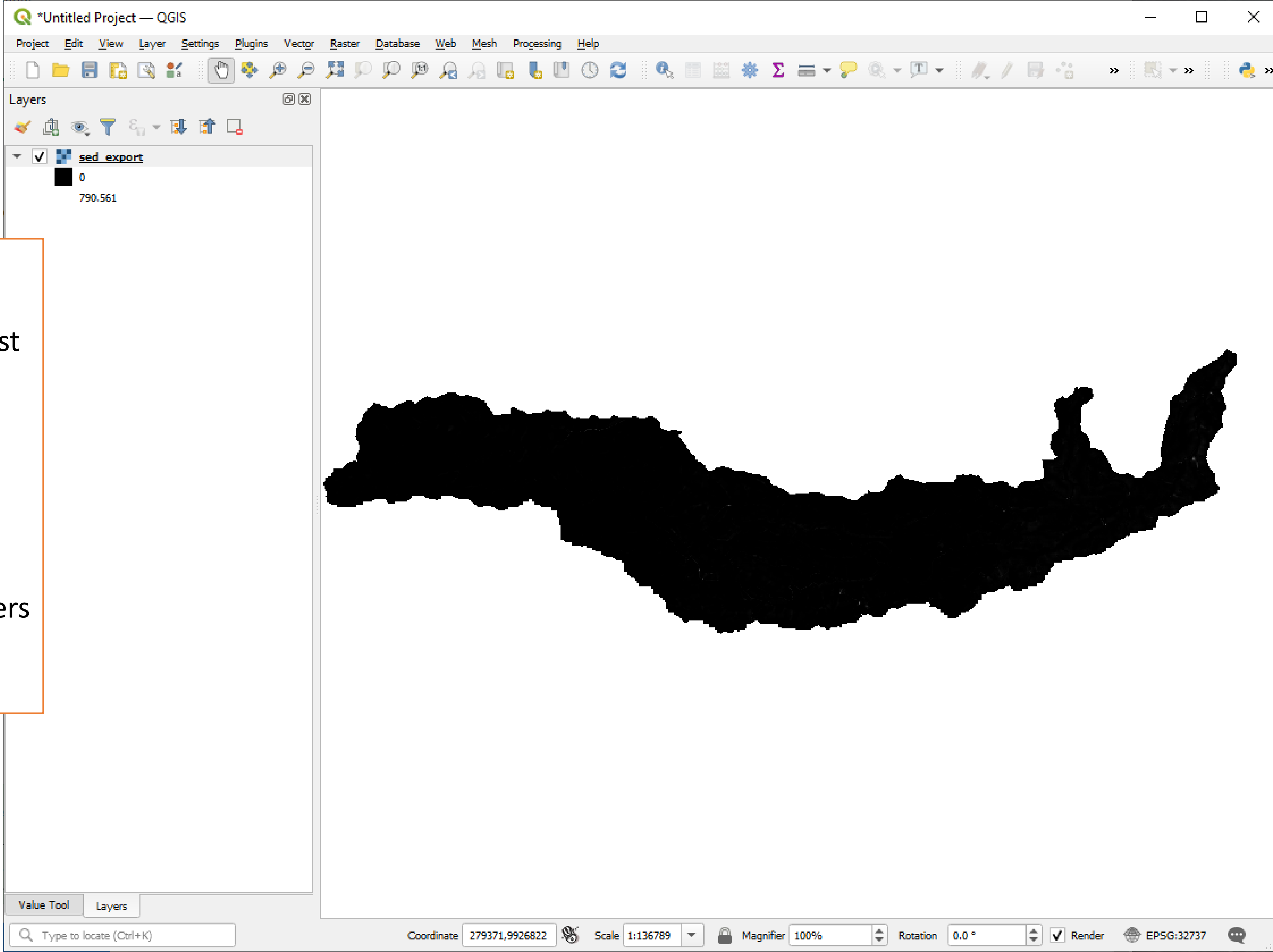
- Click Run!


invest-workbench
File Edit View Window About
InVEST
Sediment Delivery Ratio
Setup
Log
Load parameters from file
Save to JSON
Save to Python script
Save datastack
User's Guide
Frequently Asked Questions
Run
Soil Erodibility
C:\Users\jajohns\Files\Research\bas
Land Use/Land Cover
C:\Users\jajohns\Files\Research\bas
Biophysical Table
C:\Users\jajohns\Files\Research\bas
Watersheds
C:\Users\jajohns\Files\Research\bas
Drainages (optional)
raster
Threshold Flow Accumulation (number of pixels)
1000
Borselli K Parameter
2
Maximum SDR Value
.8
Borselli IC0 Parameter
.5
Maximum L Value
122

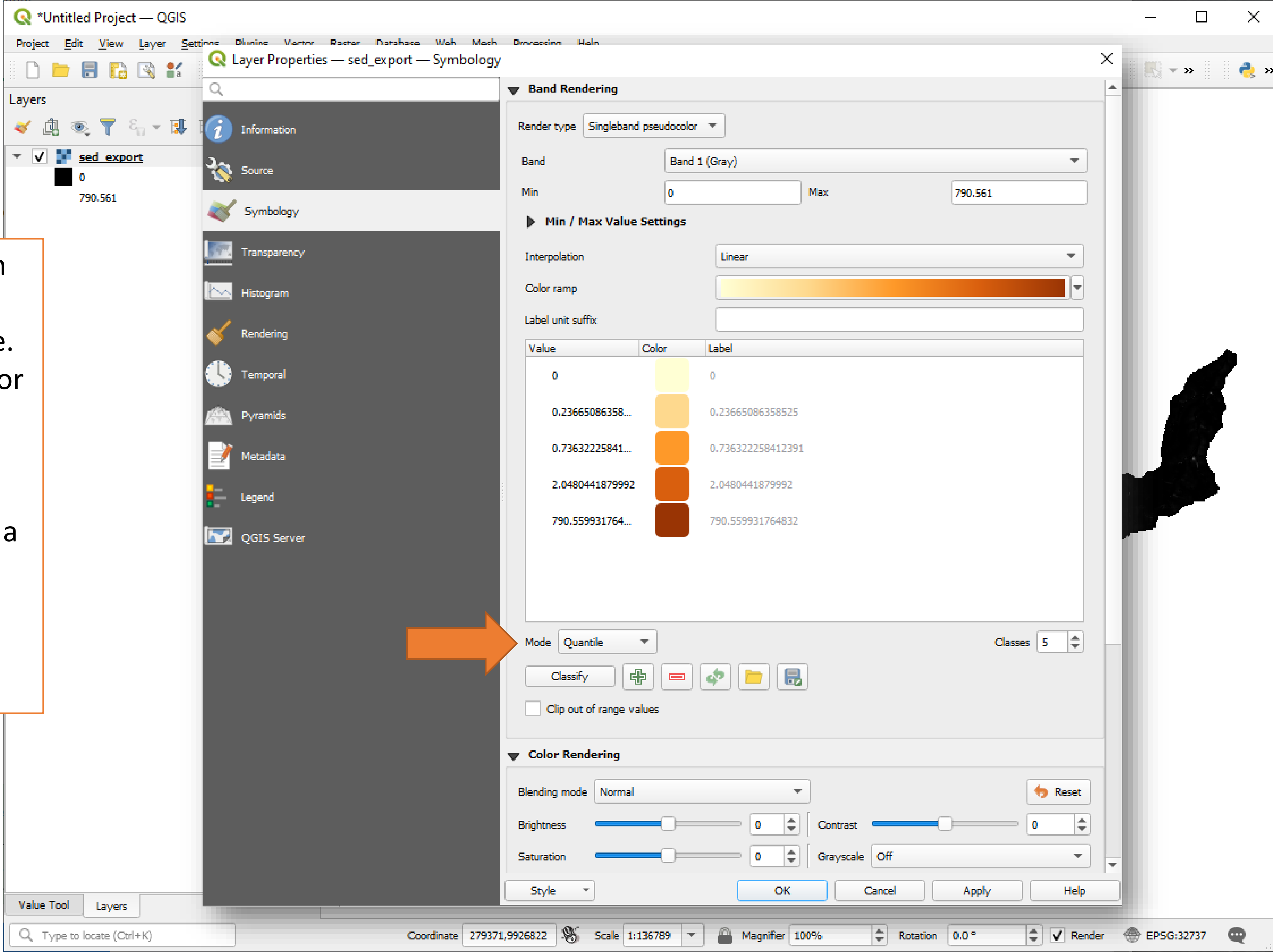
- Click the Open Workspace button.
- There are many more results than for the carbon model. Each has it’s own interpretation.
- Load sed_export.tif into QGIS.



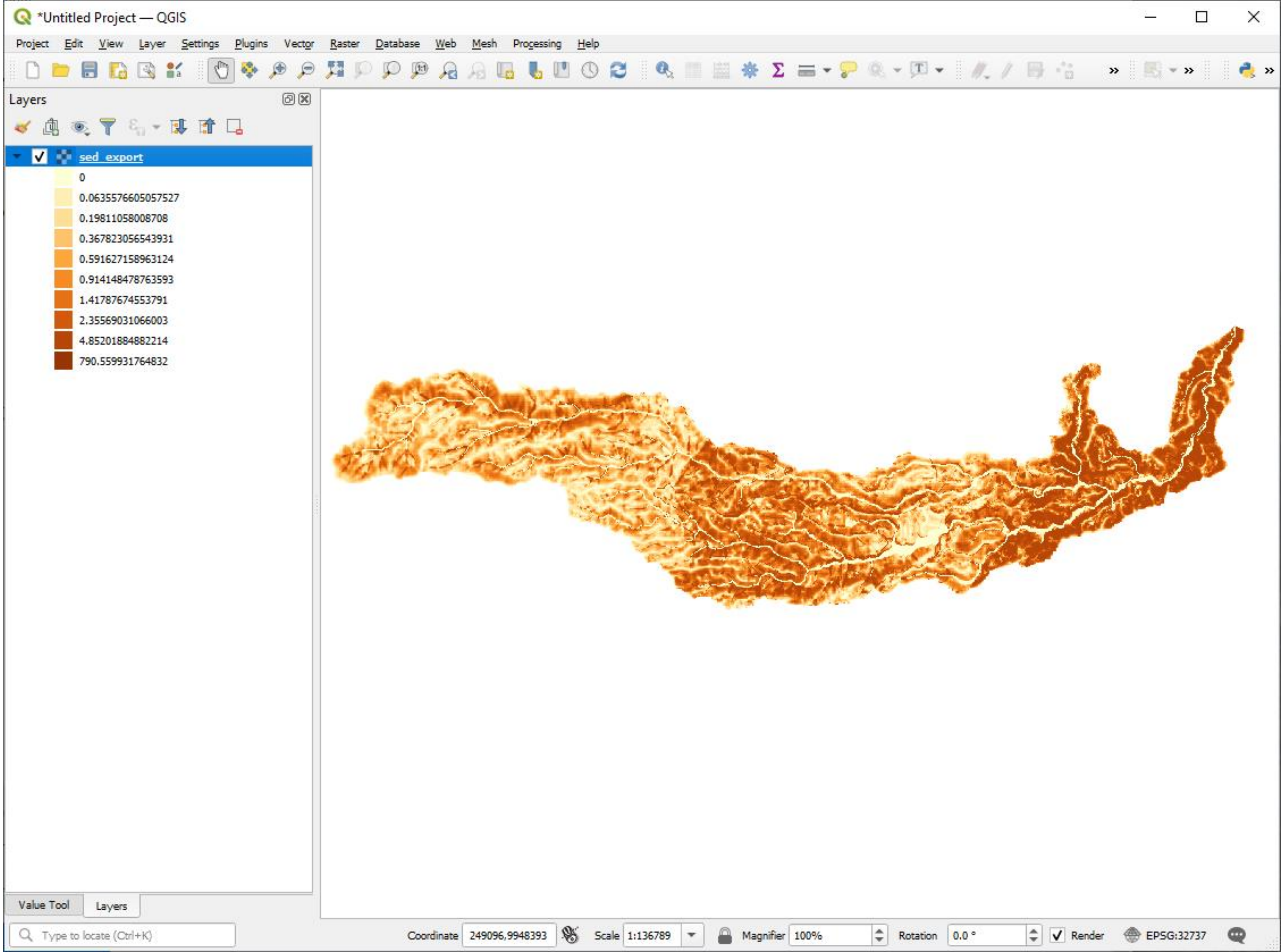
- Pretty ugly on its own.
- One challenge for interpretation is that most values are very close to zero but some spots are very high.
- Let’s colorize the map to showcase this.
- Double-click on the sed_export.tif in the Layers window



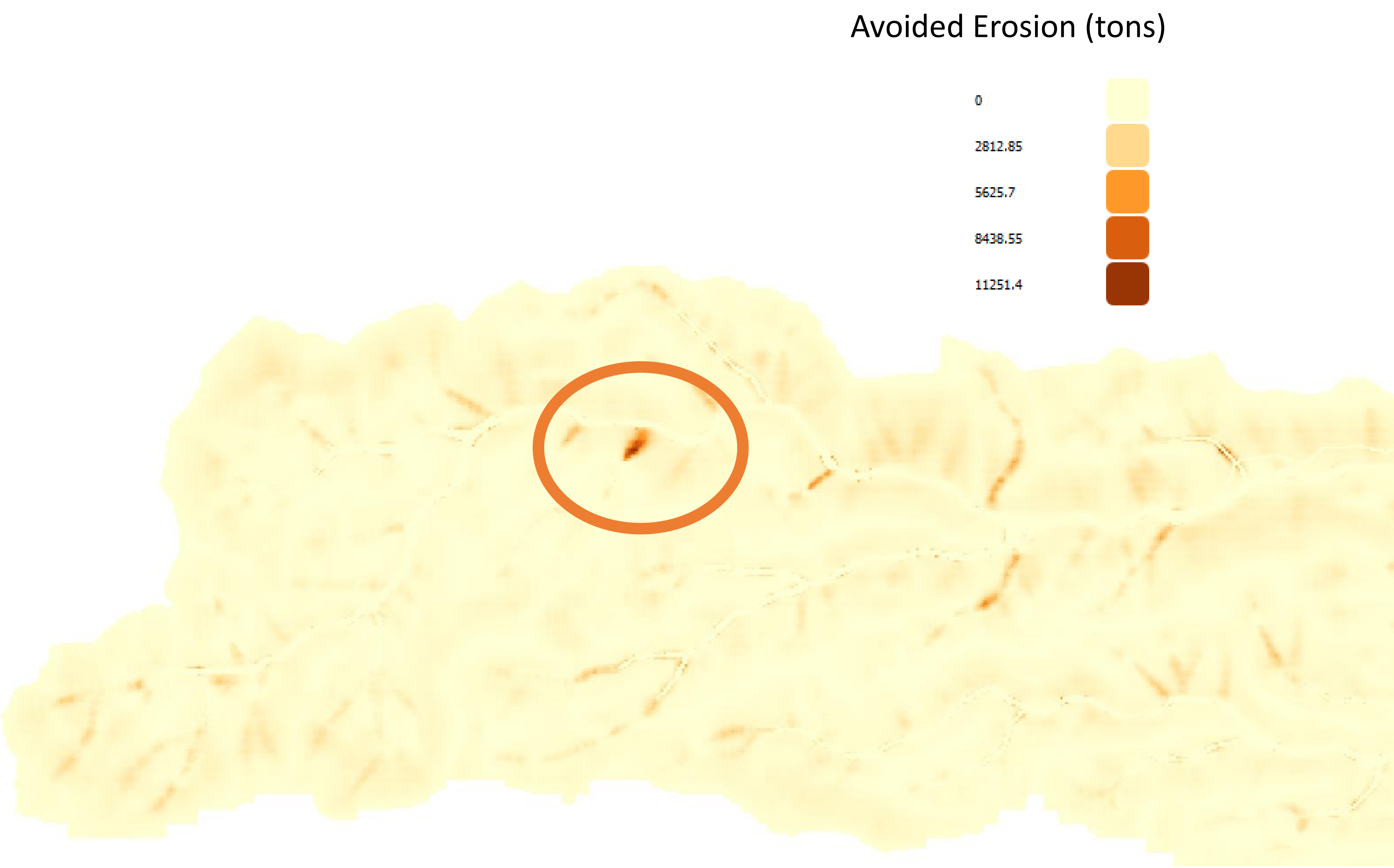
- I chose a thematic Brown color ramp.
- Set the mode to Quantile.
- This makes it so each color has the same number of pixels in its range.
- Optionally, increase the number of classes to get a more detailed colorbar.



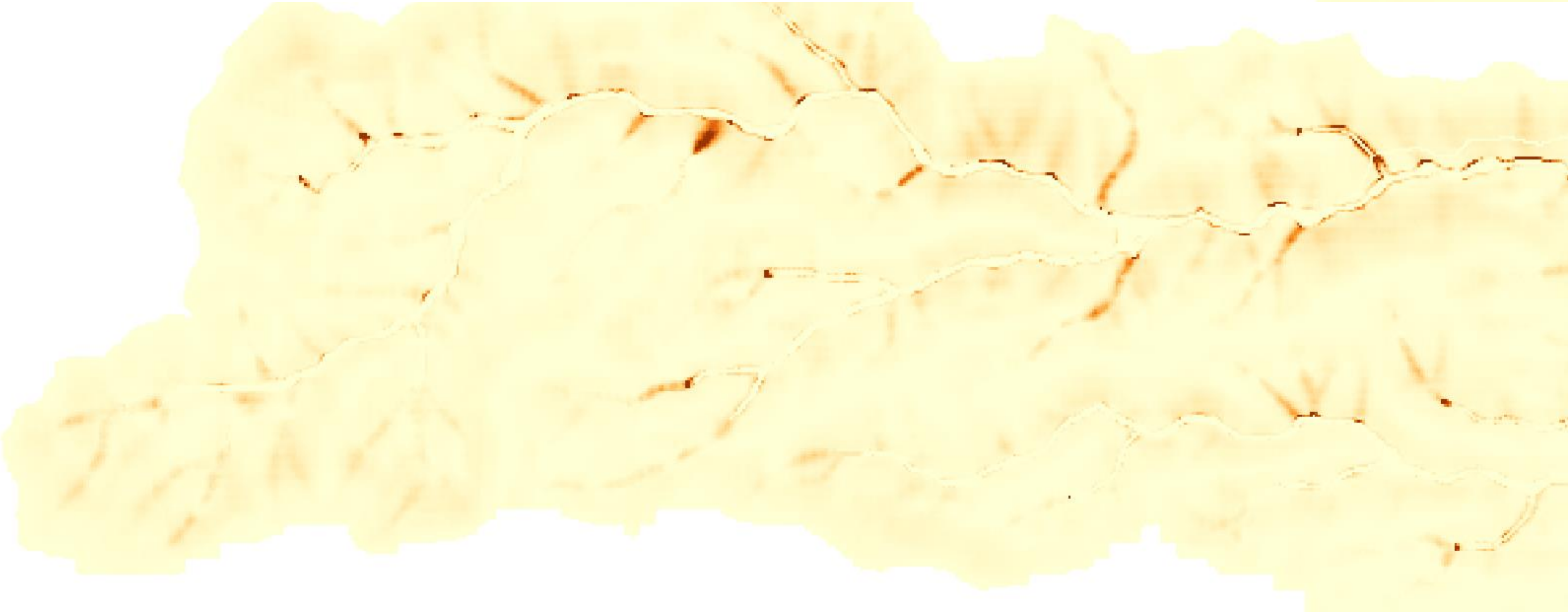
- Much prettier!
- This map plots the Tons of Sediment exported from each pixel into the stream network.
- This may be exactly the number you are looking to report to the policy maker.
- However, it is still not the “Ecosystem Service” itself.



- Here I have added a new layer, sed_retention.tif and colorized it.
- I chose a linear colorbar. This will highlight the places that are particularly bad.
- The policy advice becomes clear here. Do not degrade this natural land in particular!



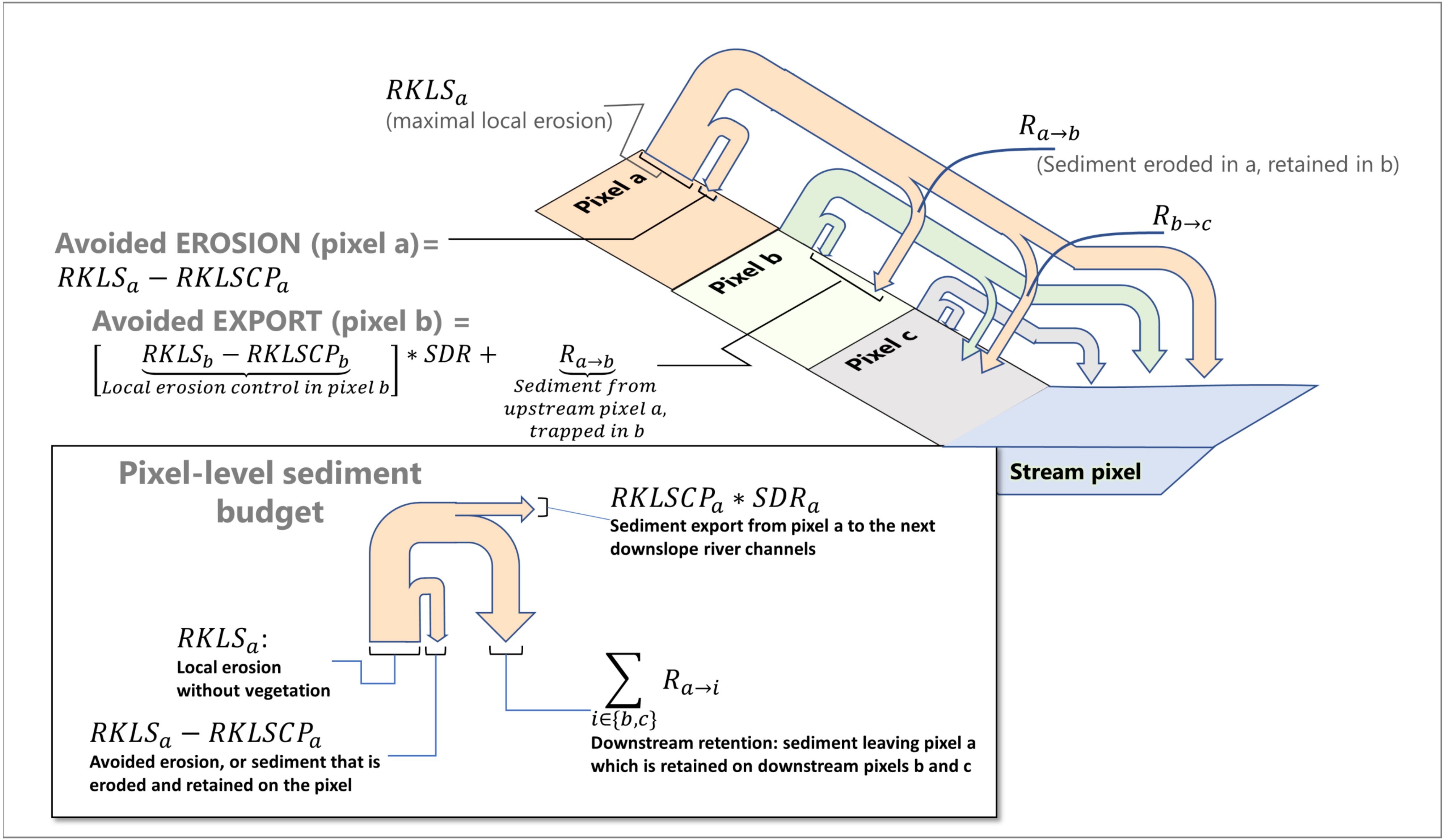
- Avoided Erosion (top)
- Avoided export (into the stream, bottom)
- Similar, but imply different optimal management strategies:
  - Preserve steep, erodible slopes versus preserve riparian vegetation along the stream



Recap

- The Sediment Delivery Model calculates both erosion and stream export
- Shows some locations can be orders-of-magnitude more important to conservation outcomes
- Foreshadow:
  - Originally, most InVEST Sediment runs focused on export (and its impact on reservoir sedimentation).
    - Valued via e.g. avoided dredging values
  - We also calculate erosion's impact on crop yield
    - Degraded soil has lower yields

Appendix


$RKLS_a$
(maximal local erosion)
Pixel a
Pixel b
Pixel c
Stream pixel
$R_{a \to b}$
(Sediment eroded in a, retained in b)
$R_{b \to c}$
Avoided EROSION (pixel a) =
$RKLS_a - RKLSCP_a$
Avoided EXPORT (pixel b) =
$\left[\underbrace{RKLS_b - RKLSCP_b}_{Local\ erosion\ control\ in\ pixel\ b}\right] * SDR + \underbrace{R_{a \to b}}_{Sediment\ from\ upstream\ pixel\ a,\ trapped\ in\ b}$
Pixel-level sediment budget
$RKLSCP_a * SDR_a$
Sediment export from pixel a to the next downslope river channels
$RKLS_a$:
Local erosion without vegetation
$RKLS_a - RKLSCP_a$
Avoided erosion, or sediment that is eroded and retained on the pixel
$\sum_{i \in \{b,c\}} R_{a \to i}$
Downstream retention: sediment leaving pixel a which is retained on downstream pixels b and c

Concepts

VALUATION

- Very context-specific!
- Built-in replacement and avoided cost approaches for reservoir dredging or water treatment
- In InVEST: retention is calculated using a reference scenario of **bare soil**
  - $Retention = Export_{bare\_soil} - Export_{current\_land\_use}$