Institute of Hydrology
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LAWI301244 Application of GIS in Hydrology and Water Management

Unit 2 – Catchment and Stream Network Delineation

Mathew Herrnegger

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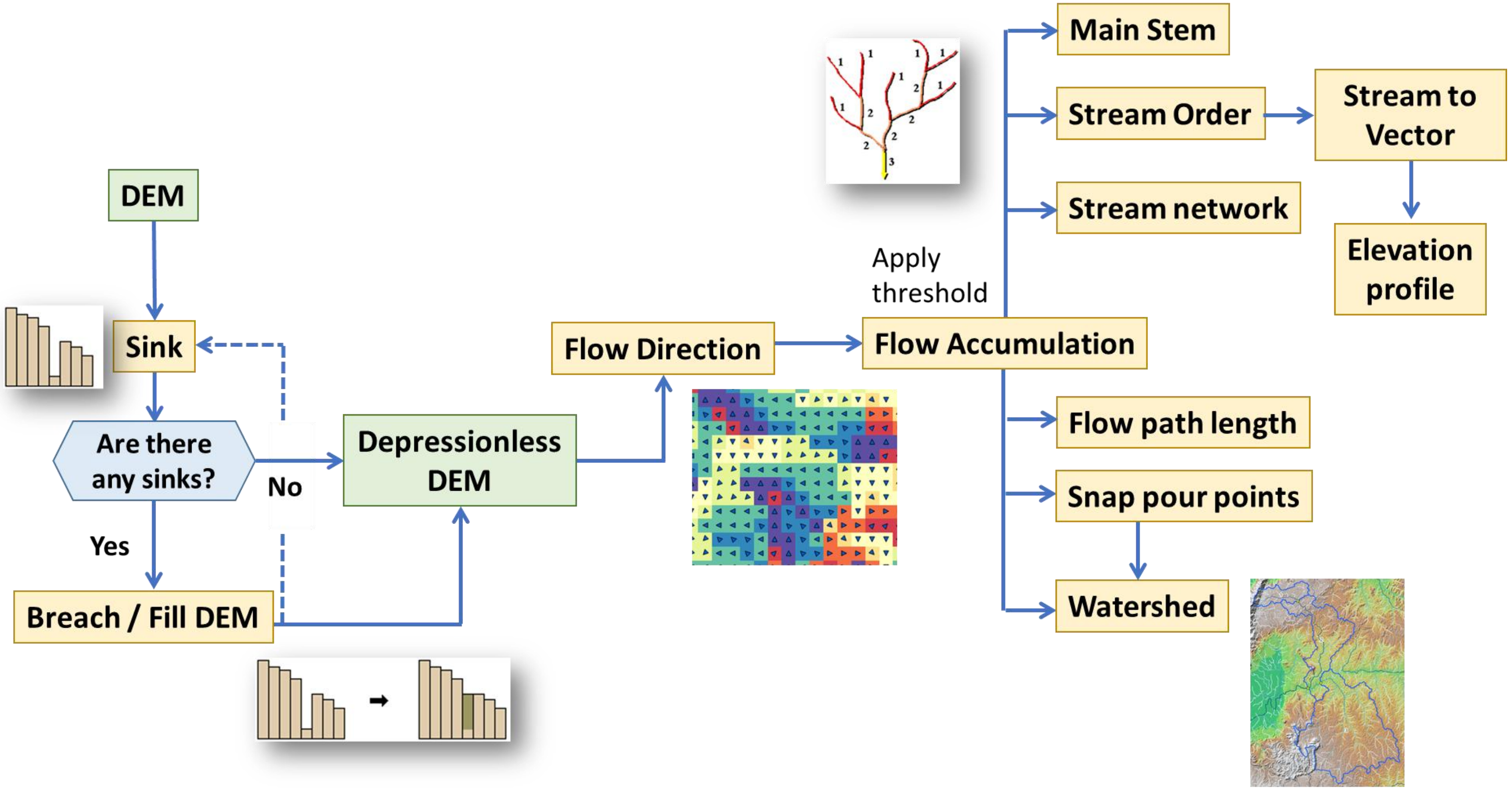
Content

- Introduction - DEMs
- Catchment and stream network delineation



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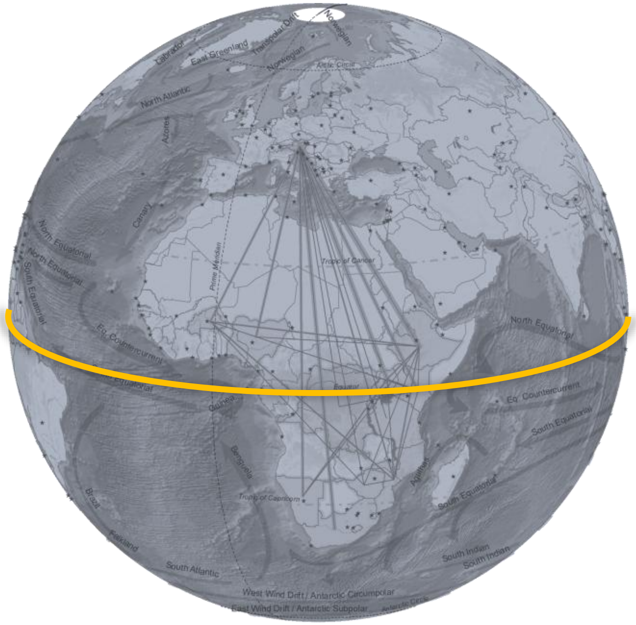
Introduction: Digital elevation models (DEMs)



Esri, Garmin, GEBCO, NOAA NGDC, and other contributors

Introduction: Digital elevation models (DEMs)

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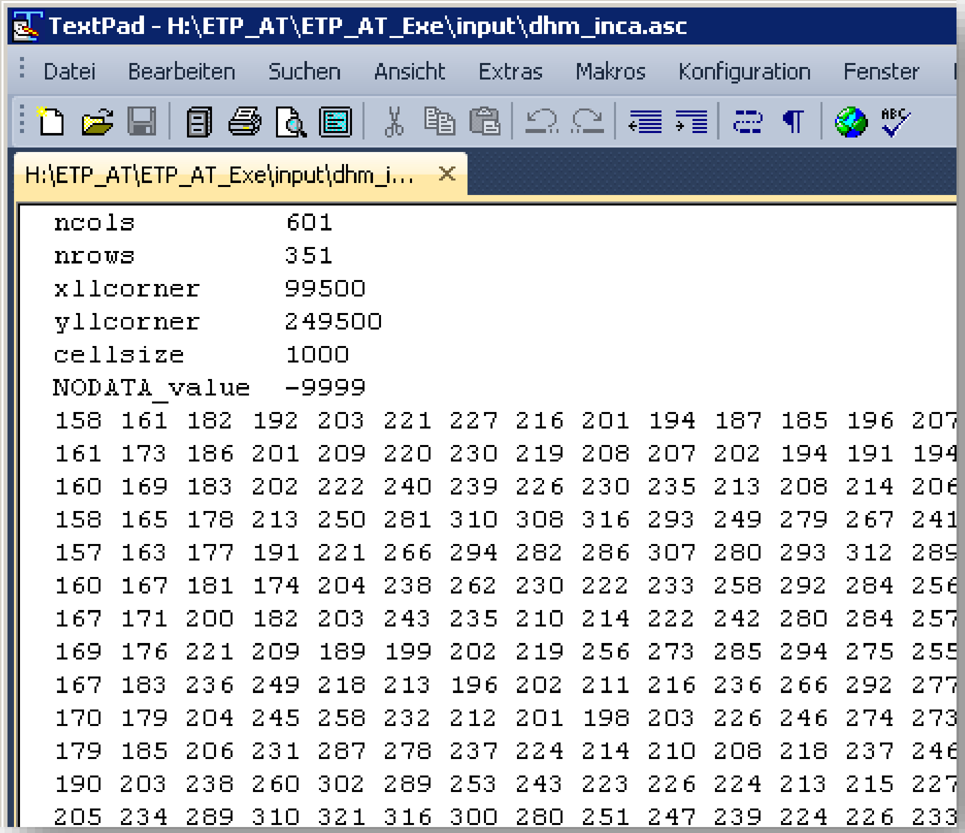
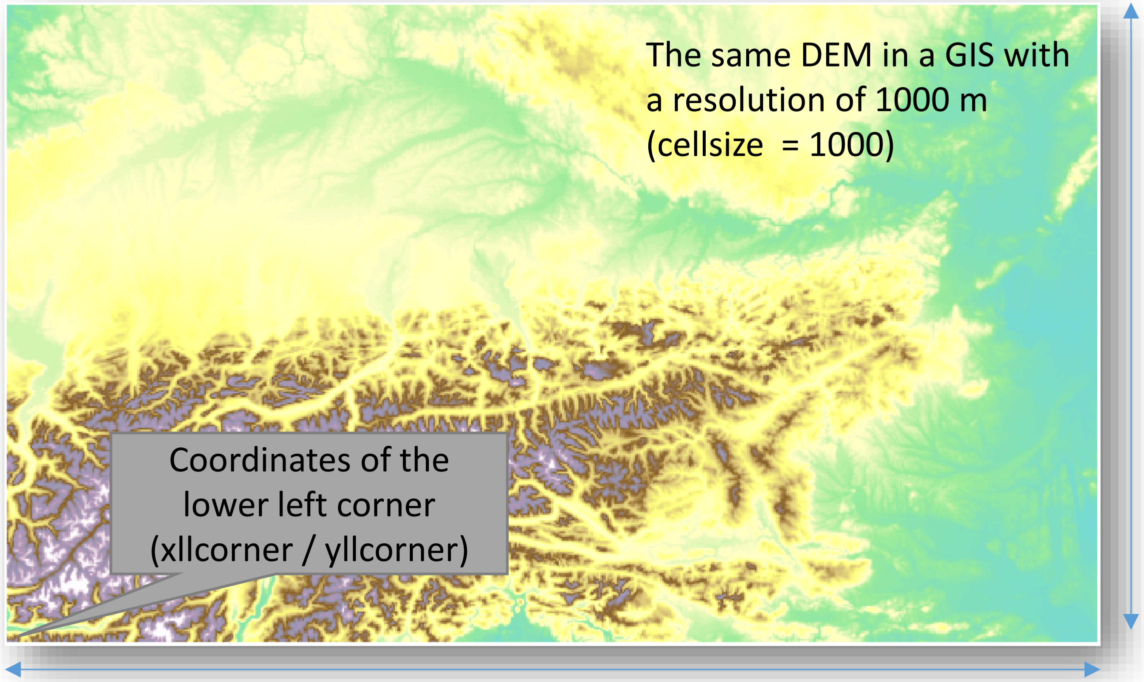
- Digital model or 3D representation of a terrain's surface, providing key information on topography or geomorphology (e.g. slope, aspect, solar potential) for many different uses (e.g. environmental sciences, hydrology, engineering, visualization etc.)
- Digital Terrain Model or Digital Land Surface Model is a digital raster map representing elevations of terrain / bare surface.

Example of a DEM stored as an „ESRI ASCII GRID“ viewed in a standard text editor





Number of rows (nrows) = 351

Number of columns (ncol) = 601

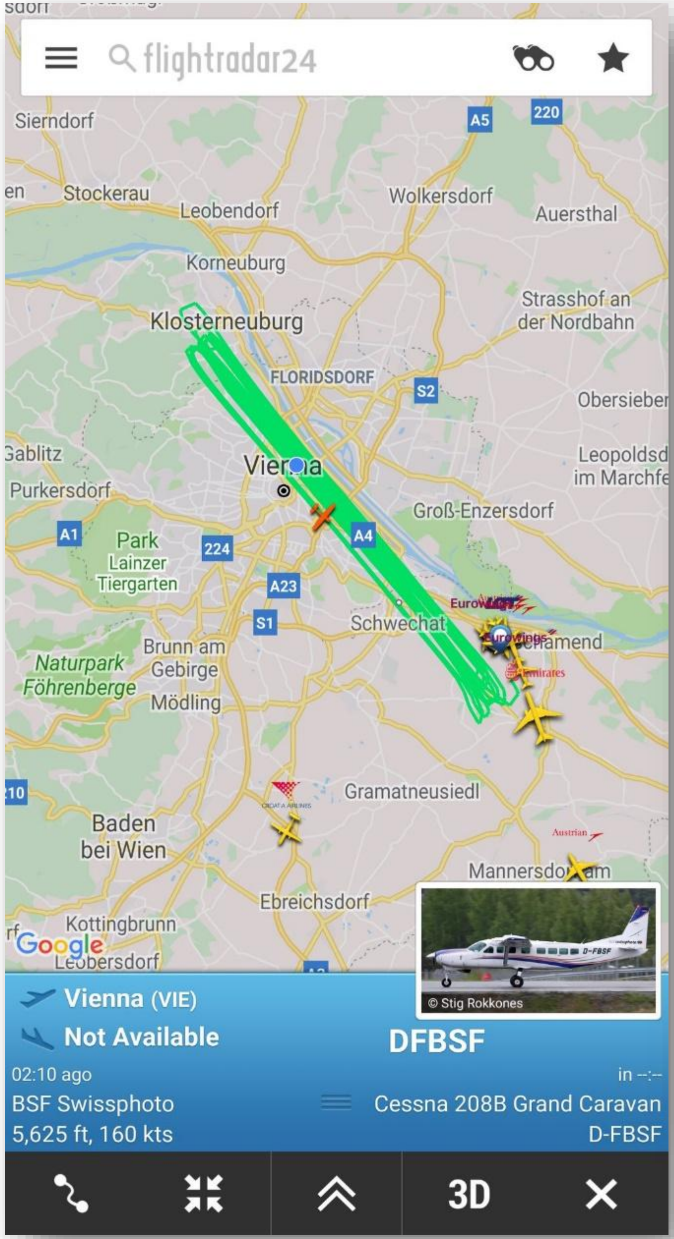
Introduction: Digital elevation models (DEMs)

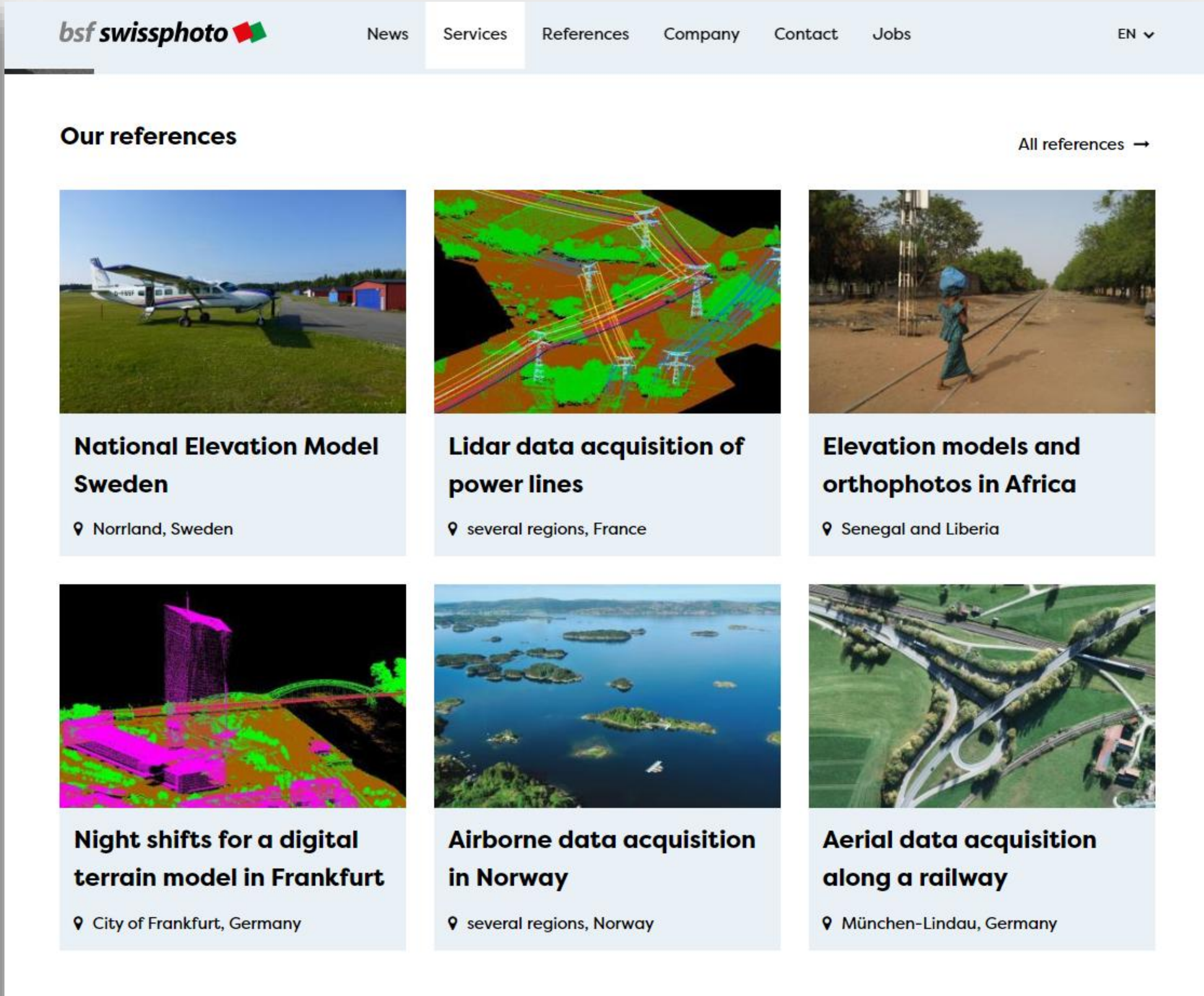
- DEMs differ on the basis of the method used to derive the elevation information and the spatial resolution
  - DEM derived from other elevation information: Geometric surveys, topographic maps
  - DEMs from laser scans (LIDAR) have spatial resolutions of <30 cm to 1 m
  - Typical DEMs generated from satellite data have a spat. res. of about 30 to 90 m

Satellite image & DEM of Cape peninsula (NASA)

Detail of a DEM for the Upper Mur in Austria

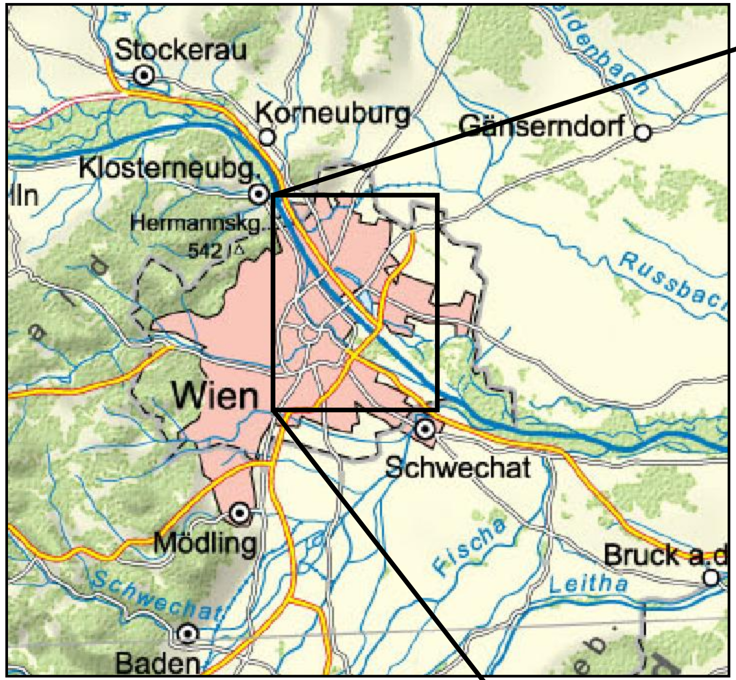
Introduction: Digital elevation models (DEMs)

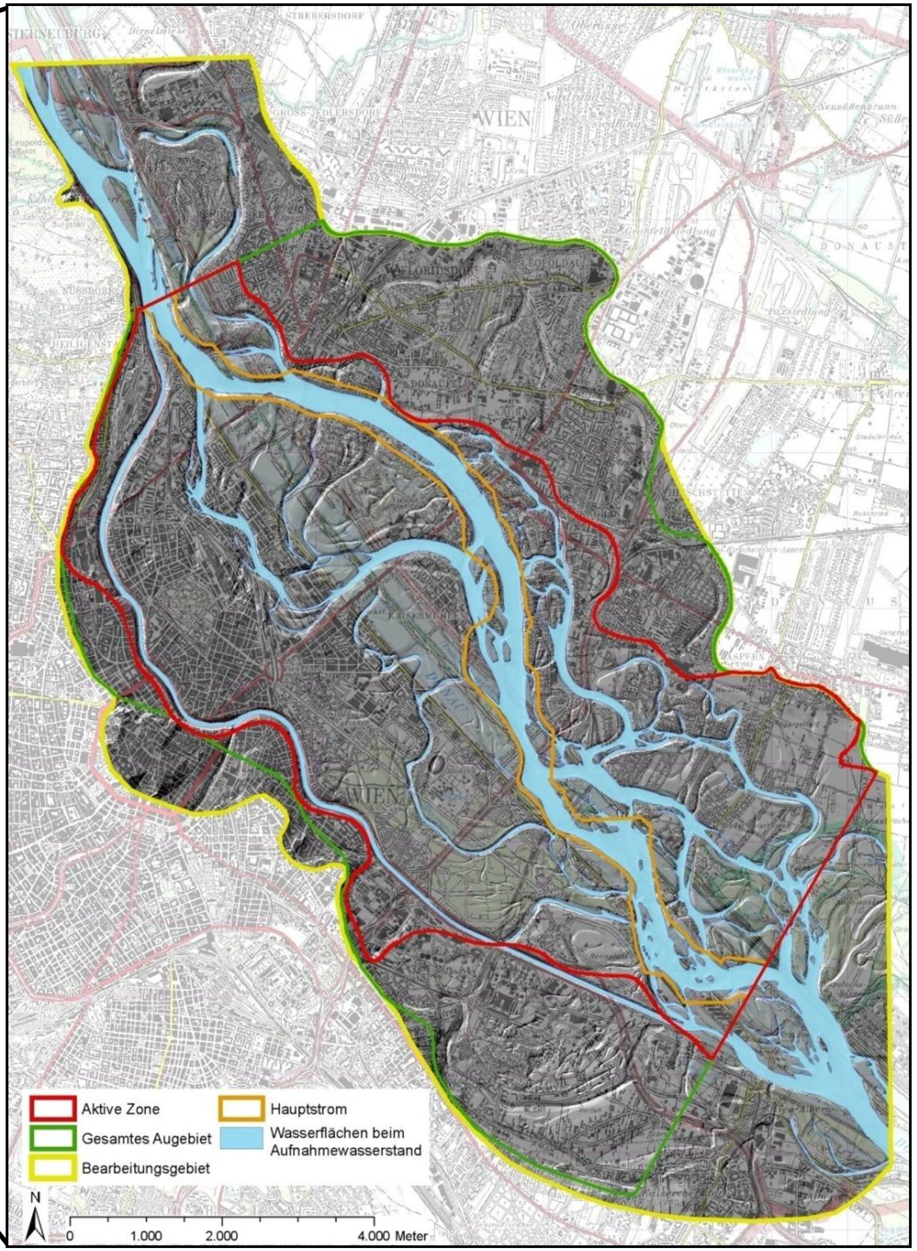




Flight tracked on 06.02.2019 – Is Vienna getting a new DEM?

Introduction: Digital elevation models (DEMs)





Example for a DEM derived from other elevation information: *Reconstruction of the Danube Floodplain at Vienna in 1849 (Master thesis Herrnegger, 2007)*

Introduction: Digital elevation models (DEMs)

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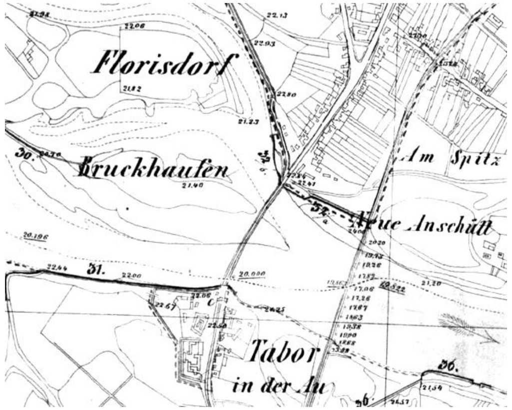
Several maps and other data sources build the basis for the reconstruction of the historic DEM

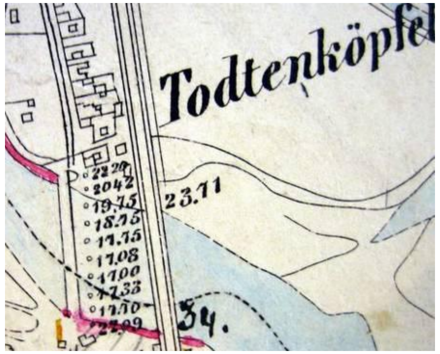
Plastische Darstellung der Donau bei Wien

Hydrotechnische Vermessung d. Donau

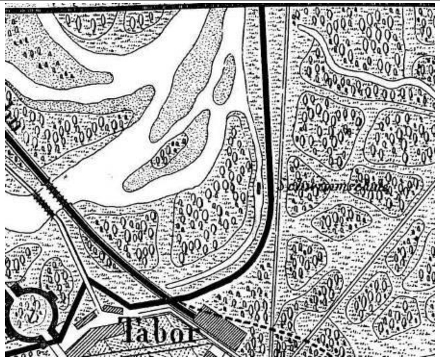


Lage- & Schichtenplan Kazda / Killian

Fotos Plan NÖLA (1849)



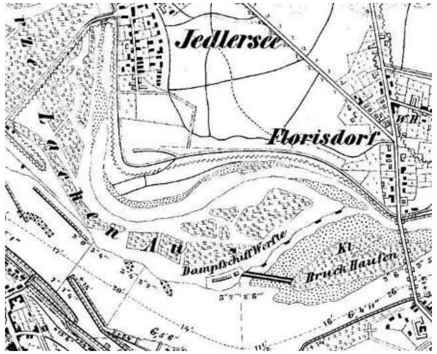
Karte Rigel (1850)



ÖK50

Studie MA49 (1841)

Passeti-Karte (1857)

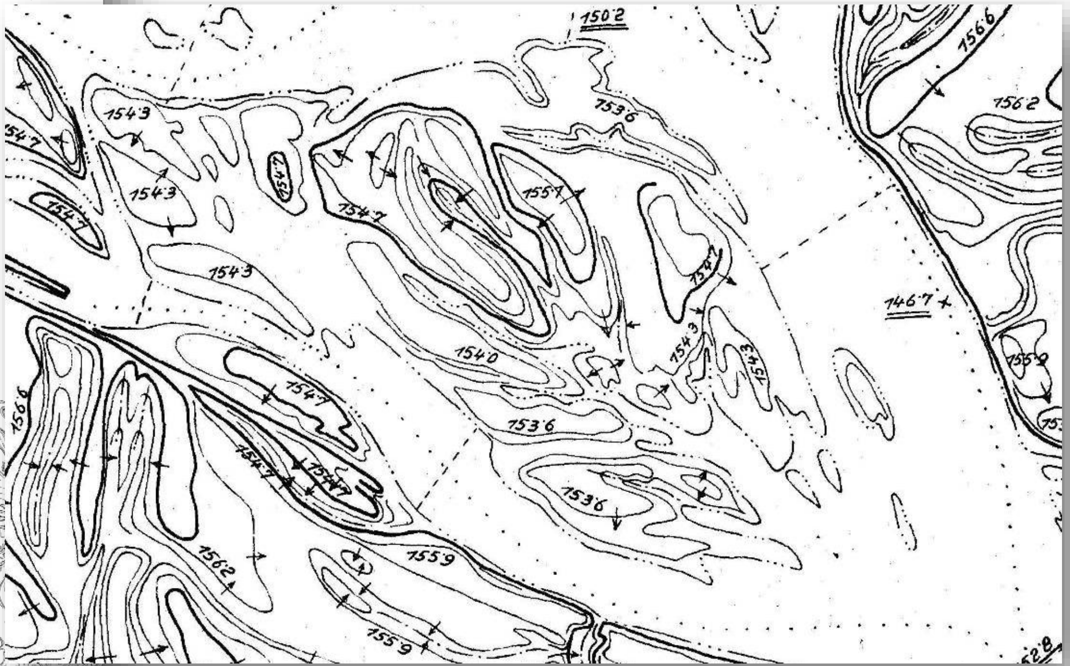


Mehrzweckkarte d. MA41-Stadtvermessung

Introduction: Dig

Several maps and ot … reconstruction of the historic DEM

Lage- & Schichtenplan
Kazda / Killian



Map of contour lines, which were digitalized in ArcMap

Introduction: Di

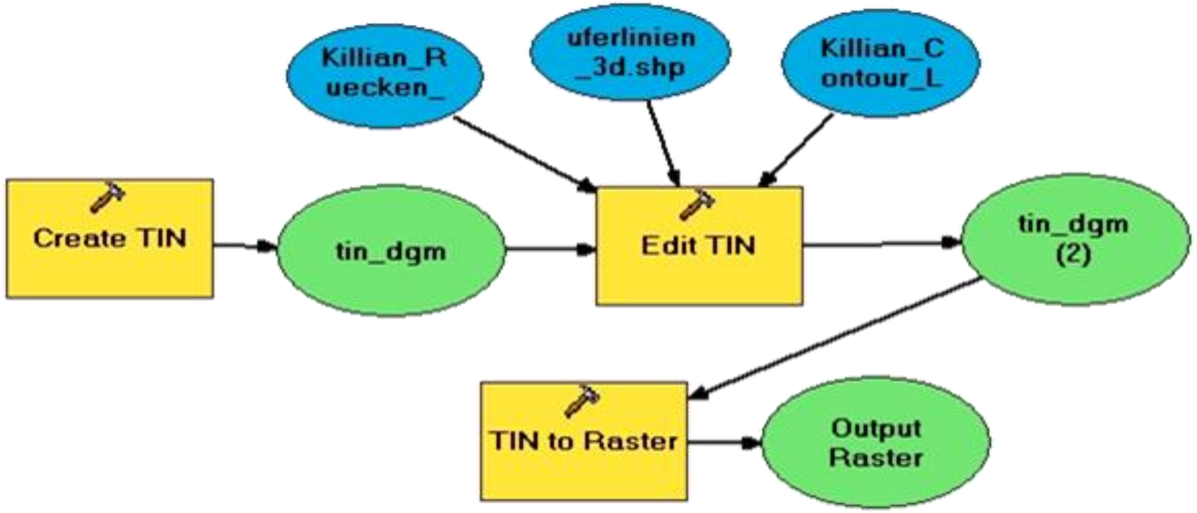
Several maps and o ... he reconstruction of the historic DEM

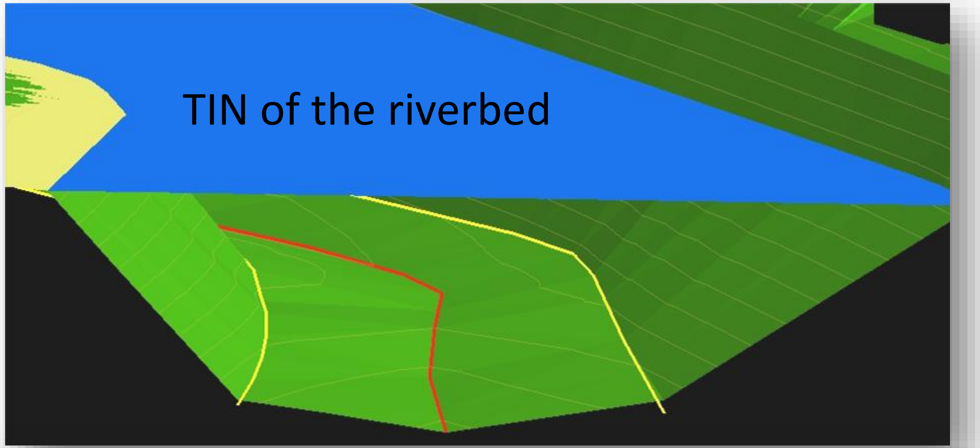
Plastische Darstellung der Donau bei Wien

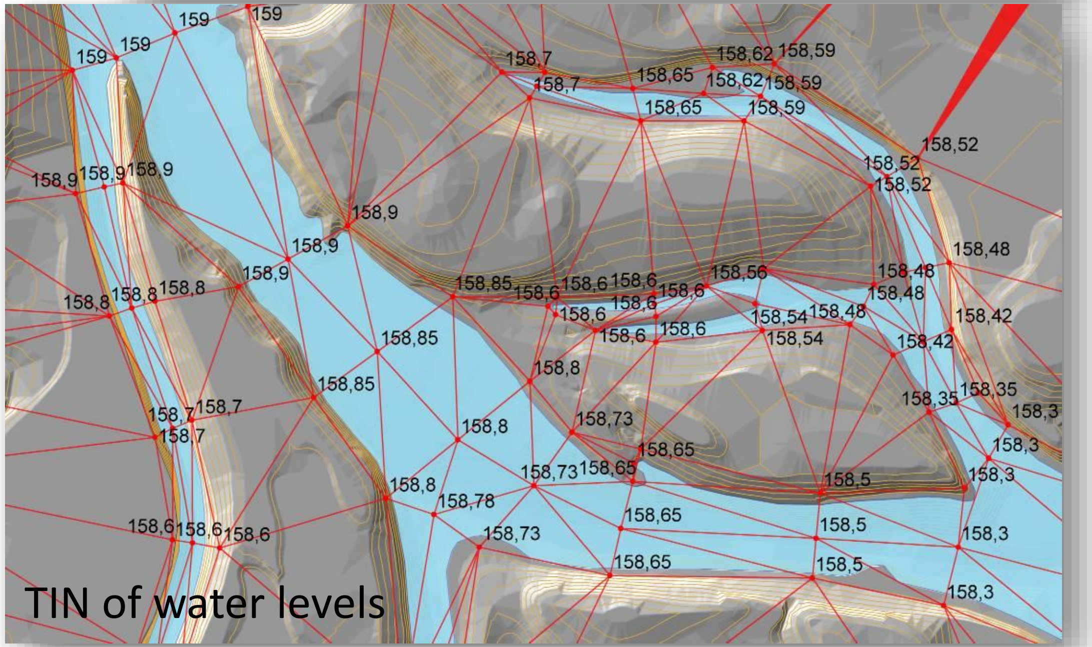
Georeferenced mosaic of images of the plastic model located at the Technical Museum Vienna

Introduction: Digital elevation models (DEMs)

ArcGIS Model builder is used to derive a Triangular Irregular Network (TIN) and the DEM



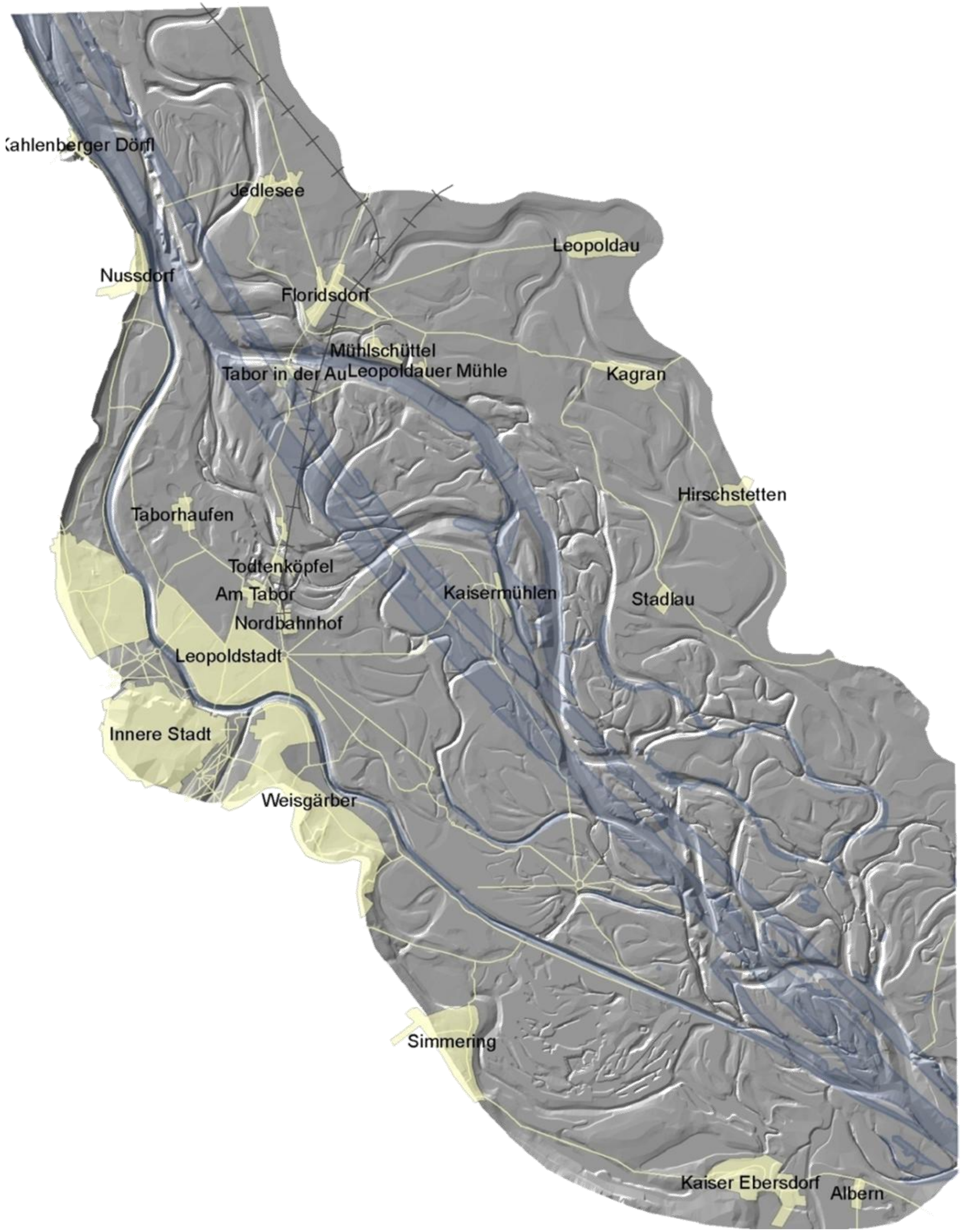




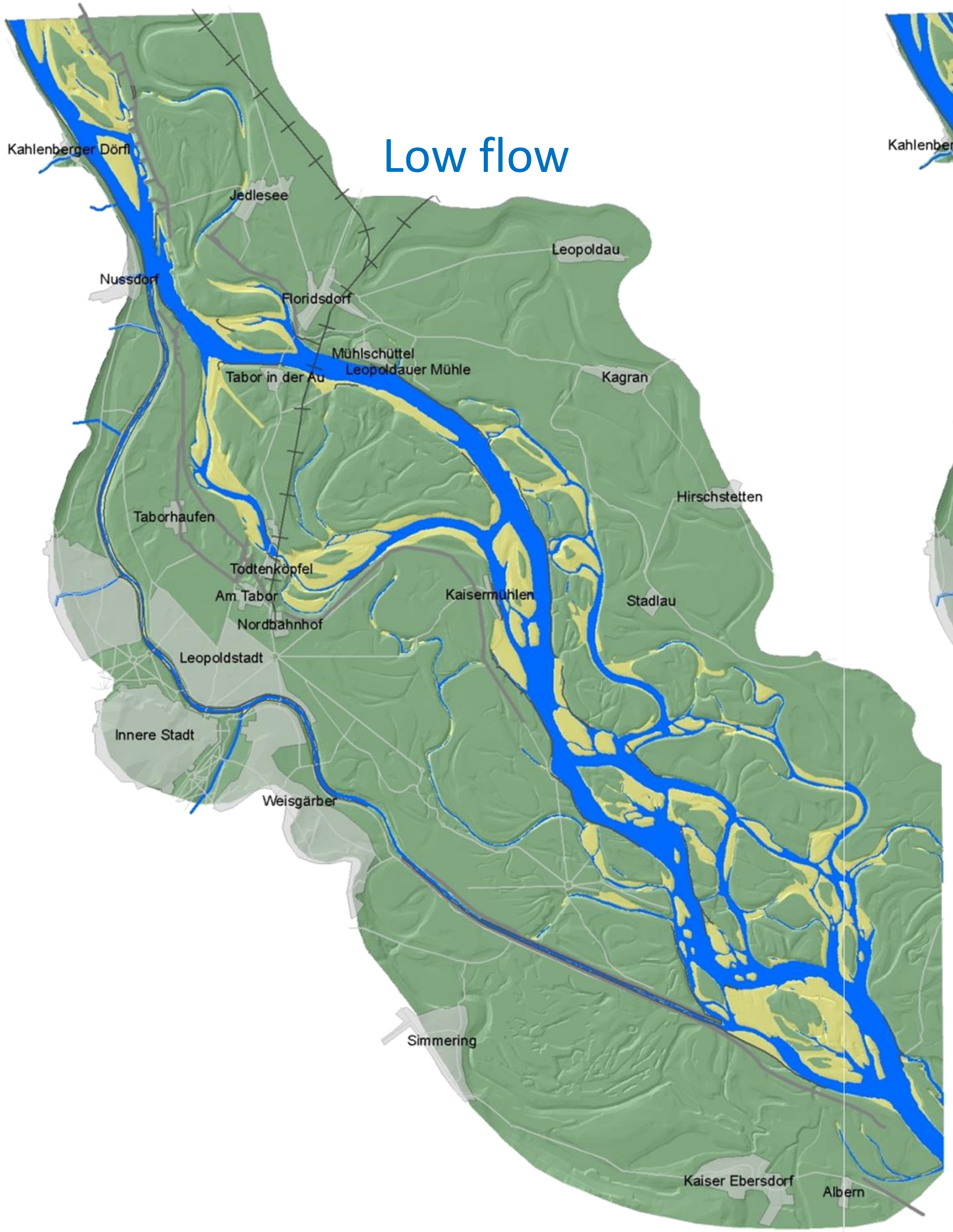
Introduction: Digital elevation models (DEMs)

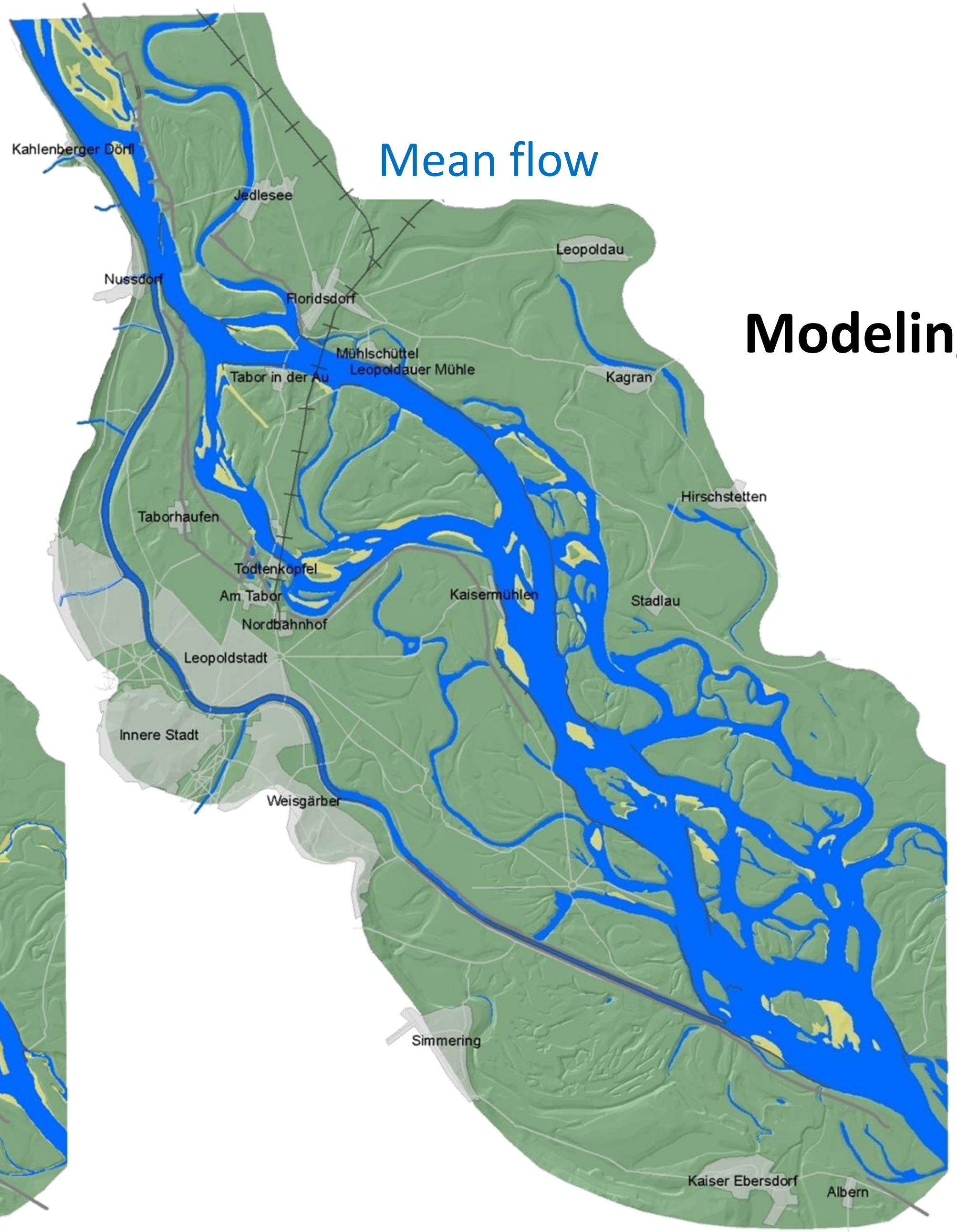
Final result

3-D-Information of the river landscape



Introduction: Digital elevation models (DEMs)





Modeling different discharges

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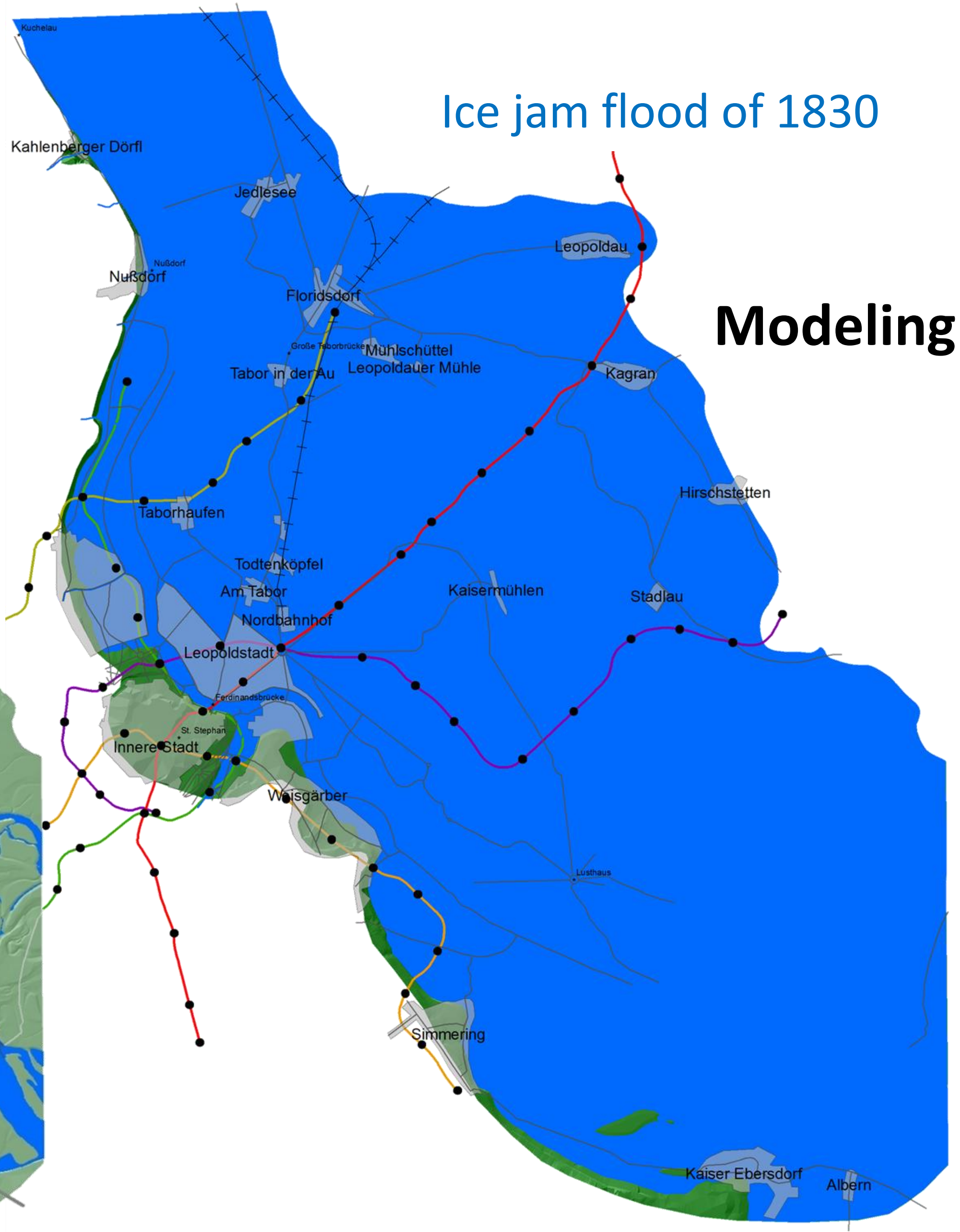
Introduction: Digital elevation models (DEMs)

Mean annual flood discharge

Ice jam flood of 1830



Modeling different discharges

Introduction: Digital elevation models (DEMs)

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Ice jam flood of 1830

odeling different discharges

Introduction: Digital elevation models (DEMs)

Ice jam flood of 1830

Jägerzeile, todays Praters

Schmidgasse, Rossau

Introduction: Digital elevation models (DEMs)

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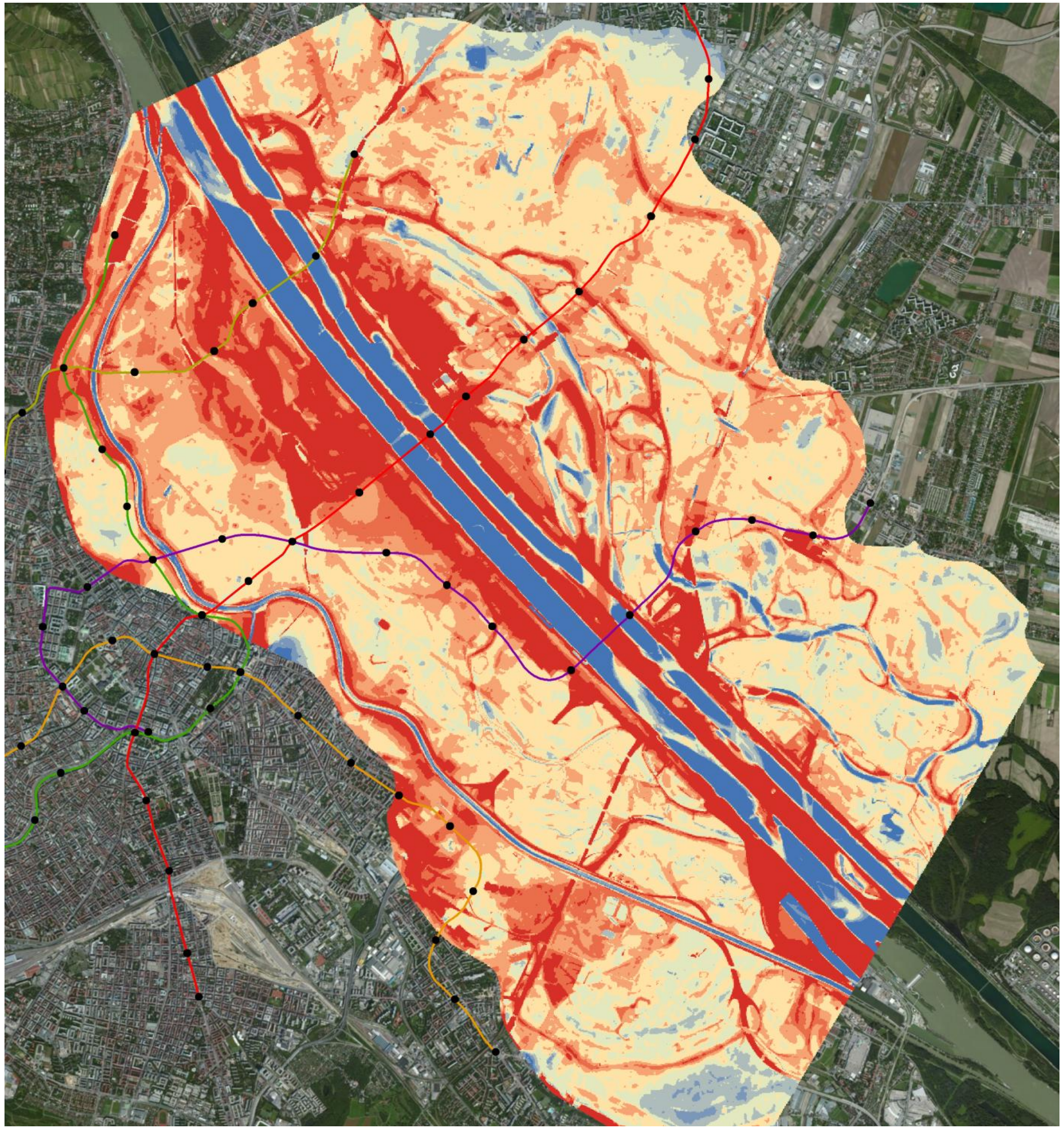
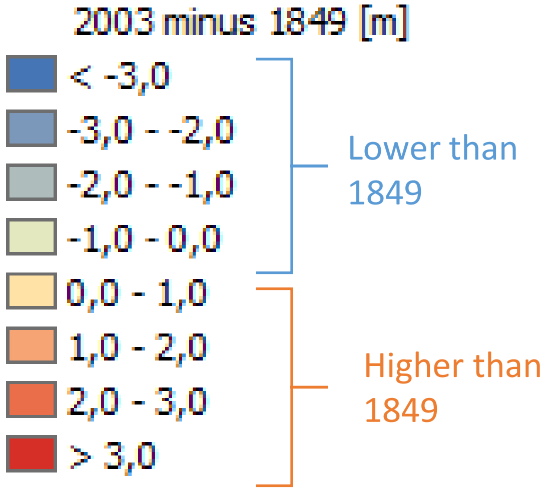


Topographical changes – 1849 vs. 2003

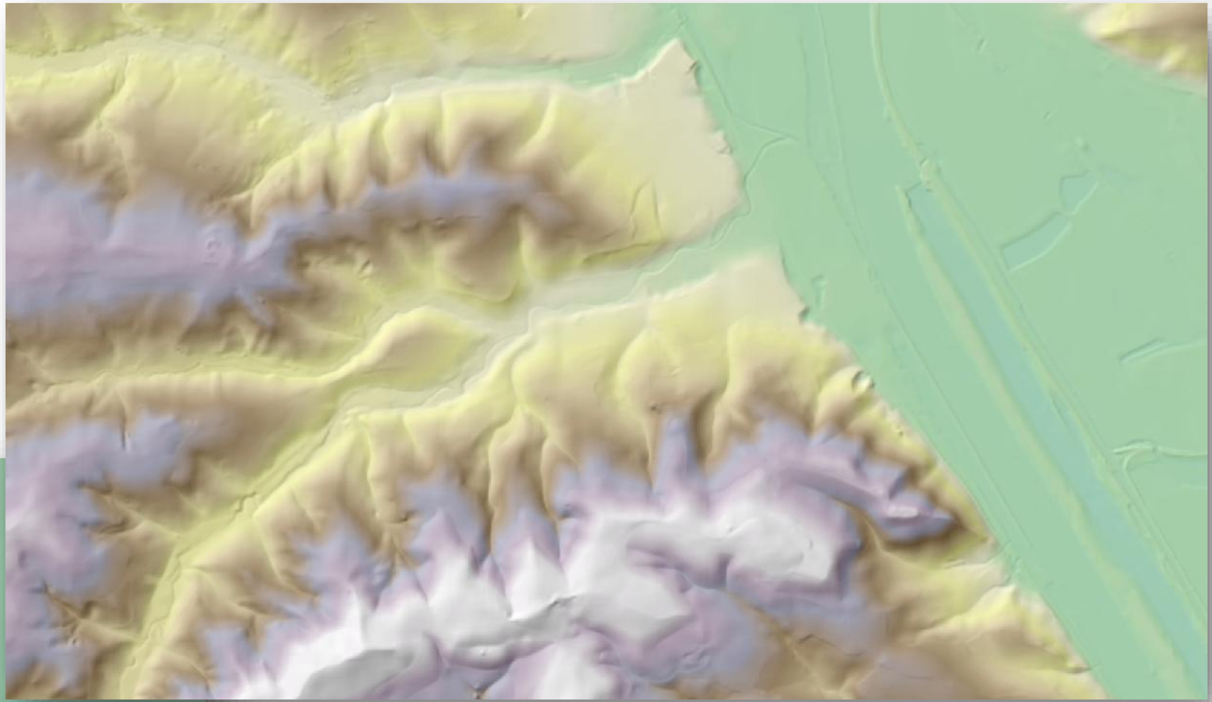
Today, ~35 km² or 24 % of Vienna‘s urban area is situated in the former Danube floodplains



Spatial Resolutions

Example of 2 different spatial resolutions:

10x10 m vs. 100 x100m



An area north of Vienna is shown

Spatial Resolutions

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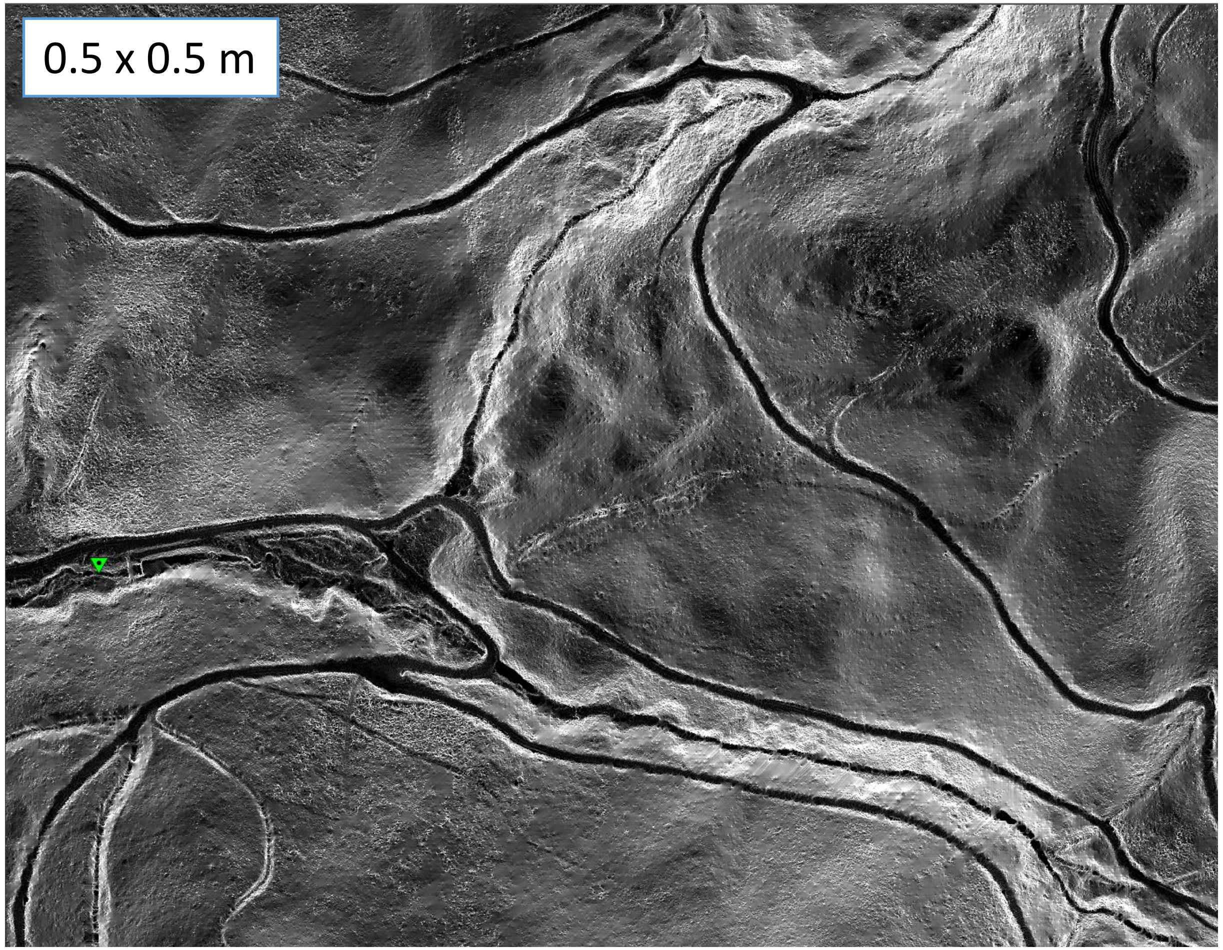
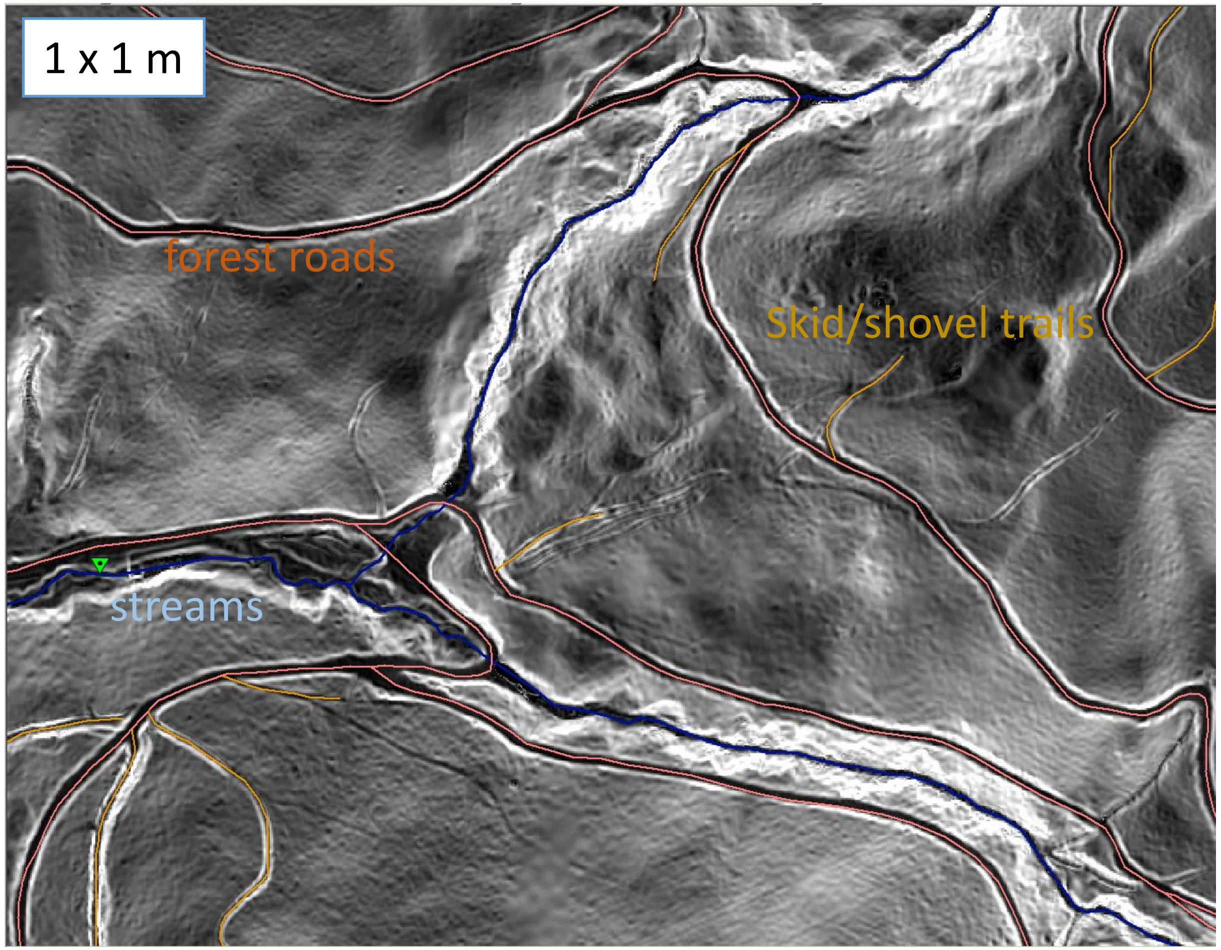
Very high resolution DEM spatial – Example “Rosalia Research Catchment”

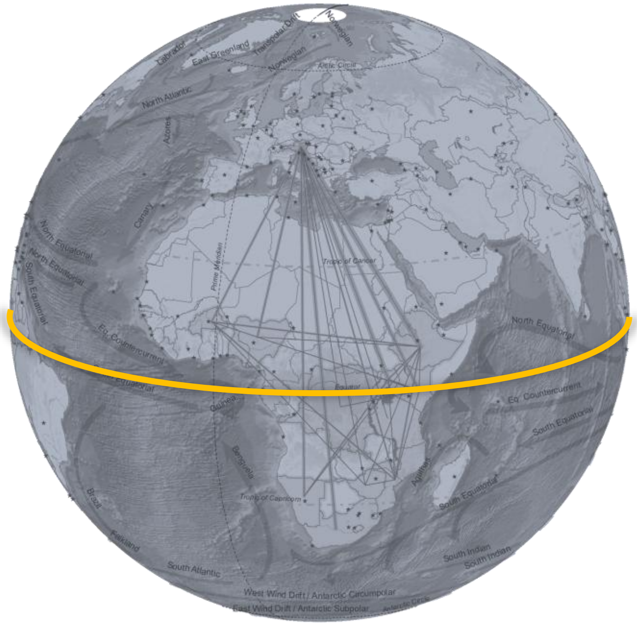




Spatial Resolutions

Very high resolution DEM spatial – Example Loboi – Lake Bogoria (Kenya)

Data sources for DEMs



Esri, Garmin, GEBCO, NOAA NGDC, and other contributors

Data sources for DEMs

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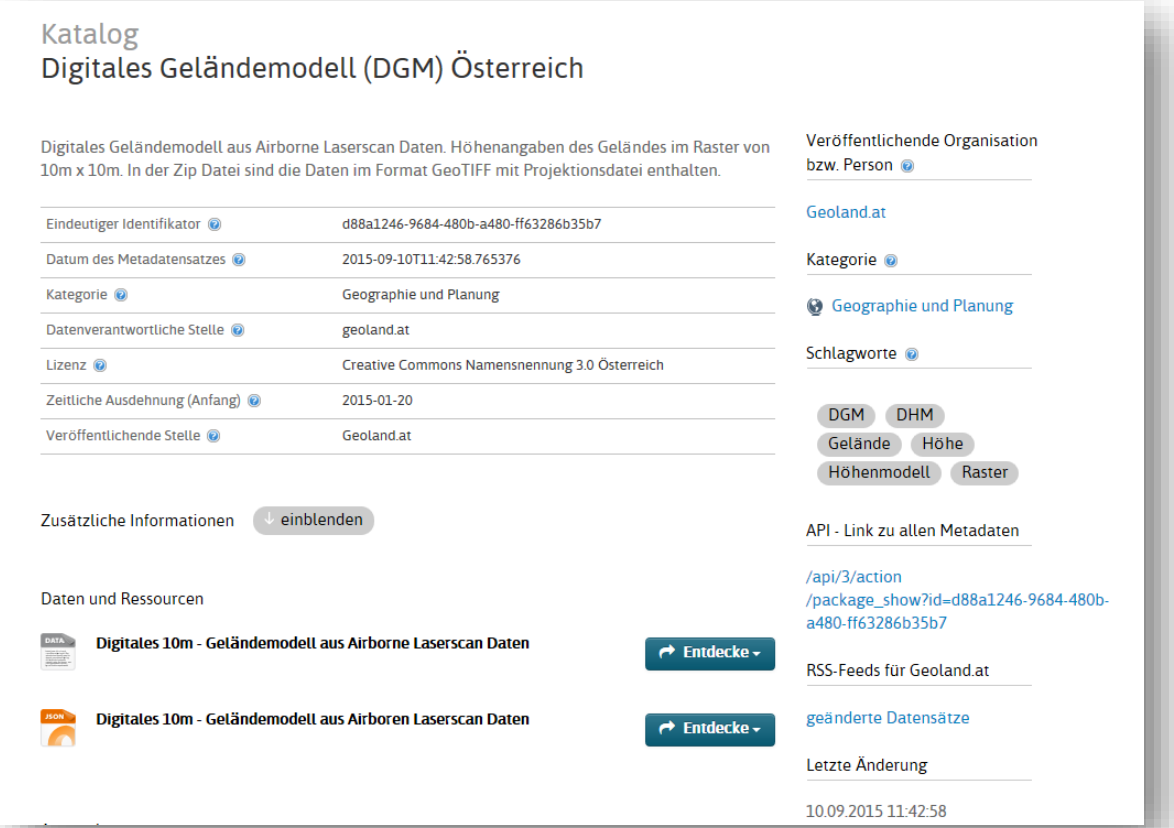
- Austria: Digital elevation model is available with a spatial resolution of 10x10 m, derived from Airborne Laserscan data
    - via https://www.data.gv.at/



Katalog

Digitales Geländemodell (DGM) Österreich

Digitales Geländemodell aus Airborne Laserscan Daten. Höhenangaben des Geländes im Raster von 10m x 10m. In der Zip Datei sind die Daten im Format GeoTIFF mit Projektionsdatei enthalten.

Eindeutiger Identifikator	d88a1246-9684-480b-a480-ff63286b35b7
Datum des Metadatensatzes	2015-09-10T11:42:58.765376
Kategorie	Geographie und Planung
Datenverantwortliche Stelle	geoland.at
Lizenz	Creative Commons Namensnennung 3.0 Österreich
Zeitliche Ausdehnung (Anfang)	2015-01-20
Veröffentlichende Stelle	Geoland.at

Zusätzliche Informationen einblenden

Daten und Ressourcen

Digitales 10m - Geländemodell aus Airborne Laserscan Daten Entdecke

Digitales 10m - Geländemodell aus Airboren Laserscan Daten Entdecke

Veröffentlichende Organisation bzw. Person

Geoland.at

Kategorie

Geographie und Planung

Schlagworte

DGM DHM Gelände Höhe Höhenmodell Raster

API - Link zu allen Metadaten

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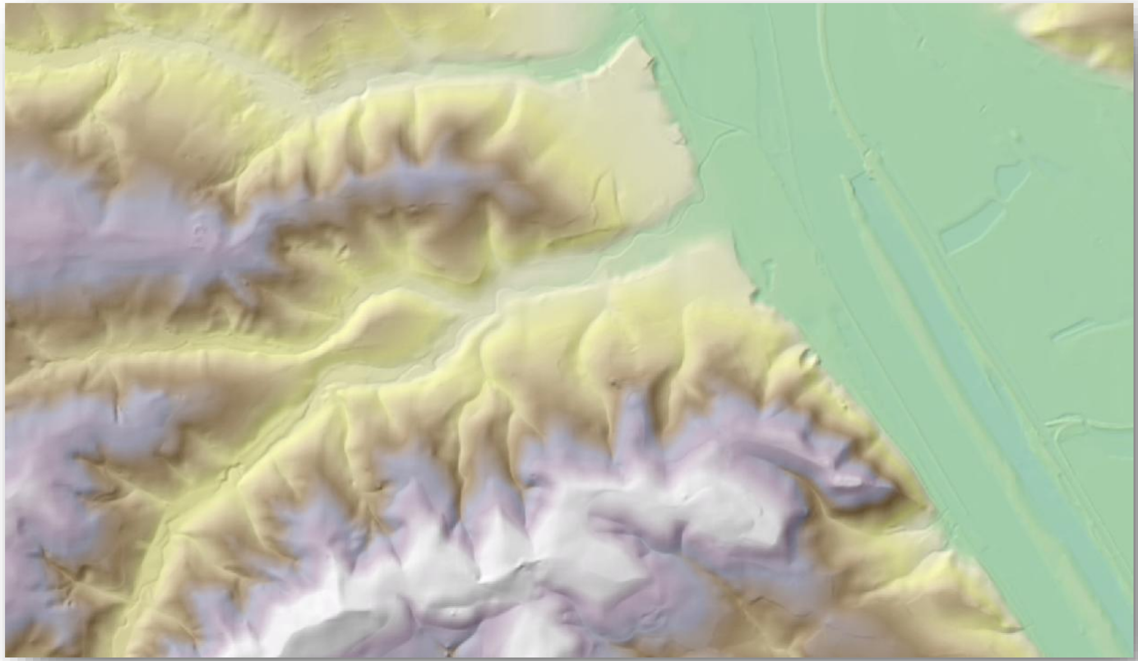
RSS-Feeds für Geoland.at

geänderte Datensätze

Letzte Änderung

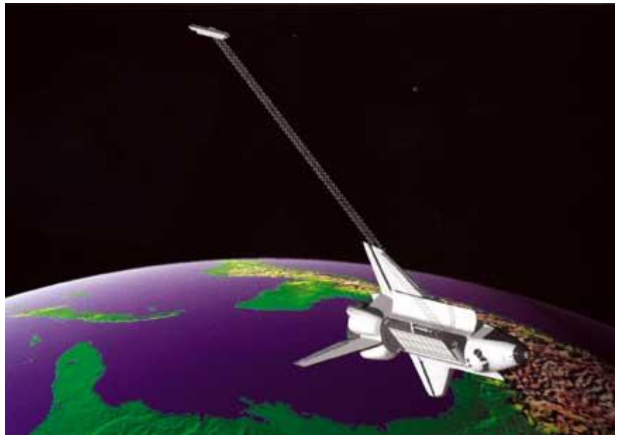
10.09.2015 11:42:58

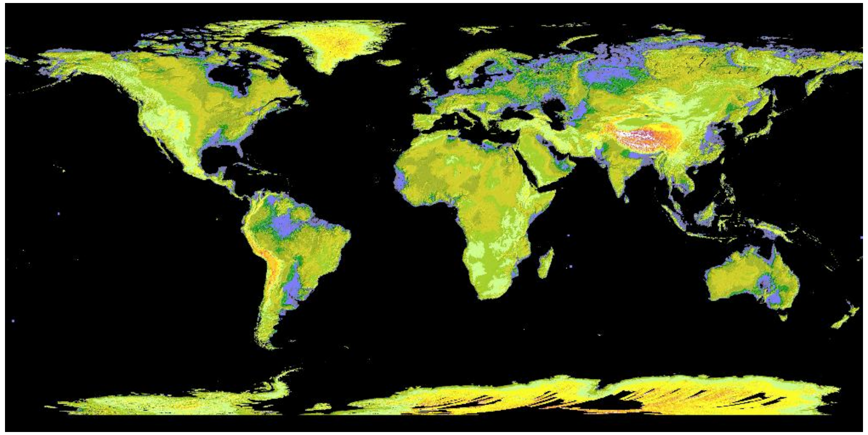


Example of the 10x10 m DEM for the area north of Vienna

Data sources for DEMs

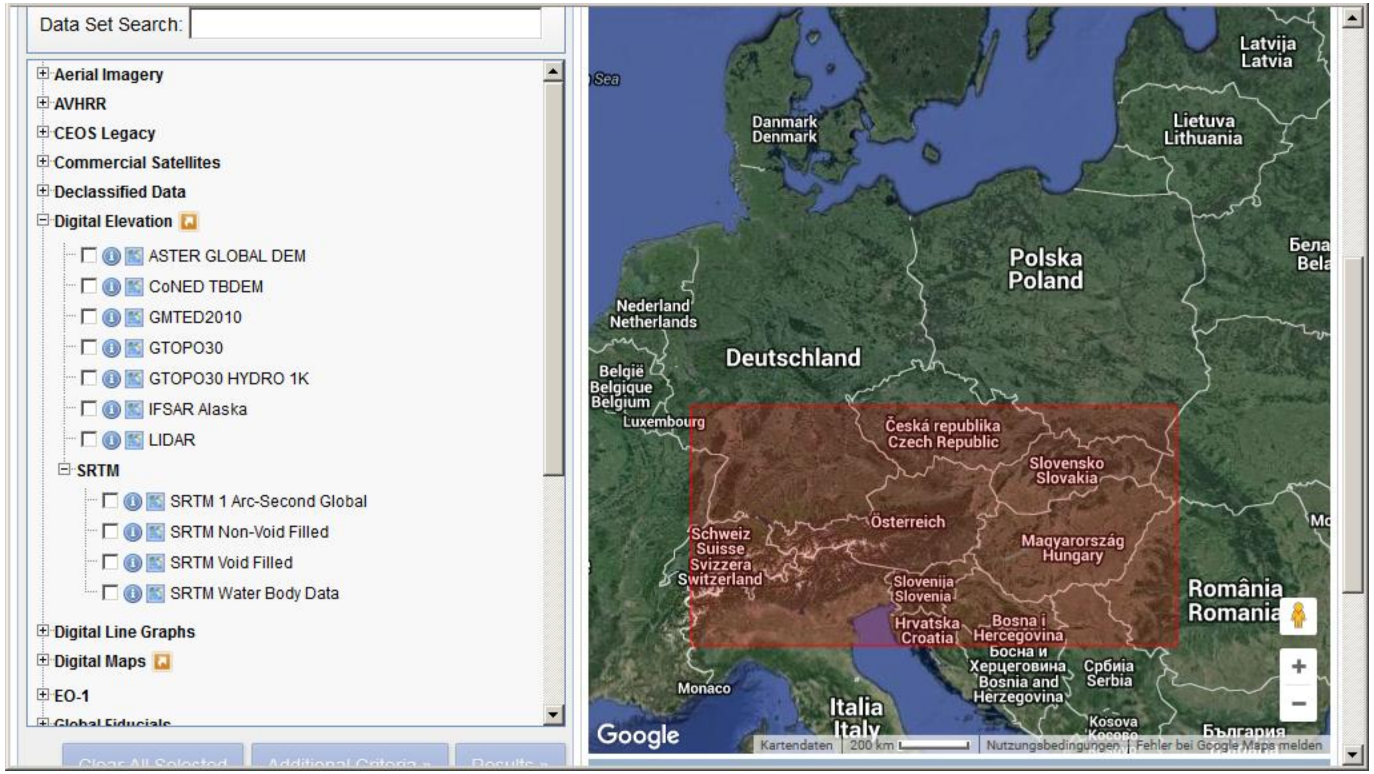
- Due to their coverage of nearly the entire earth, the most widely used DEMs (where no other data is available) are based on Remote sensing-data obtained from satellite platforms, e.g.:
  - Shuttle Radar Topography Mission (SRTM) (90 m to 30 m in the latest release)
  - ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) Global Digital Elevation Model (Spatial resolution of 30m)
  - For hydrological applications: MERIT Hydro strongly recommended
  - See OpenTopography - Data Catalog for an overview of newly available DEMs, e.g. from COPERNICUS
  - Hydrography90m: a new high-resolution global hydrographic dataset


SRTM on Space Shuttle Endevour (2000)


Coverage of ASTER GDEM

Data sources for DEMs

- **Shuttle Radar Topography Mission (SRTM)**
  - Flown aboard the space shuttle Endeavour February 11-22, 2000.
  - Spatial resolution varies between 30 and 90 m, depending on the level processing
  - Data available as GeoTIFF-files
  - Download under http://earthexplorer.usgs.gov/ (screenshot) or [OpenTopography]()

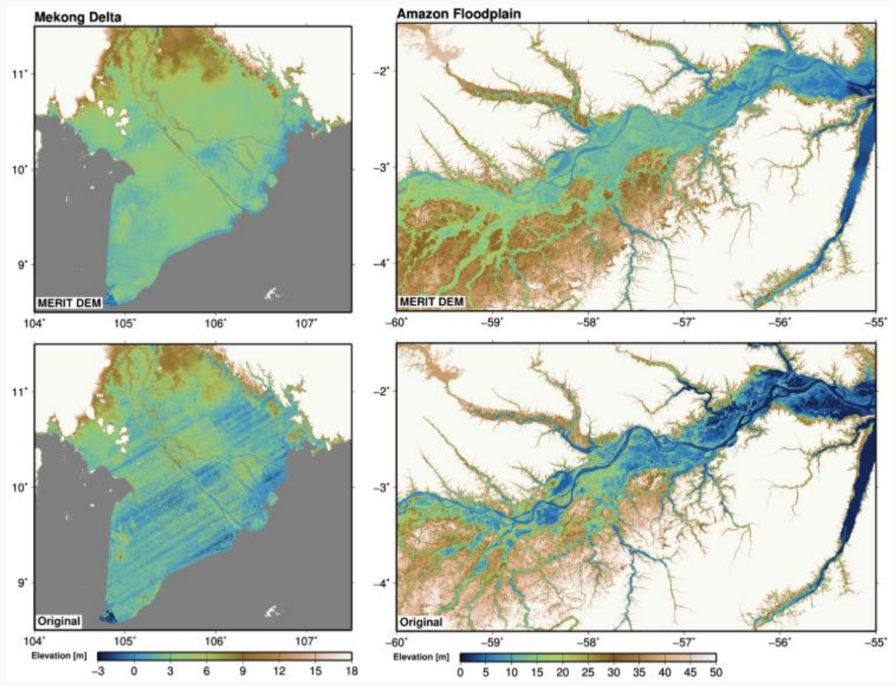


GUI probably outdated

Data sources for DEMs

- **MERIT DEM: Multi-Error-Removed Improved-Terrain DEM**
  - High accuracy global DEM at 3 arcsecond resolution (~90 m at the equator)
  - Major error components from existing DEMs (NASA SRTM3 DEM, JAXA AW3D DEM, Viewfinder Panoramas' DEM) have been eliminated
  - Multiple satellite datasets and filtering techniques are used to separate absolute bias, stripe noise, speckle noise and tree height bias. Vertical accuracy was increased from 39% to 58%.
  - Significant improvements were found in flat regions where height errors larger than topography variability, and landscapes such as river networks and hill-valley structures became clearly represented
  - Additional Information: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2017GL072874
  - Download under: http://hydro.iis.u-tokyo.ac.jp/~yamadai/MERIT_DEM/

  - **For hydrological applications: MERIT Hydro strongly recommended**
  - Includes data on flow direction, flow accumulation, hydrologically adjusted elevations, and river channel width
  - Download under: http://hydro.iis.u-tokyo.ac.jp/~yamadai/MERIT_Hydro/



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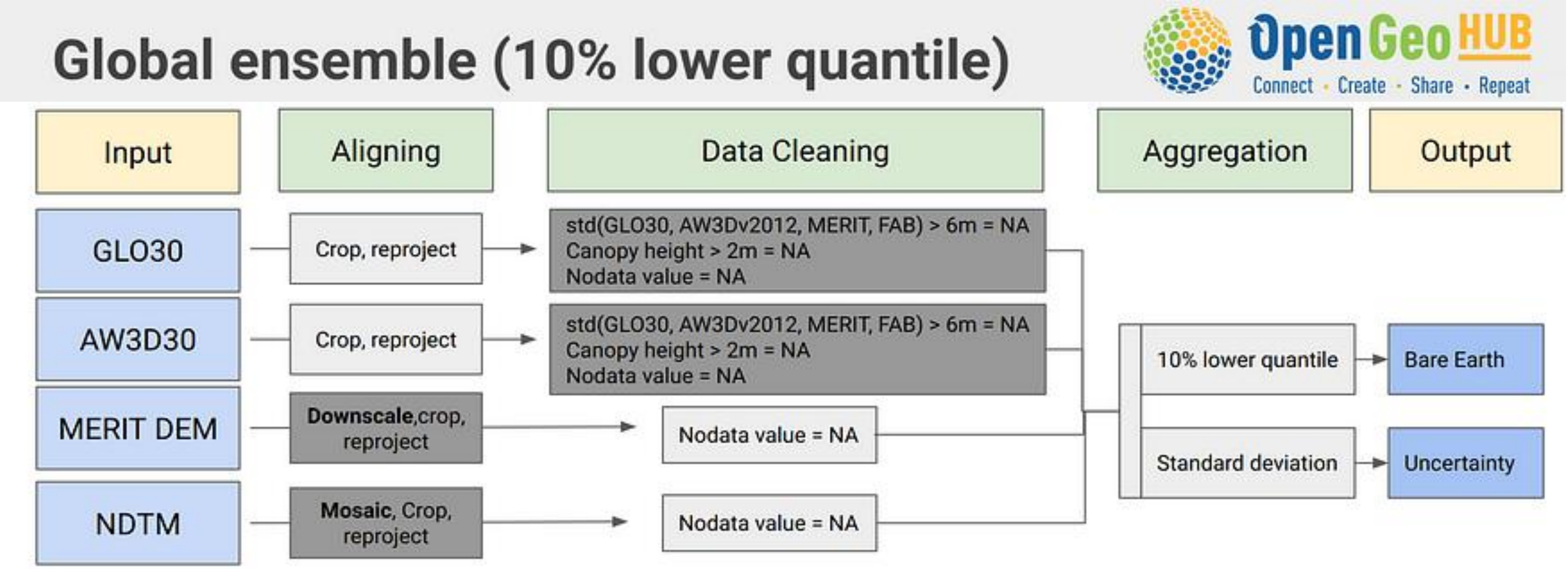
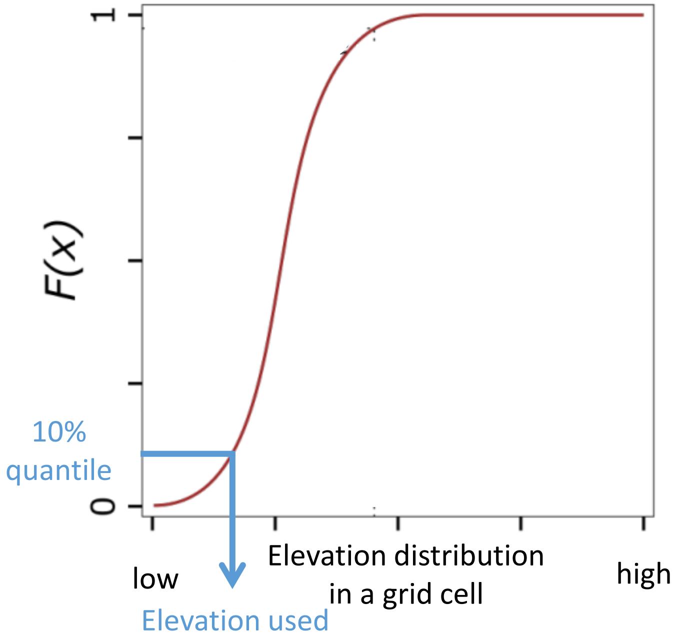
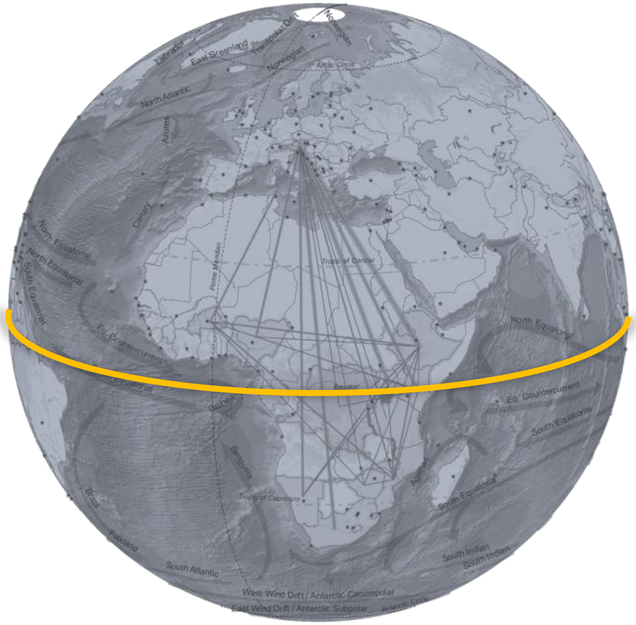
Data sources for DEMs

- **Ensemble Digital Terrain Model of the world at 30 m spatial resolution (EDTM30)**
  https://medium.com/nerd-for-tech/an-ensemble-digital-terrain-model-of-the-world-at-30-m-spatial-resolution-edtm30-b4fcff38164c
- For most application, a Digital Terrain Model or Digital Land Surface Model representing elevations of terrain / bare surface are needed, i.e. a surface without trees/vegetations/buildings.
- Using multisource data (see inputs below), it is assumed that terrain heights are at the lower part of the elevation distribution in a grid cell between different data sets
- Assumption: Using the 10% lower quantile can further help filter out potential canopy remains and the resulting DEM represent the most probable bare-earth elevation





Introduction: Catchment and stream network delineation



Esri, Garmin, GEBCO, NOAA NGDC, and other contributors

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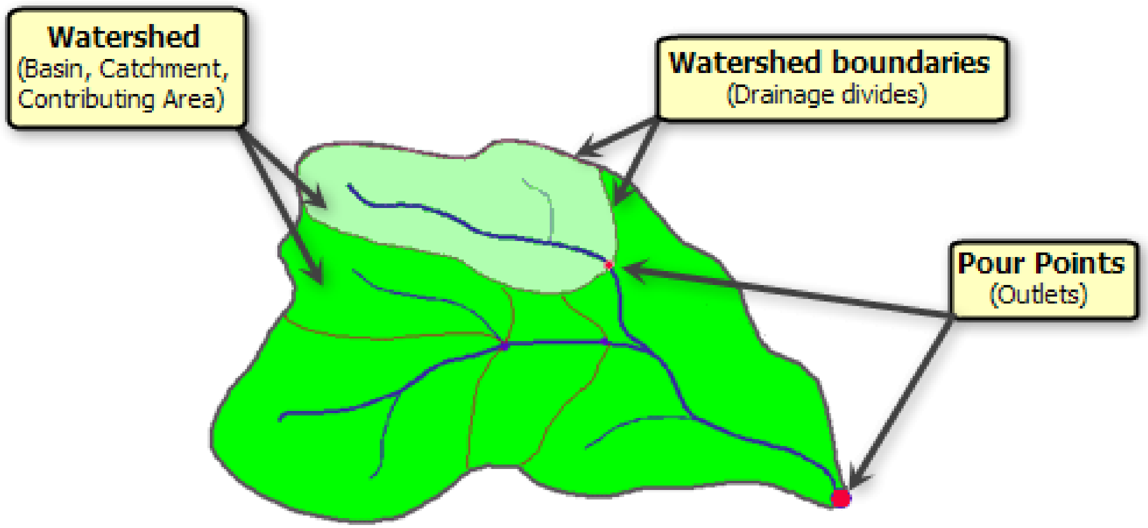
Introduction - Catchment and stream network delineation

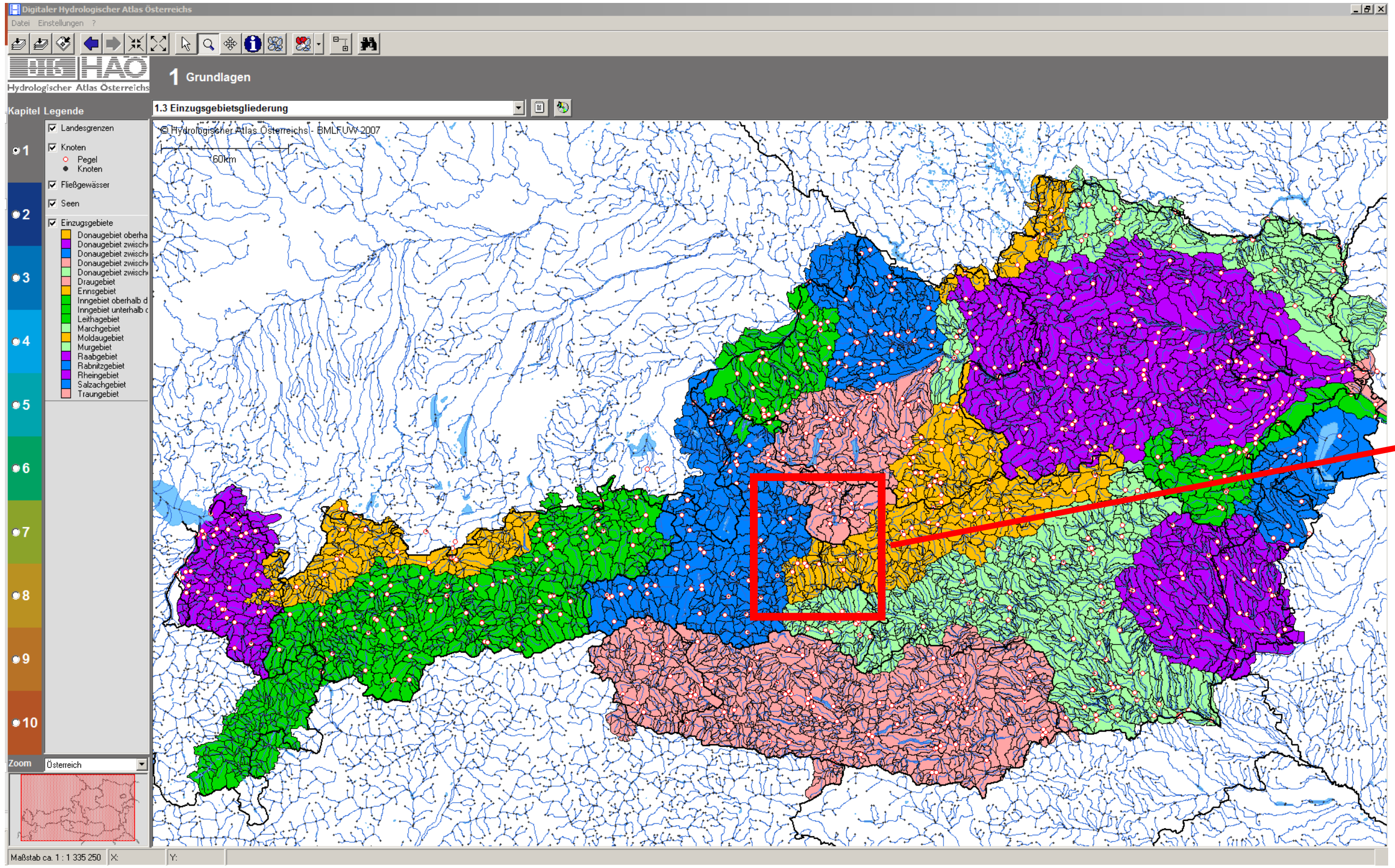
Aim is to derive, on the basis of a DEM:

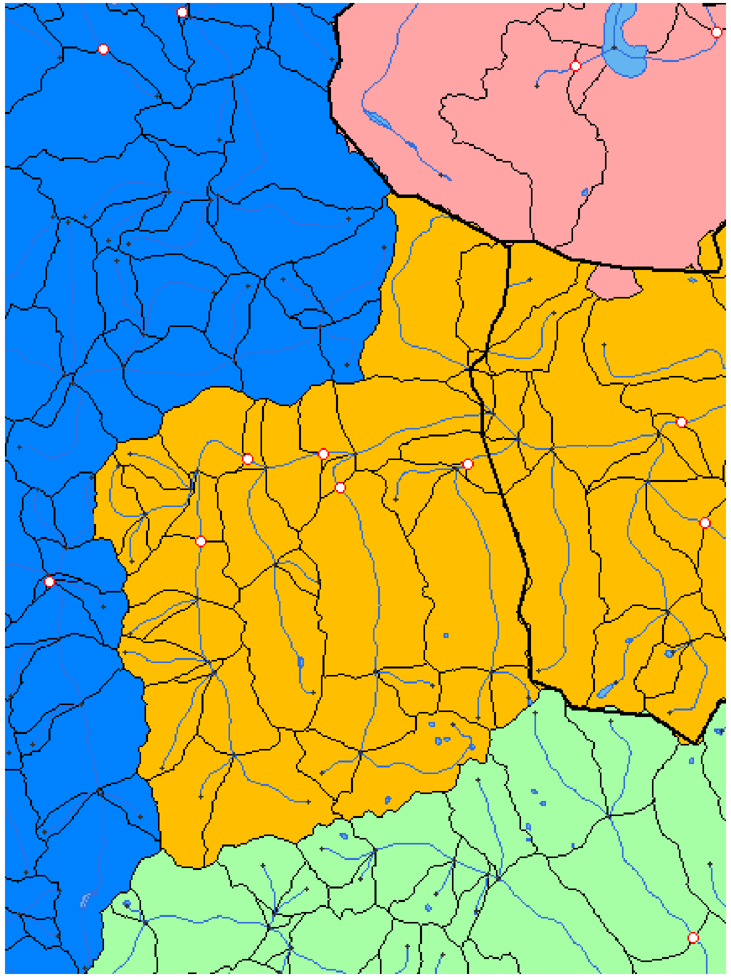
1. (Sub-) Catchment boundaries (depending on “Pour Points” (e.g. gauging stations))
2. Stream network



Introduction - Catchment and stream network delineation

(Sub-) Catchment boundaries & Stream network build the basis for nearly all hydrological and water management applications

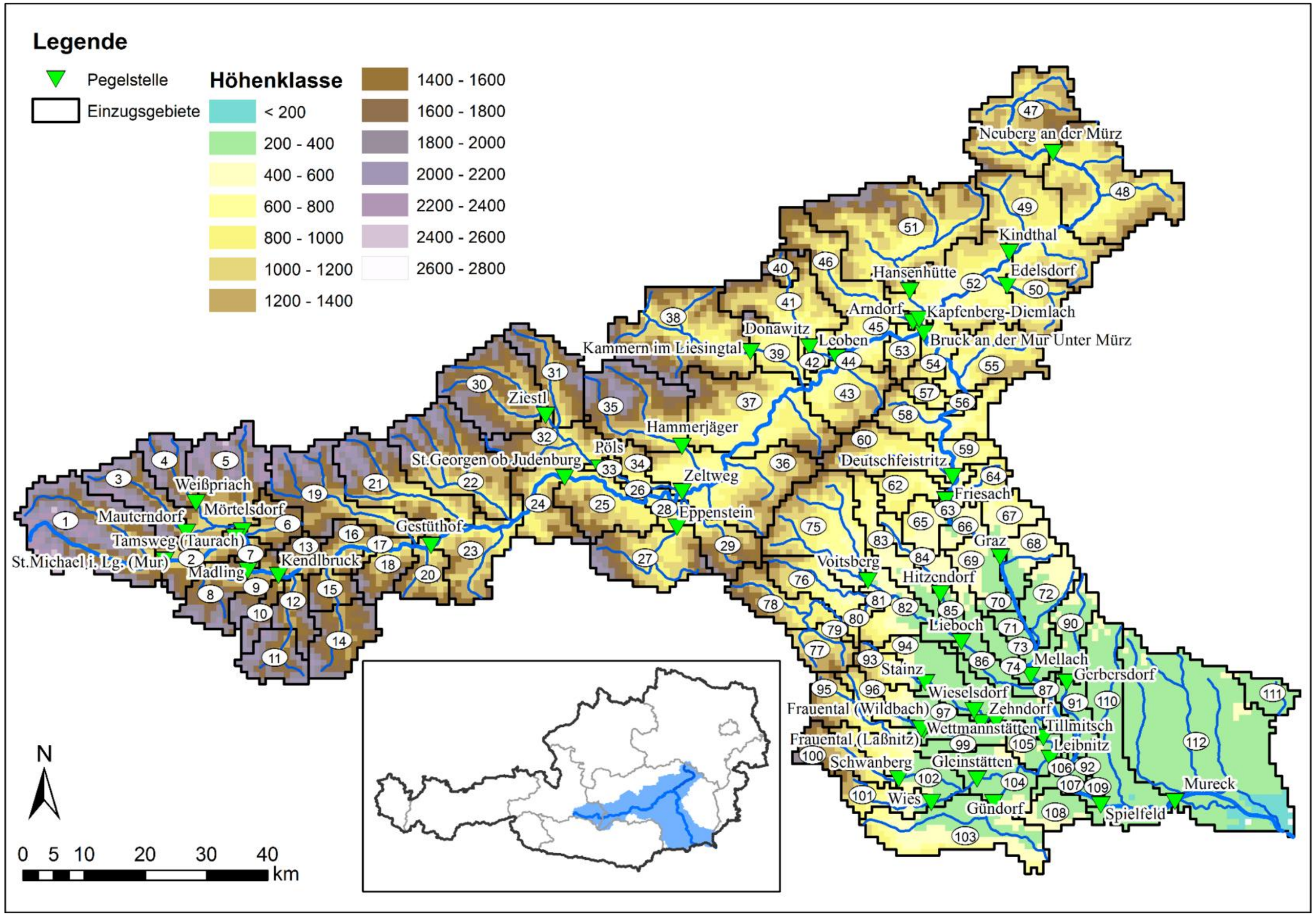




Example: Catchment boundaries in the Digital Hydrological Atlas of Austria (digHAO)

Introduction - Catchment and stream network delineation

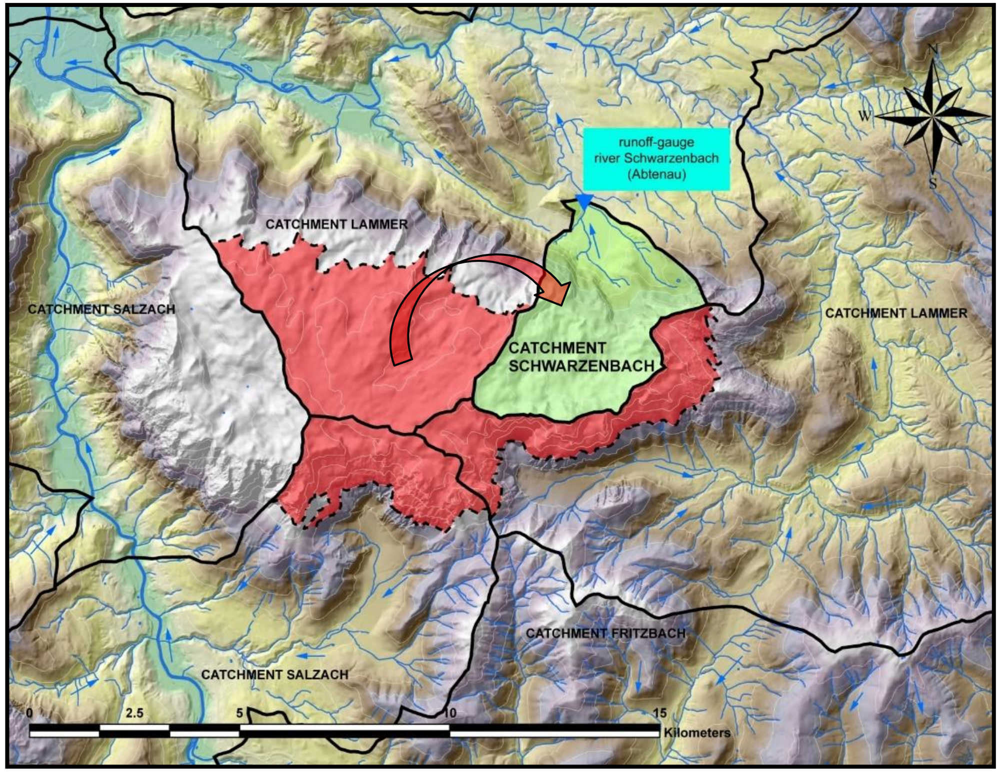
(Sub-) Catchment boundaries & Stream network build the basis for nearly all hydrological and water management applications

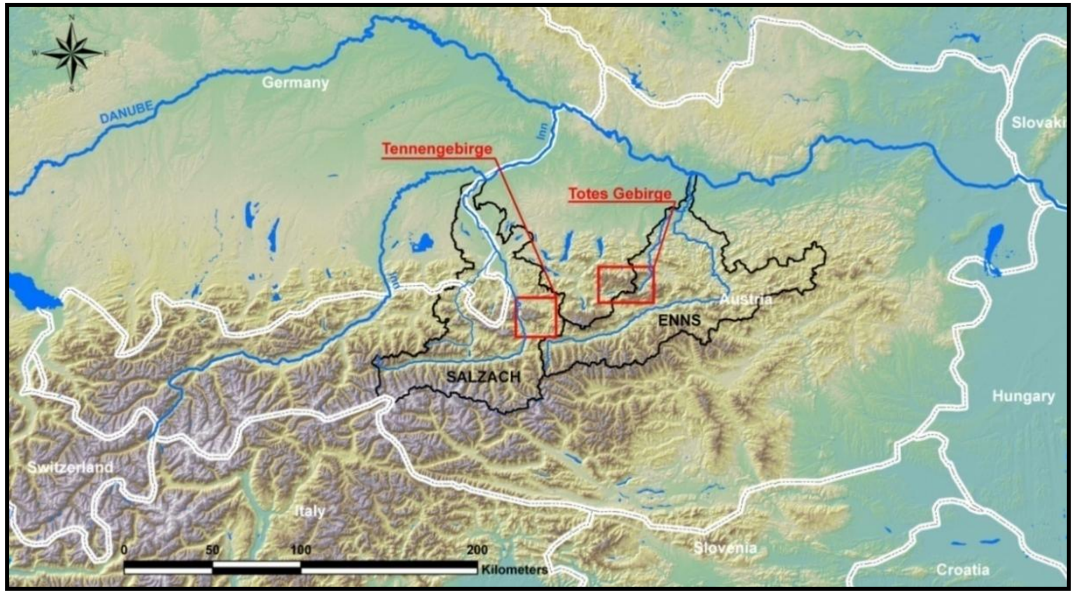


Example: Catchment boundaries for the runoff forecasting system “Mur” based on a spatial resolution of 1x1 km²

Introduction - Catchment and stream network delineation

- *Orographic catchments* boundaries are derived on the basis of the DEM
- Depending on the underlying Hydrogeology the orographic catchments boundaries may differ from the *hydrographic catchment* boundaries
  - ➢ The dissolution of karstifiable rocks (e.g. limestone) can lead to subsurface catchment boundaries that do not coincide with orographic drainage areas





Herrnegger, M., Haberl, U., Stanzel, P., Nachtnebel, H.-P., 2008. Identifying subsurface karstic drainage areas with a continuous hydrological model in the Austrian Kalkalpen, in: Geophysical Research Abstracts.

Introduction - Catchment and stream network delineation

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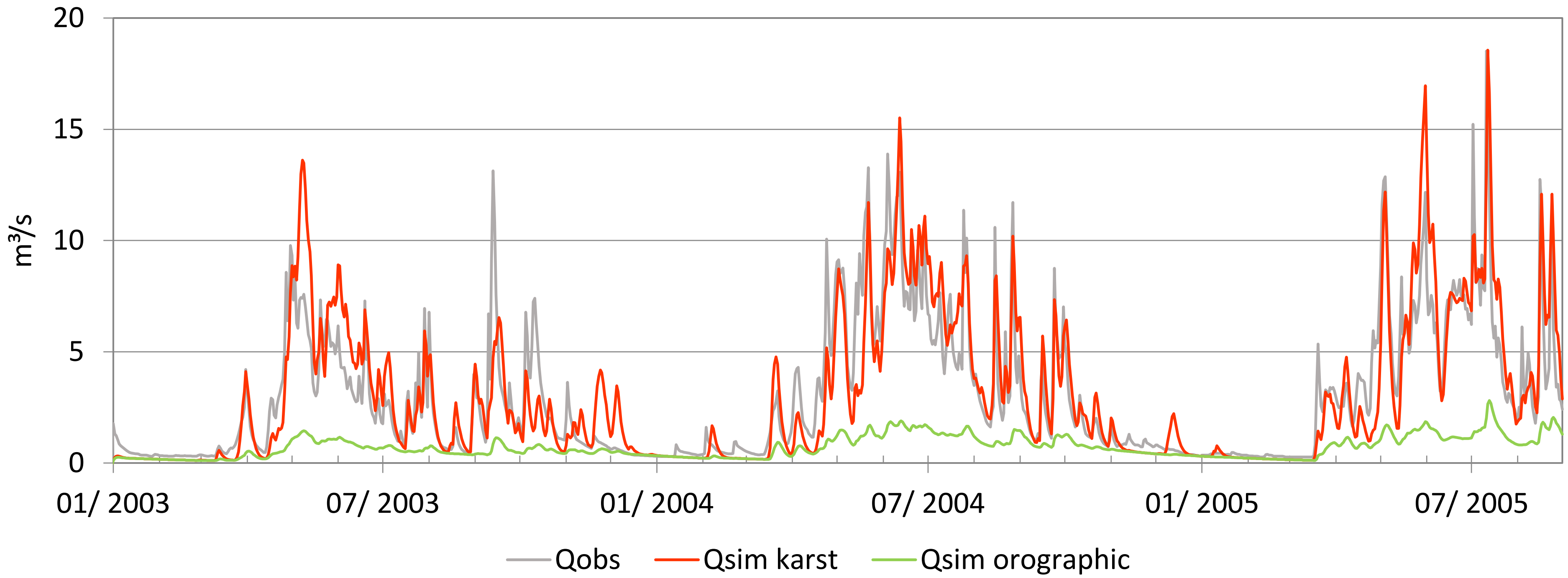
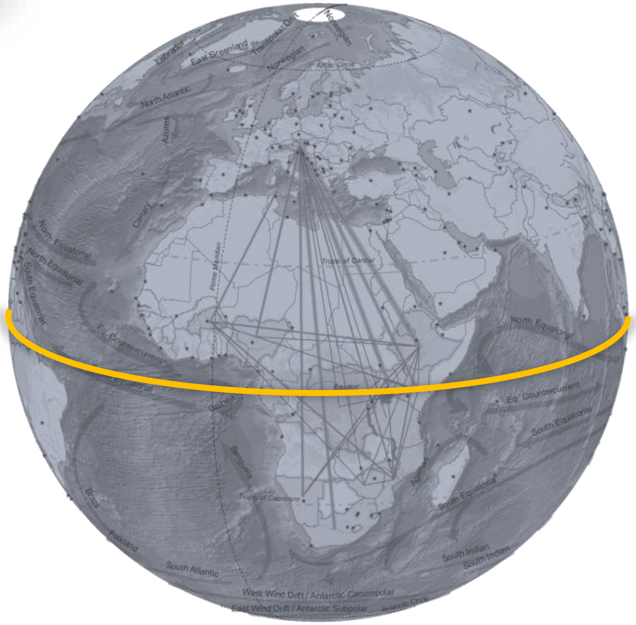


Simulation “Schwarzenbach” with orographic and hydrological catchment boundaries

Herrnegger, M., Haberl, U., Stanzel, P., Nachtnebel, H.-P., 2008. Identifying subsurface karstic drainage areas with a continuous hydrological model in the Austrian Kalkalpen, in: Geophysical Research Abstracts.

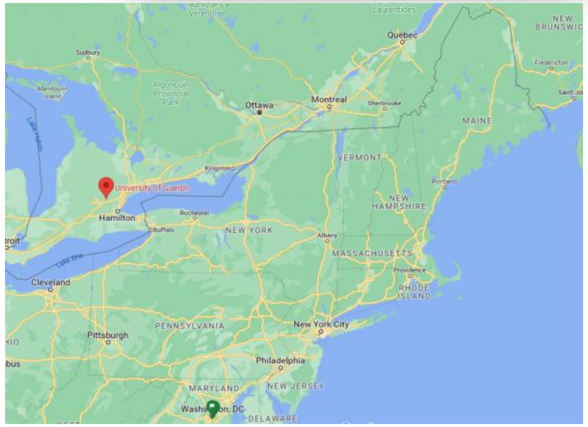
WhiteboxTools

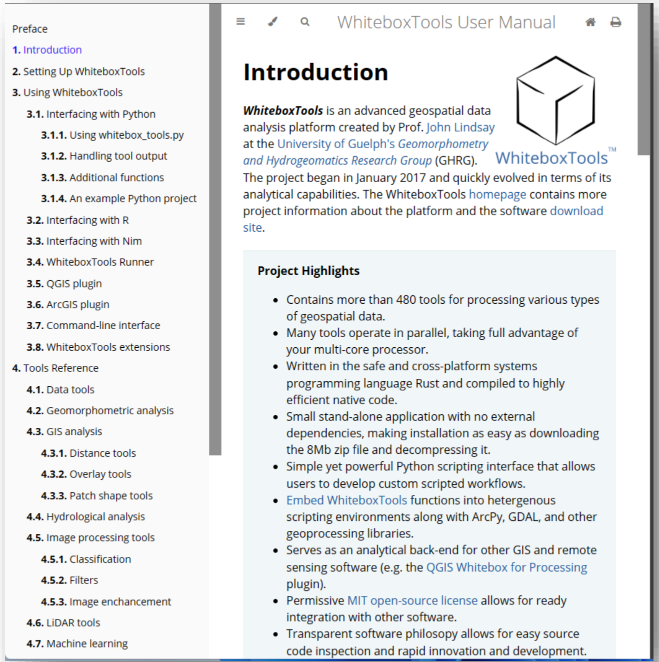


Esri, Garmin, GEBCO, NOAA NGDC, and other contributors

WhiteboxTools

- ***WhiteboxTools*** is an advanced geospatial data analysis platform created by Prof. John Lindsay at the University of Guelph's *Geomorphometry and Hydrogeomatics Research Group* (GHRG)
- **Highlights**
  - Contains **more than 480 tools** for processing various types of geospatial data
  - Many tools **operate in parallel**, taking full advantage of multi-core processors
  - Written in the **safe and cross-platform systems programming language Rust** and compiled to highly efficient native code
  - Small **stand-alone application with no external dependencies**, making installation as easy as downloading the 8Mb zip file and decompressing it
  - Simple yet powerful **Python and R scripting interface** that allows users to develop custom scripted workflows
  - Serves as an **analytical back-end for other GIS** and remote sensing software (e.g. the QGIS Whitebox for Processing plugin) - it is not a cartographic or spatial data visualization package
  - Permissive MIT open-source license allows for ready integration with other software
  - **Transparent software philosophy** allows for easy source code inspection and rapid innovation and development
- Excellent documentation: Introduction - WhiteboxTools User Manual (whiteboxgeo.com)





WhiteboxTools

- The *WhiteboxTools* platform currently contains approximately 485 tools organized into thematic toolboxes. The thematic toolboxes include:
  - Data Tools
  - Geomorphometric Analysis
  - GIS Analysis
  - Hydrological Analysis
  - Image Analysis
  - LiDAR Analysis
  - Machine Learning Tools
  - Mathematical and Statistical Analysis
  - Precision Agriculture
  - Stream Network Analysis

WhiteboxTools

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WhiteboxTools™

- Thematic toolboxes Hydrological Analysis (with good documentation of the single tools):

AverageFlowpathSlope	Basins	BreachSingleCellPits
AverageUpslopeFlowpathLength	BreachDepressions	BurnStreamsAtRoads
D8FlowAccumulation	BreachDepressionsLeastCost	DepthInSink
D8MassFlux	D8Pointer	DepthToWater
DInfFlowAccumulation	DInfMassFlux	DownslopeDistanceToStream
DInfPointer	DownslopeFlowpathLength	EdgeContamination
ElevationAboveStream	ElevationAboveStreamEuclidean	Fd8FlowAccumulation
Fd8Pointer	FillBurn	FillDepressions
FillDepressionsPlanchonAndDarboux	FillDepressionsWangAndLiu	FillSingleCellPits
FindNoFlowCells	FindParallelFlow	FlattenLakes
FloodOrder	FlowAccumulationFullWorkflow	FlowLengthDiff
Hillslopes	HydrologicConnectivity	ImpoundmentSizeIndex
InsertDams	Isobasins	JensonSnapPourPoints
LongestFlowpath	LowPointsOnHeadwaterDivides	MaxUpslopeFlowpathLength
MaxUpslopeValue	MdInfFlowAccumulation	NumInflowingNeighbours
QinFlowAccumulation	QuinnFlowAccumulation	RaiseWalls
Rho8FlowAccumulation	Rho8Pointer	RiverCenterlines
Sink	SnapPourPoints	StochasticDepressionAnalysis
StrahlerOrderBasins	Subbasins	TraceDownslopeFlowpaths
UnnestBasins	UpslopeDepressionStorage	Watershed

D8FlowAccumulation

This tool is used to generate a flow accumulation grid (i.e. catchment area) using the D8 (O'Callaghan and Mark, 1984) algorithm. This algorithm is an example of single-flow-direction (SFD) method because the flow entering each grid cell is routed to only one downslope neighbour, i.e. flow divergence is not permitted. The user must specify the name of the input digital elevation model (DEM) or flow pointer raster (`--input`) derived using the D8 or Rho8 method (**D8Pointer**, **Rho8Pointer**). If an input DEM is used, it must have been hydrologically corrected to remove all spurious depressions and flat areas. DEM pre-processing is usually achieved using the **BreachDepressionsLeastCost** or **FillDepressions** tools. If a D8 pointer raster is input, the user must also specify the optional `--pntr` flag. If the D8 pointer follows the Esri pointer scheme, rather than the default WhiteboxTools scheme, the user must also specify the optional `--esri_pntr` flag.

In addition to the input DEM/pointer, the user must specify the output type. The output flow-accumulation can be 1) `cells` (i.e. the number of inflowing grid cells), `catchment area` (i.e. the upslope area), or `specific contributing area` (i.e. the catchment area divided by the flow width. The default value is `cells`. The user must also specify whether the output flow-accumulation grid should be log-tranformed (`--log`), i.e. the output, if this option is selected, will be the natural-logarithm of the accumulated flow value. This is a transformation that is often performed to better visualize the contributing area distribution. Because contributing areas tend to be very high along valley bottoms and relatively low on hillslopes, when a flow-accumulation image is displayed, the distribution of values on hillslopes tends to be 'washed out' because the palette is stretched out to represent the highest values. Log-transformation provides a means of compensating for this phenomenon. Importantly, however, log-transformed flow-accumulation grids must not be used to estimate other secondary terrain indices, such as the wetness index, or relative stream power index.

Grid cells possessing the **NoData** value in the input DEM/pointer raster are assigned the **NoData** value in the output flow-accumulation image.

Reference:

O'Callaghan, J. F., & Mark, D. M. 1984. The extraction of drainage networks from digital elevation data. *Computer Vision, Graphics, and Image Processing*, 28(3), 323-344.

See Also: **FD8FlowAccumulation**, **QuinnFlowAccumulation**, **QinFlowAccumulation**, **DInfFlowAccumulation**, **MDInfFlowAccumulation**, **Rho8Pointer**, **D8Pointer**, **BreachDepressionsLeastCost**, **FillDepressions**

WhiteboxTools

- Thematic toolboxes Stream Network Analysis:

DistanceToOutlet	HortonStreamOrder	StreamLinkLength
ExtractStreams	LengthOfUpstreamChannels	StreamLinkSlope
ExtractValleys	LongProfile	StreamSlopeContinuous
FarthestChannelHead	LongProfileFromPoints	TopologicalStreamOrder
FindMainStem	RasterStreamsToVector	TributaryIdentifier
HackStreamOrder	RasterizeStreams	VectorStreamNetworkAnalysis
HortonStreamOrder	RemoveShortStreams	
LengthOfUpstreamChannels	RepairStreamVectorTopology	
LongProfile	ShreveStreamMagnitude	
LongProfileFromPoints	StrahlerStreamOrder	
RasterStreamsToVector	StreamLinkClass	
RasterizeStreams	StreamLinkIdentifier	
RemoveShortStreams	StreamLinkLength	
RepairStreamVectorTopology	StreamLinkSlope	
ShreveStreamMagnitude	StreamSlopeContinuous	
StrahlerStreamOrder	TopologicalStreamOrder	
StreamLinkClass	TributaryIdentifier	

Installing the "Whitebox Workflows for QGIS" plugin

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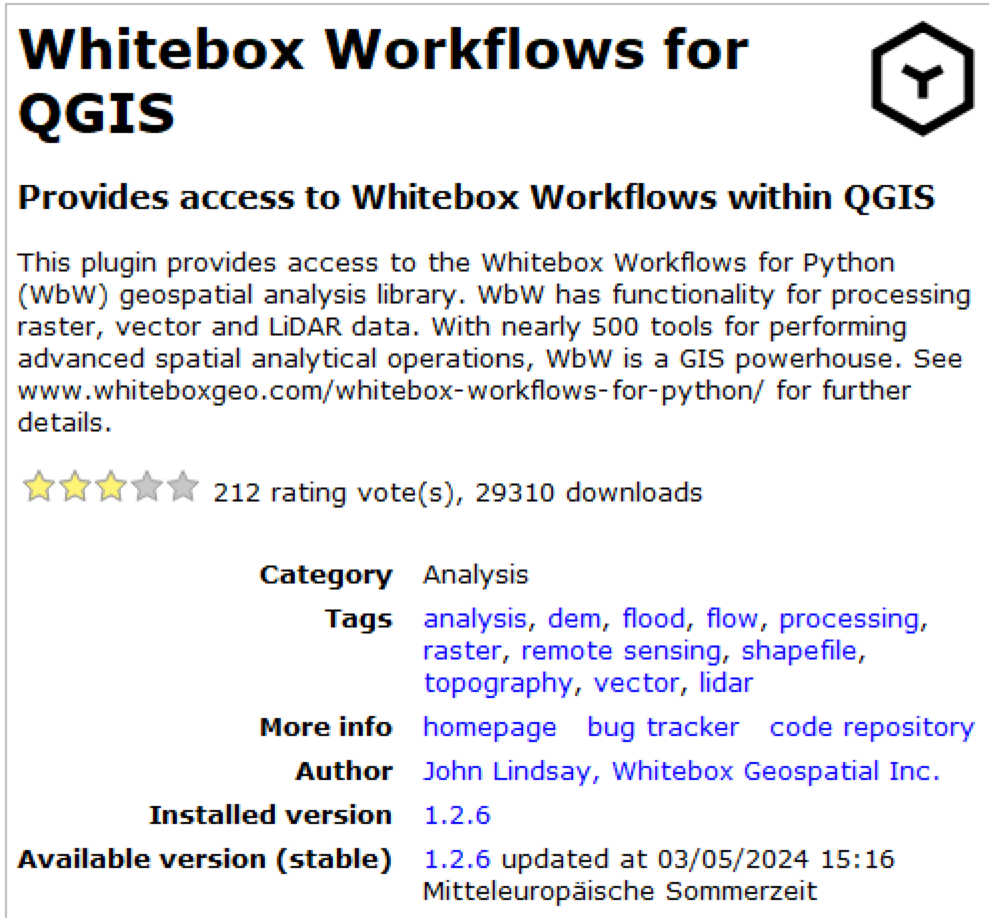
WhiteboxTools™

- Go to Plugins -> search for Whitebox -> install plugin



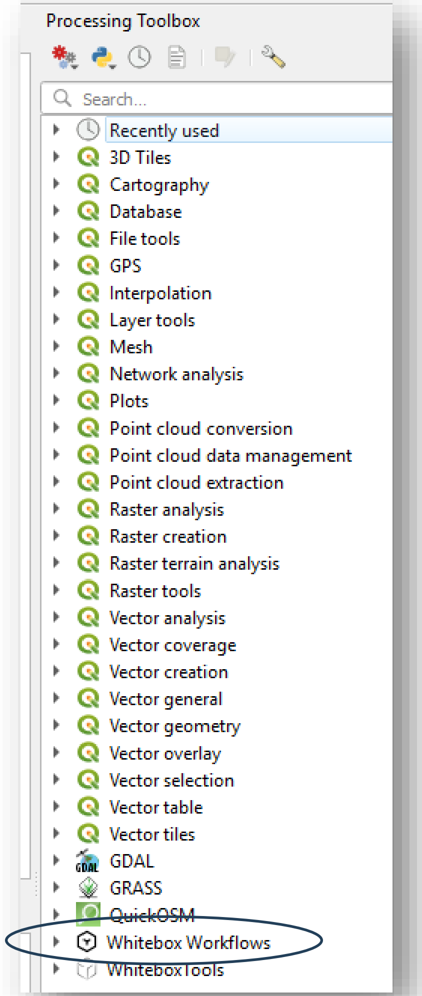
Whitebox Workflows for QGIS

Provides access to Whitebox Workflows within QGIS

This plugin provides access to the Whitebox Workflows for Python (WbW) geospatial analysis library. WbW has functionality for processing raster, vector and LiDAR data. With nearly 500 tools for performing advanced spatial analytical operations, WbW is a GIS powerhouse. See www.whiteboxgeo.com/whitebox-workflows-for-python/ for further details.

212 rating vote(s), 29310 downloads

Category	Analysis
Tags	analysis, dem, flood, flow, processing, raster, remote sensing, shapefile, topography, vector, lidar
More info	homepage bug tracker code repository
Author	John Lindsay, Whitebox Geospatial Inc.
Installed version	1.2.6
Available version (stable)	1.2.6 updated at 03/05/2024 15:16 Mitteleuropäische Sommerzeit

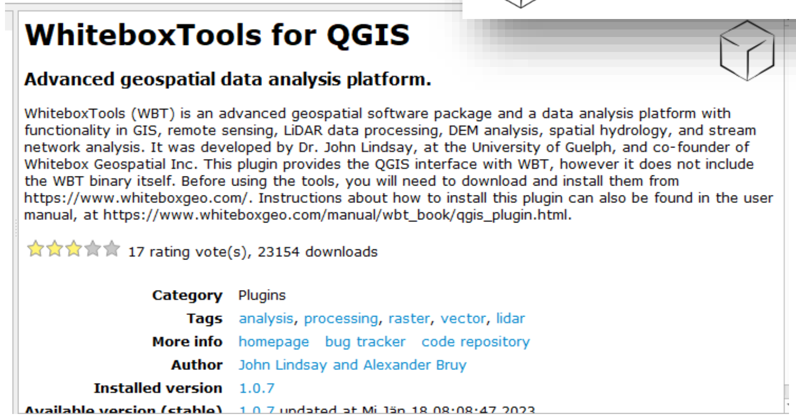


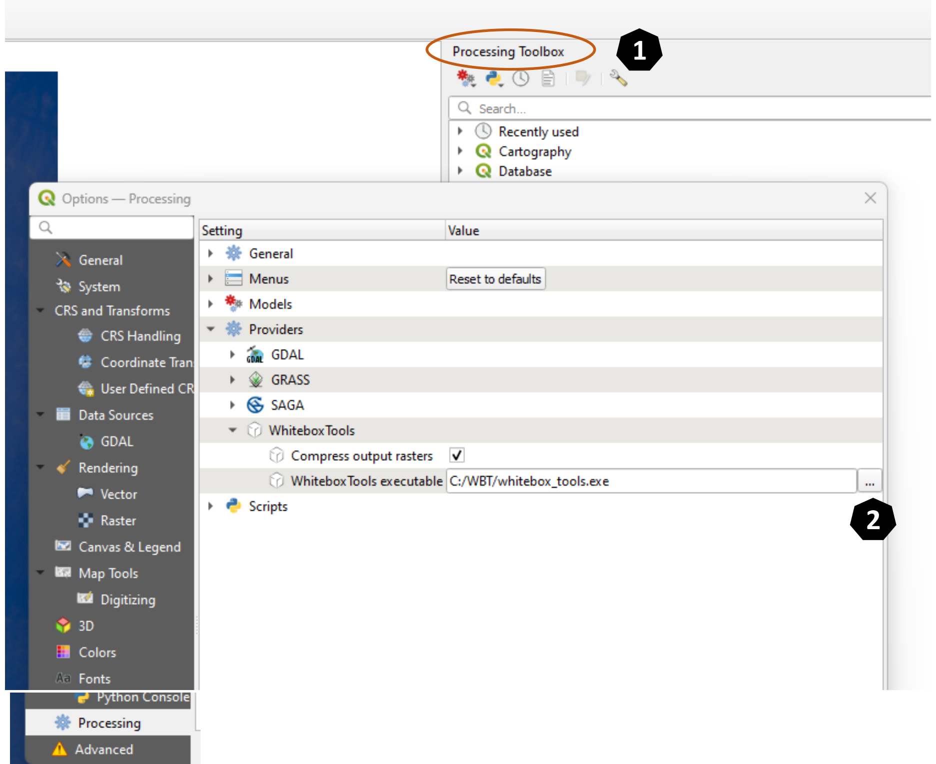
Installing the “WhiteboxTools for QGIS” plugin

- Go to Plugins -> search for WhiteboxTools -> install plugin
- Go to WhiteboxTools: Download WhiteboxTools - Whitebox Geospatial Inc and download WhiteboxTools Open Core v2.2.0 (also provided on BOKUlearn)
- Under QGIS plugin - WhiteboxTools User Manual (whiteboxgeo.com) you can find detailed instructions of how to proceed

This step is not necessary, if the installation of „Whitbox Workflows for QGIS“ plugin shown in the previous slide was successful

- On Windows, unzip the file to e.g. C:\WBT
- Then, access the processing toolbox and open the options (1)
- Under “Providers”, expand Whitebox Tools and point to the executable “exe” in the unzipped folder by clicking on the … (2)





“Whitebox Workflows for QGIS” vs. “WhiteboxTools for QGIS”

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WhiteboxTools™

- The slides partially show screenshots from “WhiteboxTools for QGIS” and not “Whitebox Workflows for QGIS”
- The same tools and functionality are however available in both plugins

Whitebox Workflows for QGIS

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WhiteboxTools for QGIS

Advanced geospatial data analysis platform.

WhiteboxTools (WBT) is an advanced geospatial software package and a data analysis platform with functionality in GIS, remote sensing, LiDAR data processing, DEM analysis, spatial hydrology, and stream network analysis. It was developed by Dr. John Lindsay, at the University of Guelph, and co-founder of Whitebox Geospatial Inc. This plugin provides the QGIS interface with WBT, however it does not include the WBT binary itself. Before using the tools, you will need to download and install them from https://www.whiteboxgeo.com/. Instructions about how to install this plugin can also be found in the user manual, at https://www.whiteboxgeo.com/manual/wbt_book/qgis_plugin.html.

17 rating vote(s), 23154 downloads

Category	Plugins
Tags	analysis, processing, raster, vector, lidar
More info	homepage bug tracker code repository
Author	John Lindsay and Alexander Bruy
Installed version	1.0.7
Available version (stable)	1.0.7 updated at Mi Jän 18 08:08:47 2023

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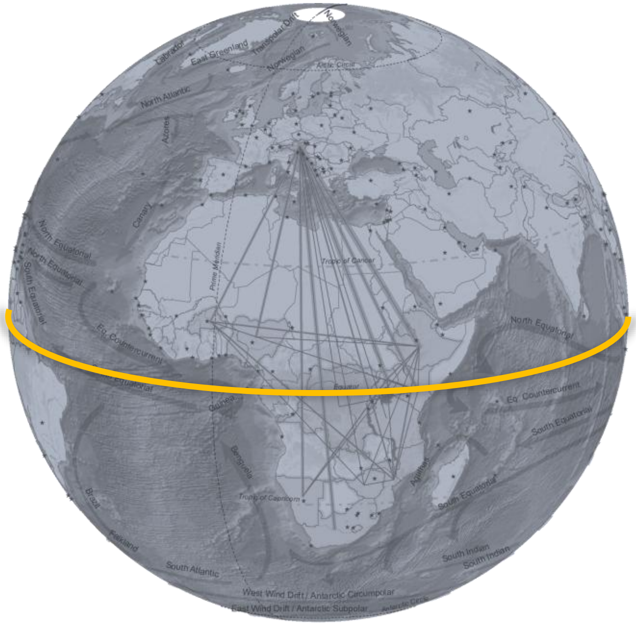
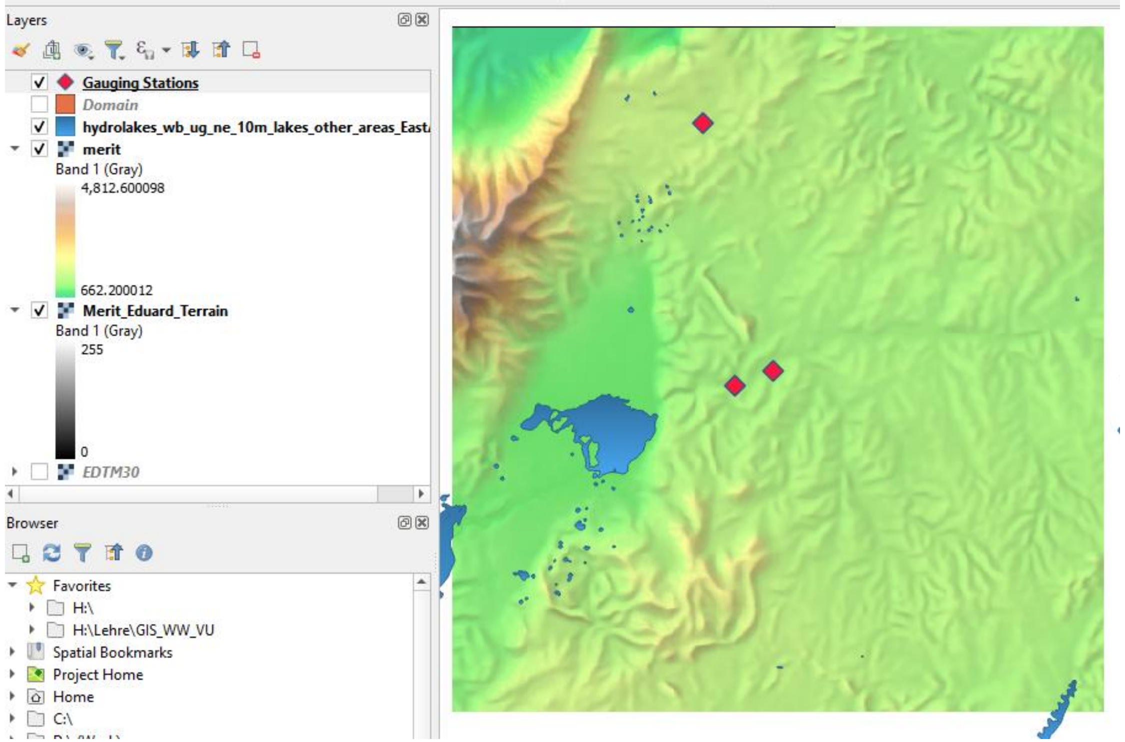
Exercise - Catchment and stream network delineation for the Mpanga



Esri, Garmin, GEBCO, NOAA NGDC, and other contributors

Load data

- Download, unzip the file provided for the Unit and copy the data to your local working folder and add it to QGIS
- Make a new working folder, since we will generate many results
- Save the project (e.g. Catchment_StreamNetwork_Mpanga.qgz)



➢ *The DEMs & the sampling locations as pour points will be used for the calculations*

Organize the layers and change symbology

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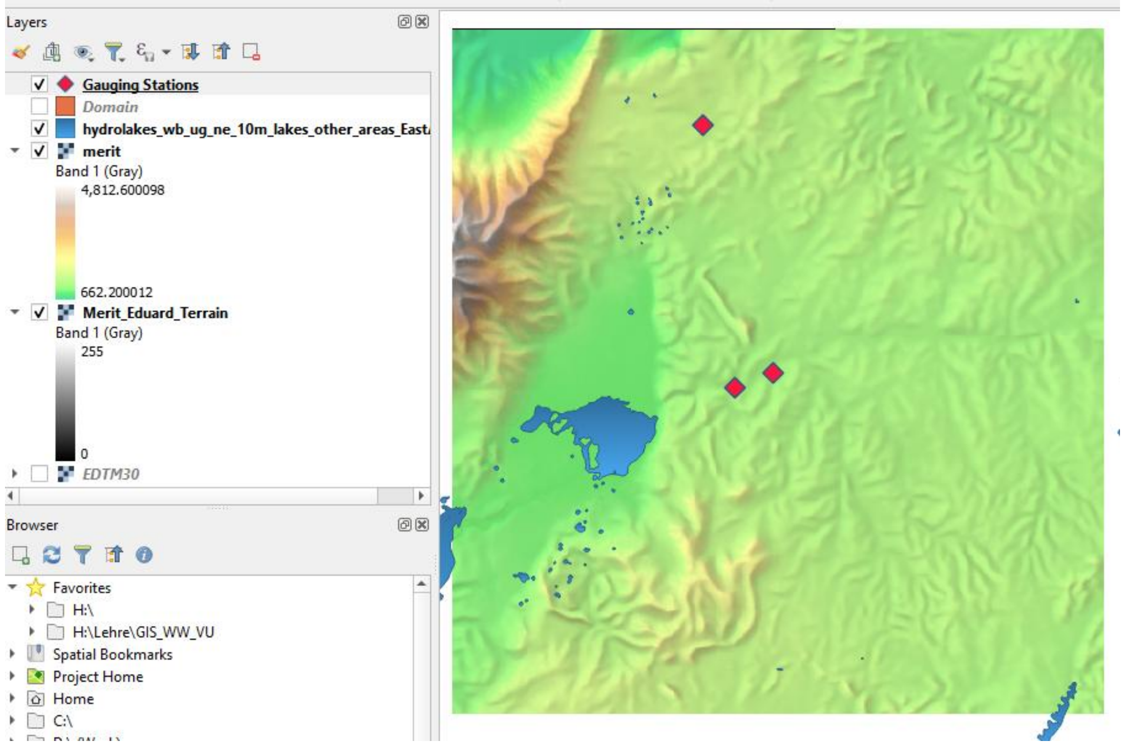
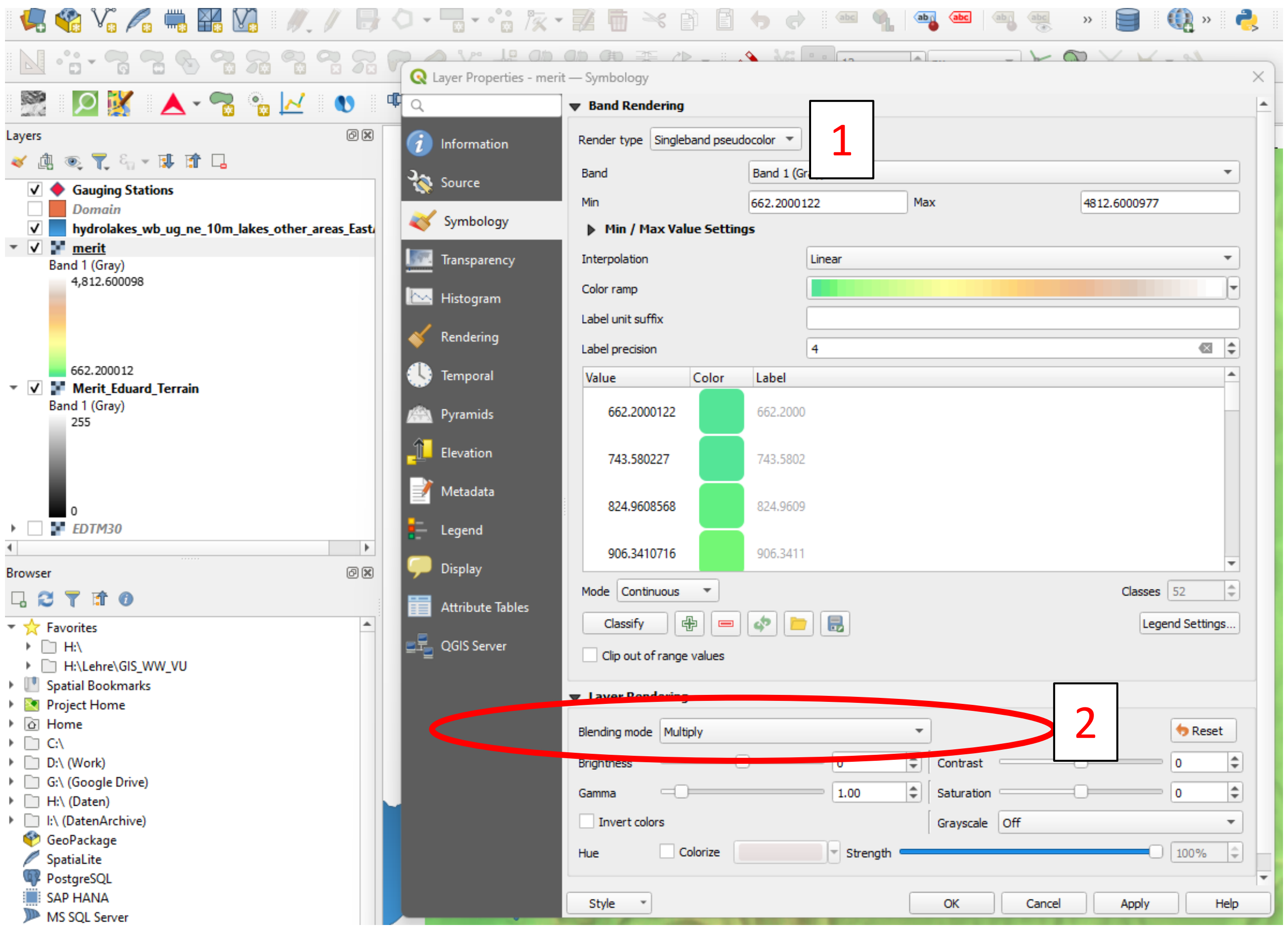
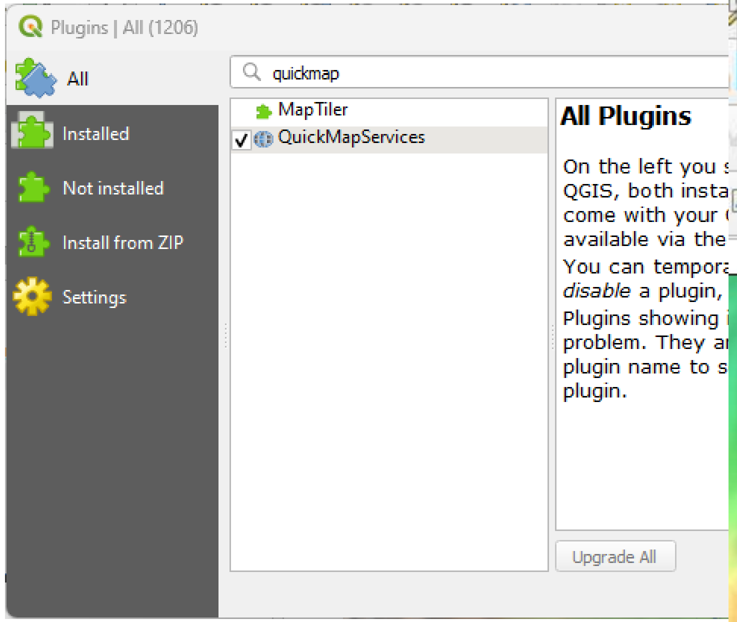
- Change order of Layers
- Change symbology & show terrain

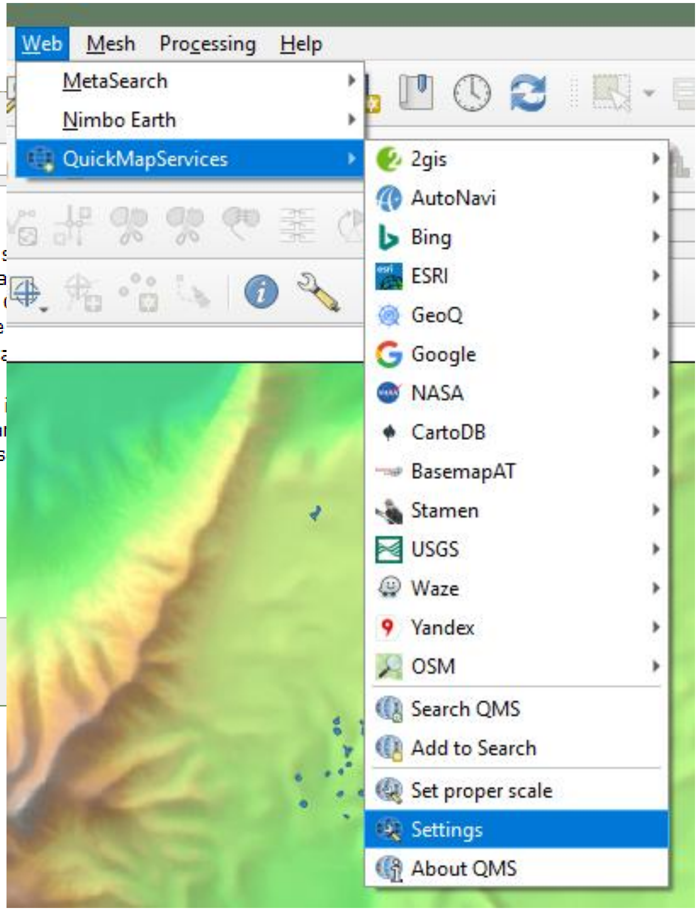


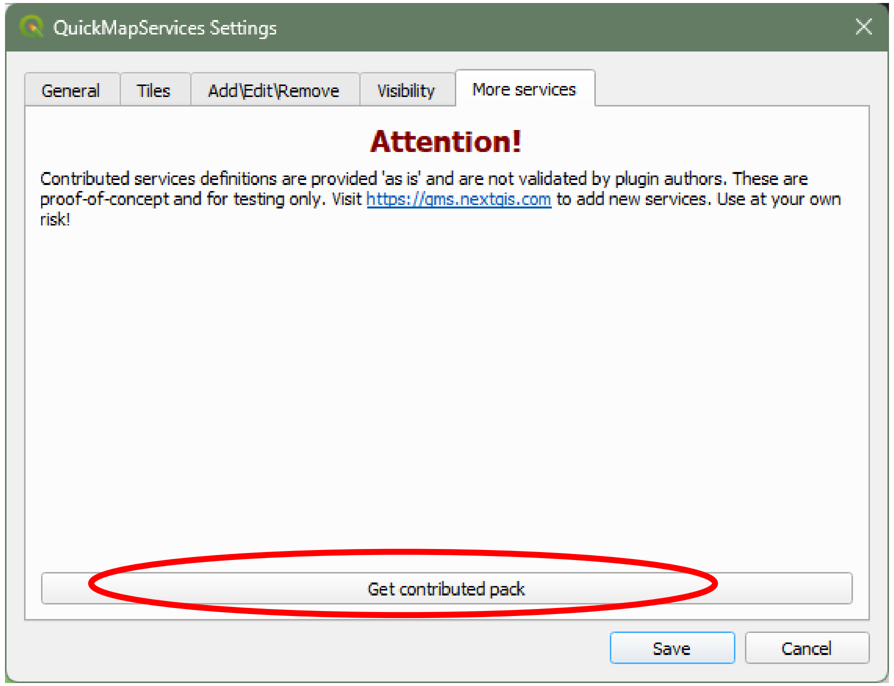


Orientate yourself – where are the gauging stations located in space?

- Install plugin “QuickMapServices” under “Plugins”
- Access „Settings“ of the Plugin and activate „Get contributed pack“ as shown
- Now, additional data sources should be available

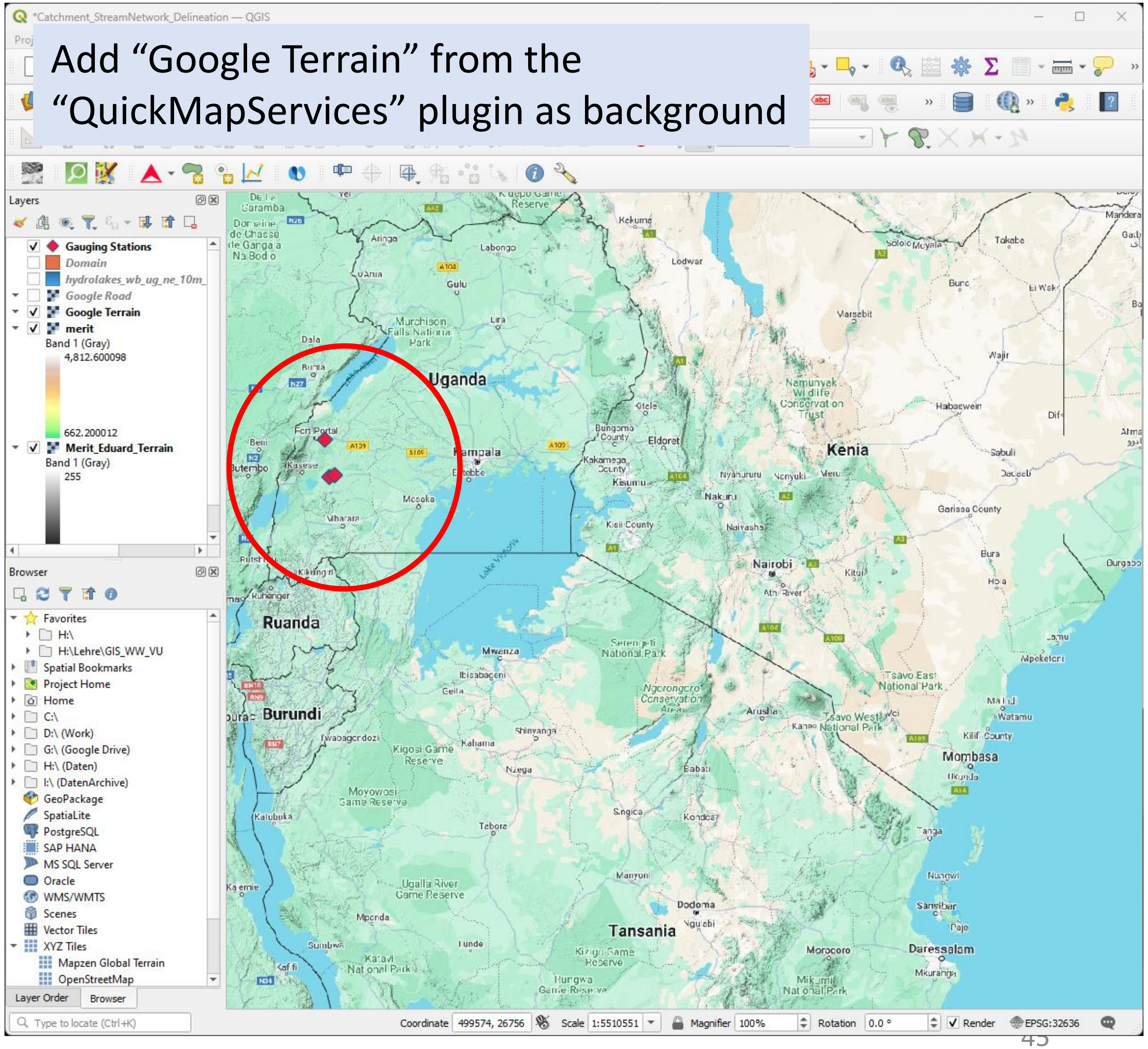






Orientate yourself – where are the gauging stations located in space?

- The gauging stations are located in the West of Uganda, on the Eastern foothills of the Rwenzori mountains
- Rwenzori Mountains are often called the "Mountains of the Moon", a name given by ancient geographers due to their mist-shrouded, mysterious appearance
- They contain Africa's third-highest peak, Mount Stanley's Margherita Peak, reaching an elevation of 5,109 meters



Add "Google Terrain" from the "QuickMapServices" plugin as background

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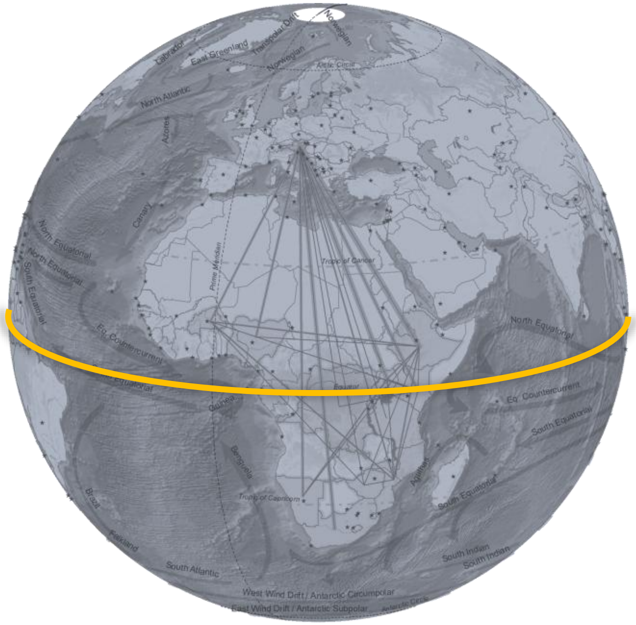
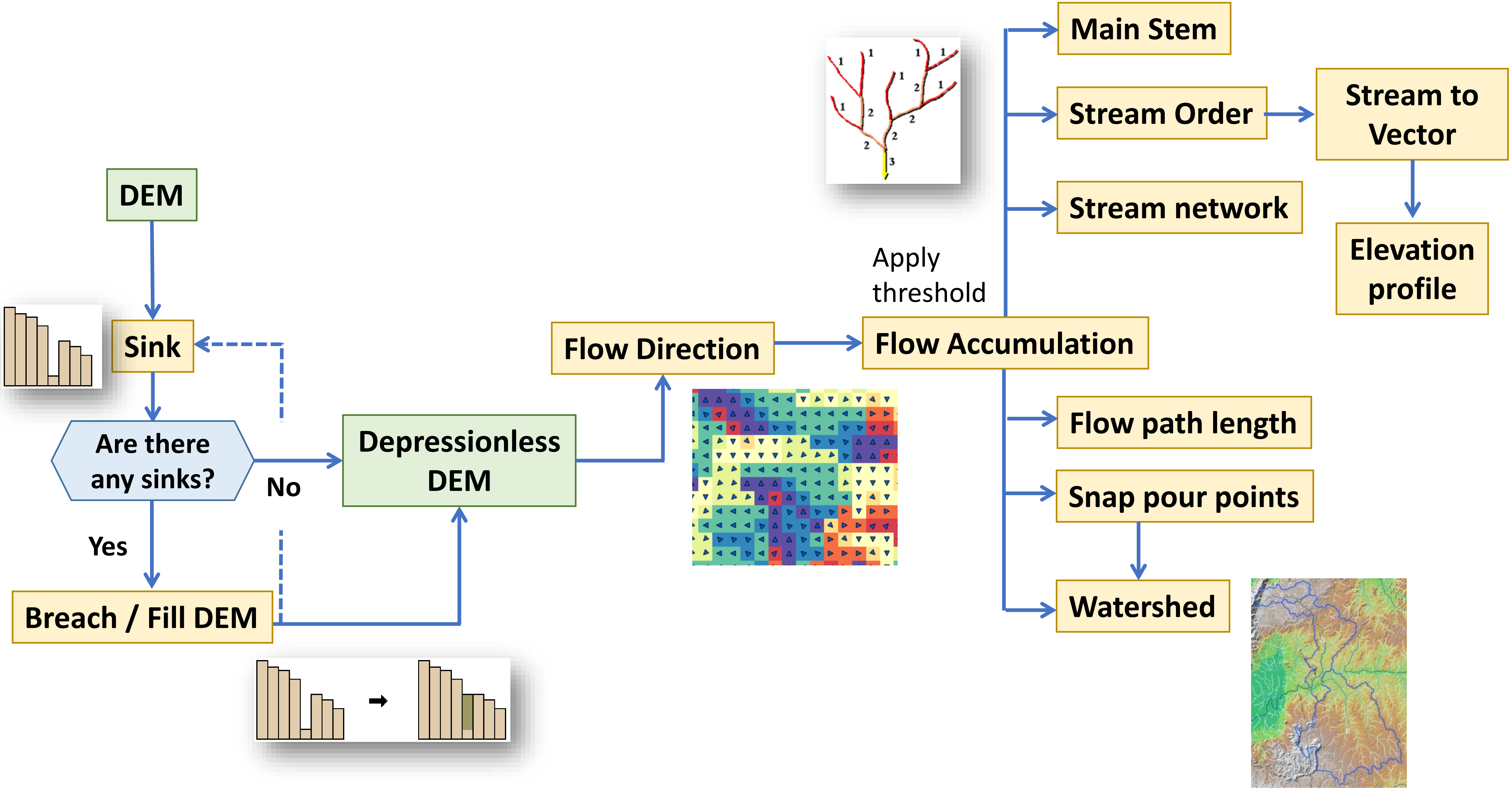
Overview of workflow



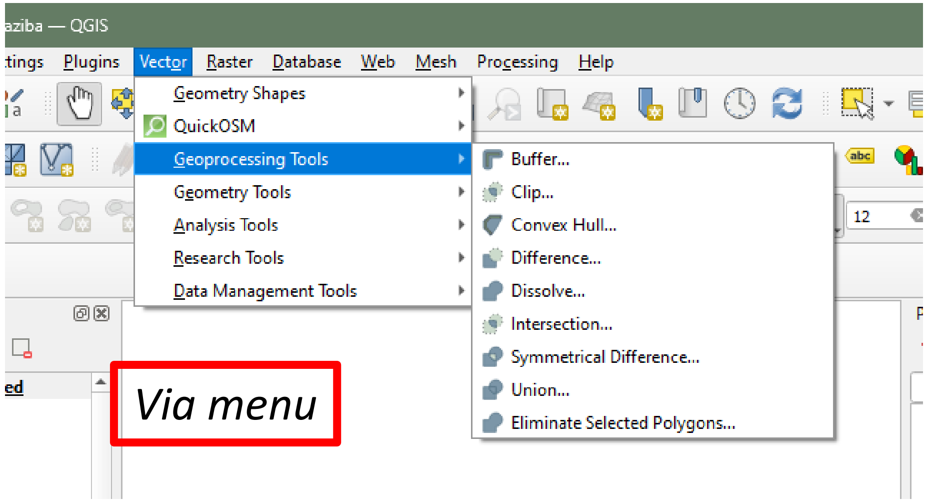
Esri, Garmin, GEBCO, NOAA NGDC, and other contributors

Catchment and stream network delineation flow chart

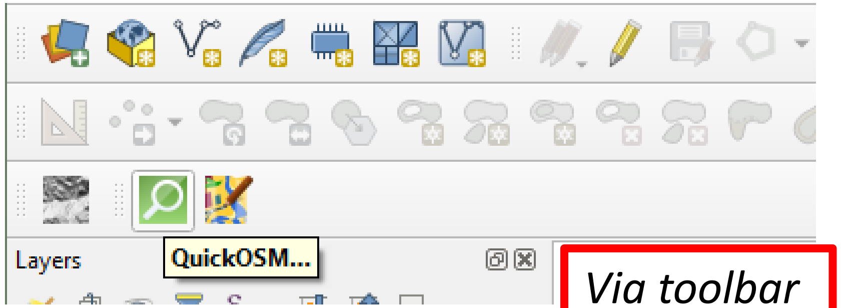


Accessing tools

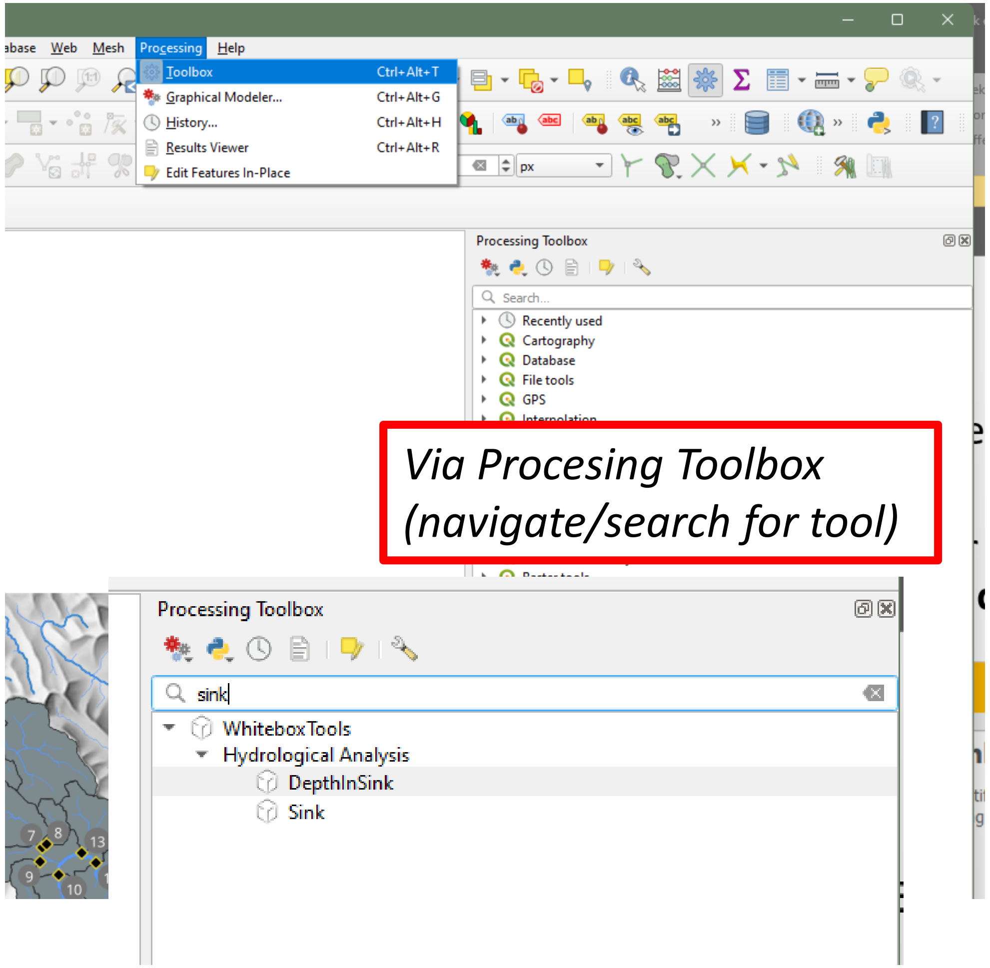
- Several options



Via menu



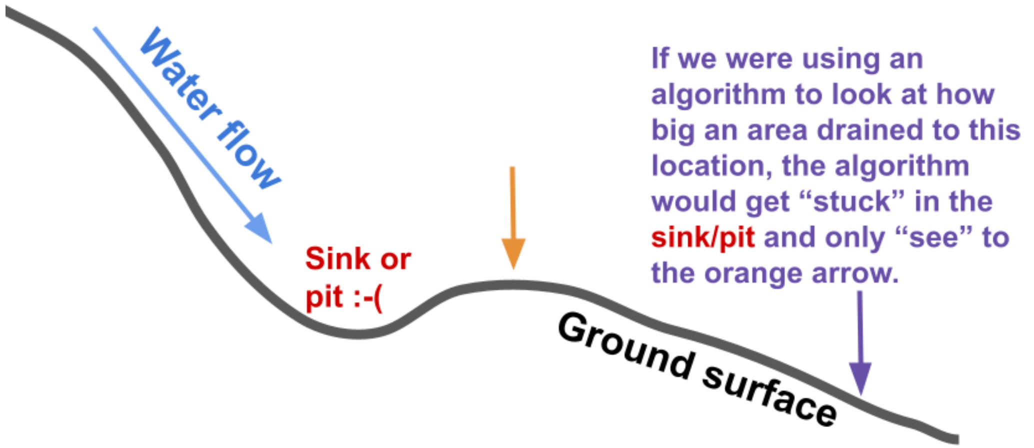
Via toolbar



Via Procesing Toolbox (navigate/search for tool)

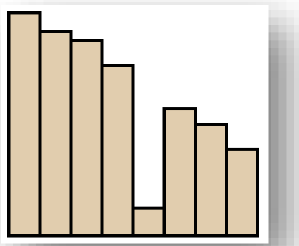
Sink

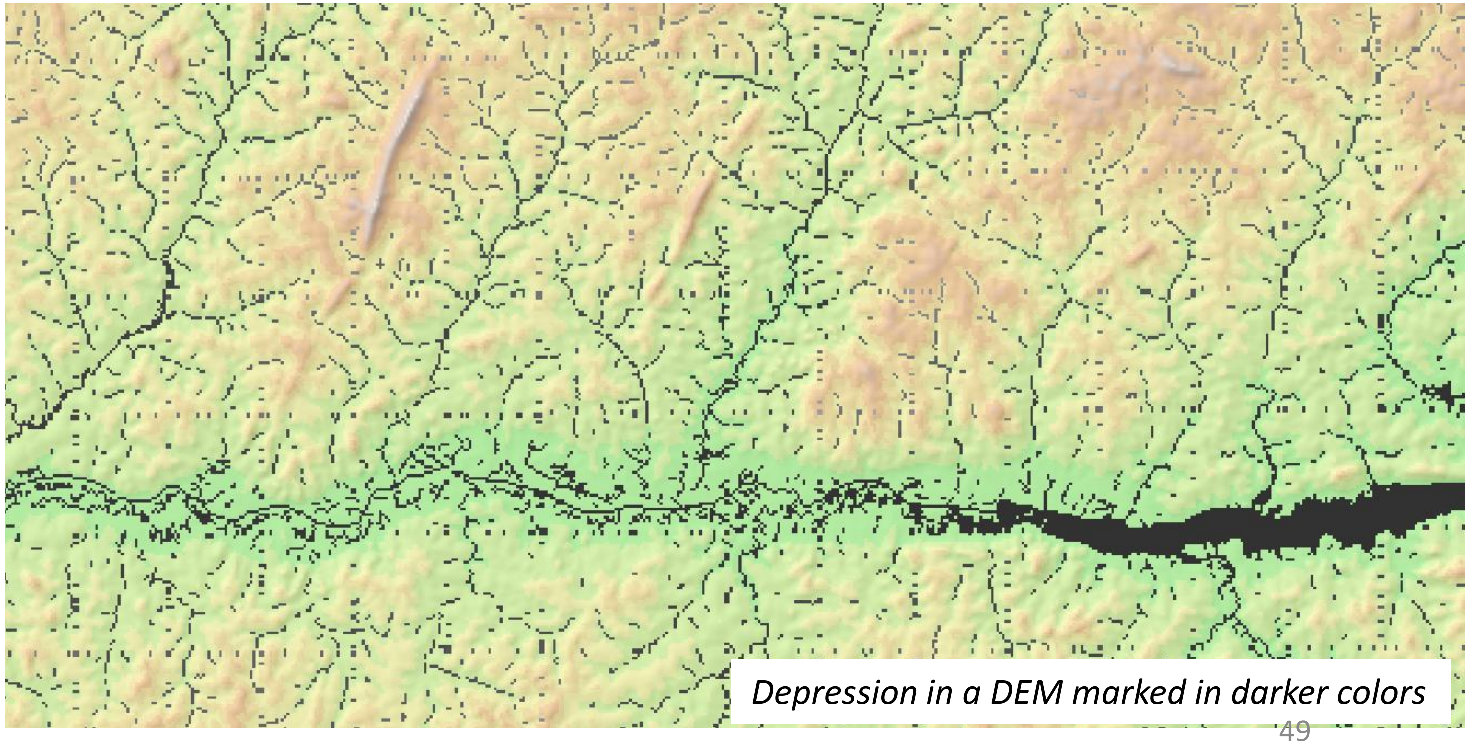
- **Sinks**: Cells or cell groups in a DEM that trap water flow, preventing proper drainage modeling
- **Identification**: Areas where all surrounding cells are higher or create circular flow paths
- **Causes**: Usually artifacts from DEM interpolation, data gaps, or processing errors
- **Natural examples**: Some exist in reality (endorheic basins, karst depressions, glacial kettles)
- **Problem**: Create interior drainage areas that disrupt watershed and stream network analysis
- **Solution**: Must be filled or breached before hydrological modeling to ensure continuous flow paths



Source: Gannon, J.P. (2024). Hydroinformatics. https://vt-hydroinformatics.github.io/Quarto_Book/

Profile view of a sink

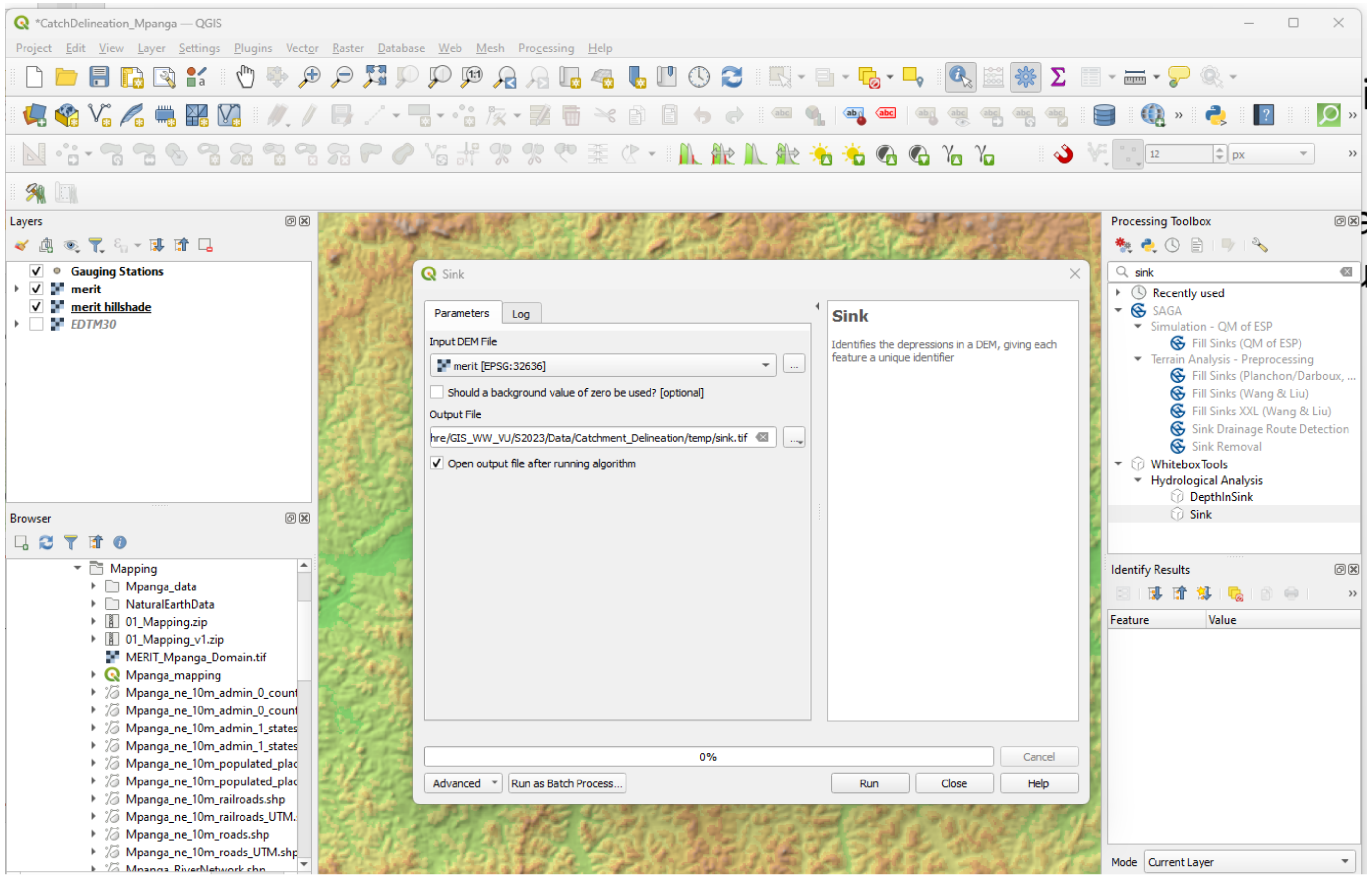


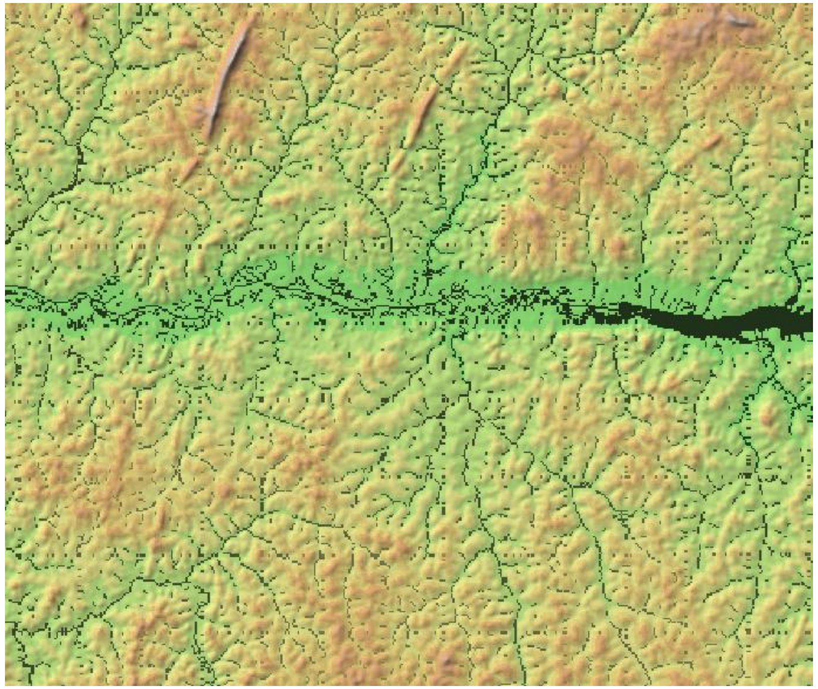


Depression in a DEM marked in darker colors

Sink

- The Sink Tool identifies these sink (i.e., topographic depression) and creates a **raster identifying all sinks** or areas of internal drainage
- The *output* of the Sink tool is a raster with each sink being assigned a **unique value**, non-zero, positive. Sinks are numbered between **one and the number of sinks**

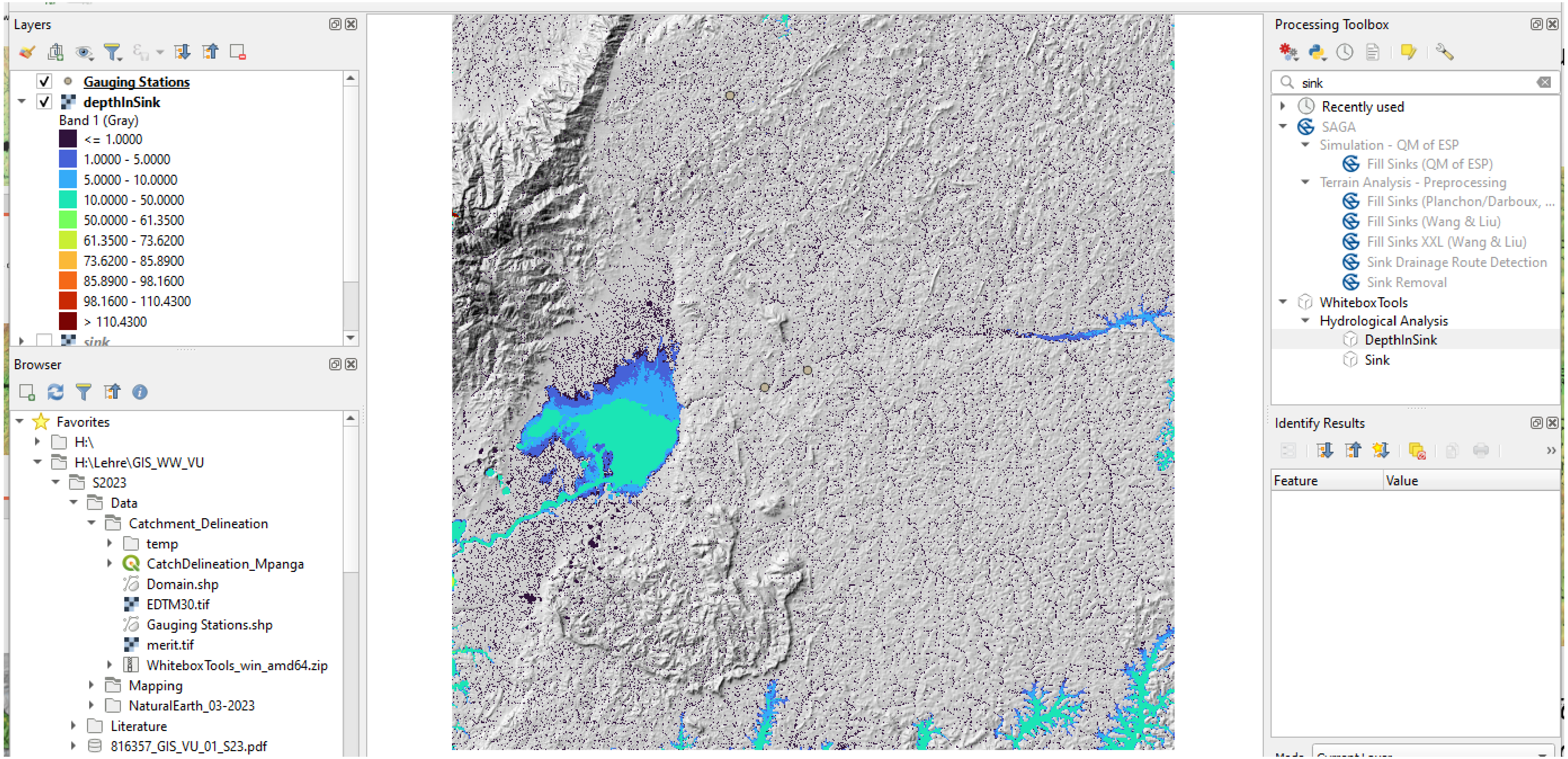




Apply the Sink Tool from the WB Tools

DepthInSinks

- Measures the depth that each grid cell in an input (--dem) raster digital elevation model (DEM) lies within a sink feature, i.e. a closed topographic depression.



Fill/Breach

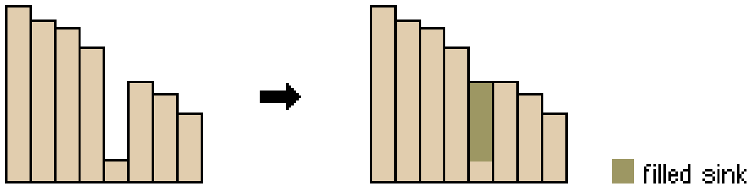
FillDepressionsTools: Eliminates depressions and flat areas in DEMs to ensure continuous downslope flow paths

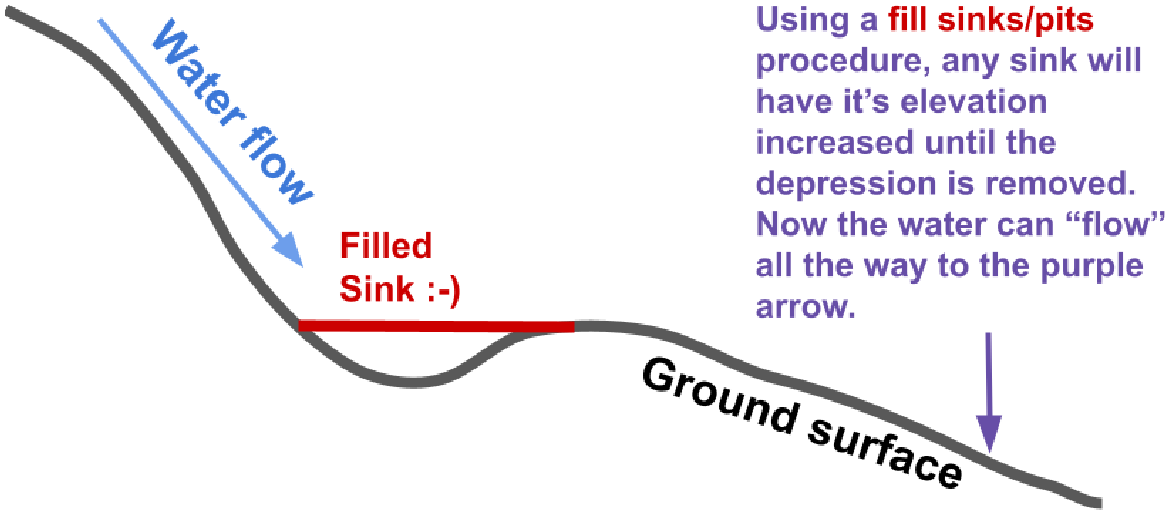
Process:

- Identifies pit cells (interior cells with no lower neighbors)
- Processes pits in descending elevation order
- Grows a region from each pit until finding a spill point (outlet)
- Raises all cells in the depression to the outlet elevation
- Applies slight slope gradient to prevent flat areas

- Limitations:
  - Creates artificial flat areas
  - Higher impact on original terrain representation
  - Generally less preferred than breaching methods

- Alternative: **BreachDepressionsLeastCost** tool offers a less intrusive solution by carving drainage paths rather than filling depressions





Source: Gannon, J.P. (2024). Hydroinformatics. https://vt-hydroinformatics.github.io/Quarto_Book/

Fill/Breach

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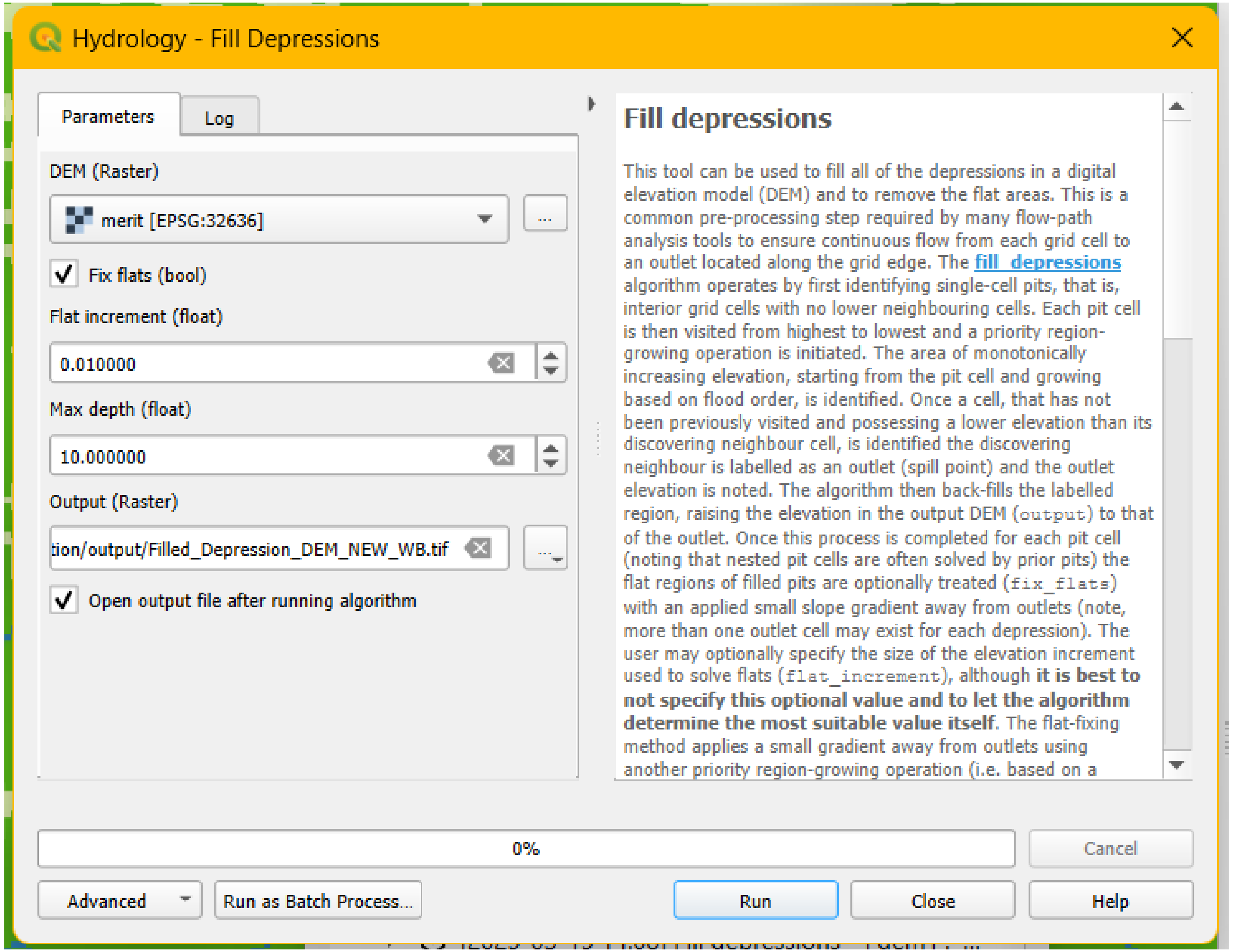


Fill/Breach

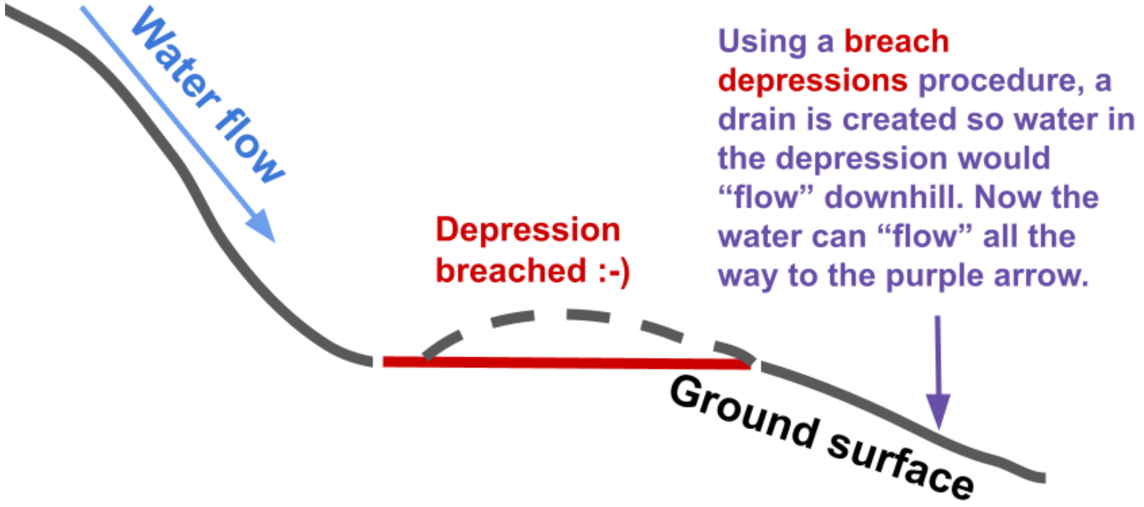
BreachDepressionsLeastCost Tool

Purpose:

- Creates drainage paths through topographic barriers in DEMs
- Provides lower-impact hydrological conditioning than depression filling

Process

- Uses least-cost path analysis to find optimal breach routes
- Slightly raises pit cells before processing to minimize breach depth
- Evaluates breach cost based on required elevation reduction
- Can optionally fill any unresolved depressions after breaching



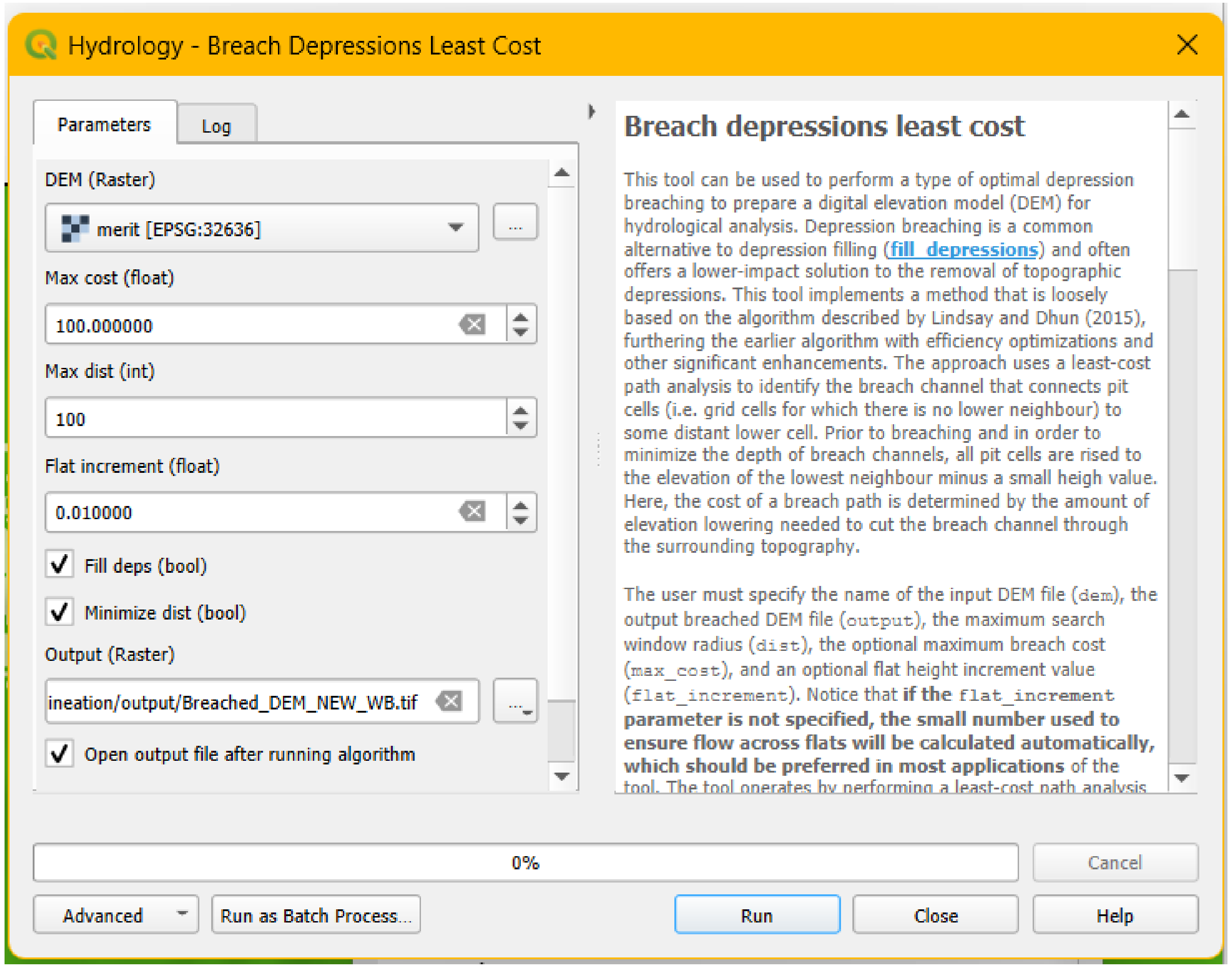
Source: Gannon, J.P. (2024). Hydroinformatics. https://vt-hydroinformatics.github.io/Quarto_Book/

Reference: Lindsay J, Dhun K. 2015. Modelling surface drainage patterns in altered landscapes using LiDAR. International Journal of Geographical Information Science, 29: 1-15.

Fill/Breach

BreachDepressionsLeastCost Tool

- DEM: Input DEM file
- Output: Output breached DEM file
- Max dist: Maximum search window radius ("Controls how far the algorithm searches for lower terrain to route the breach path")
- Max dost: Optional maximum breach cost ("Limits the depth of "digging" when breaching a depression — lower values prevent excessive terrain modification")
- Flat Increment: Optional flat height increment value ("Adds a tiny slope gradient across flat areas to ensure continuous downslope flow direction")
- Fill deps: Optional flag to fill remaining unbreached depressions. If a depression cannot be breached (Max Cost or Max Distance limits reached), it is filled instead — ensures no remaining sinks block flow routing)
- Minimize dist: Optional flag to minimize distances to choose shorter paths. (Prefers shorter breach paths when multiple routes exist — produces more realistic channels)

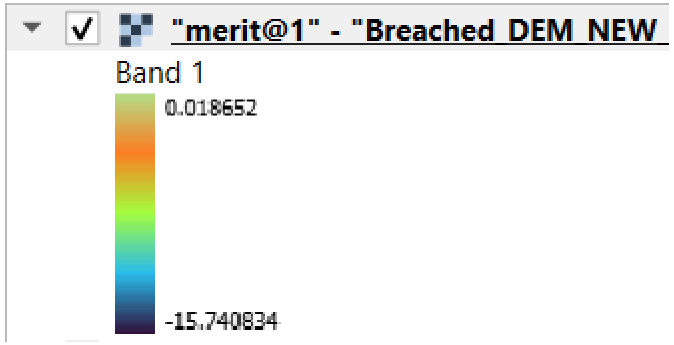


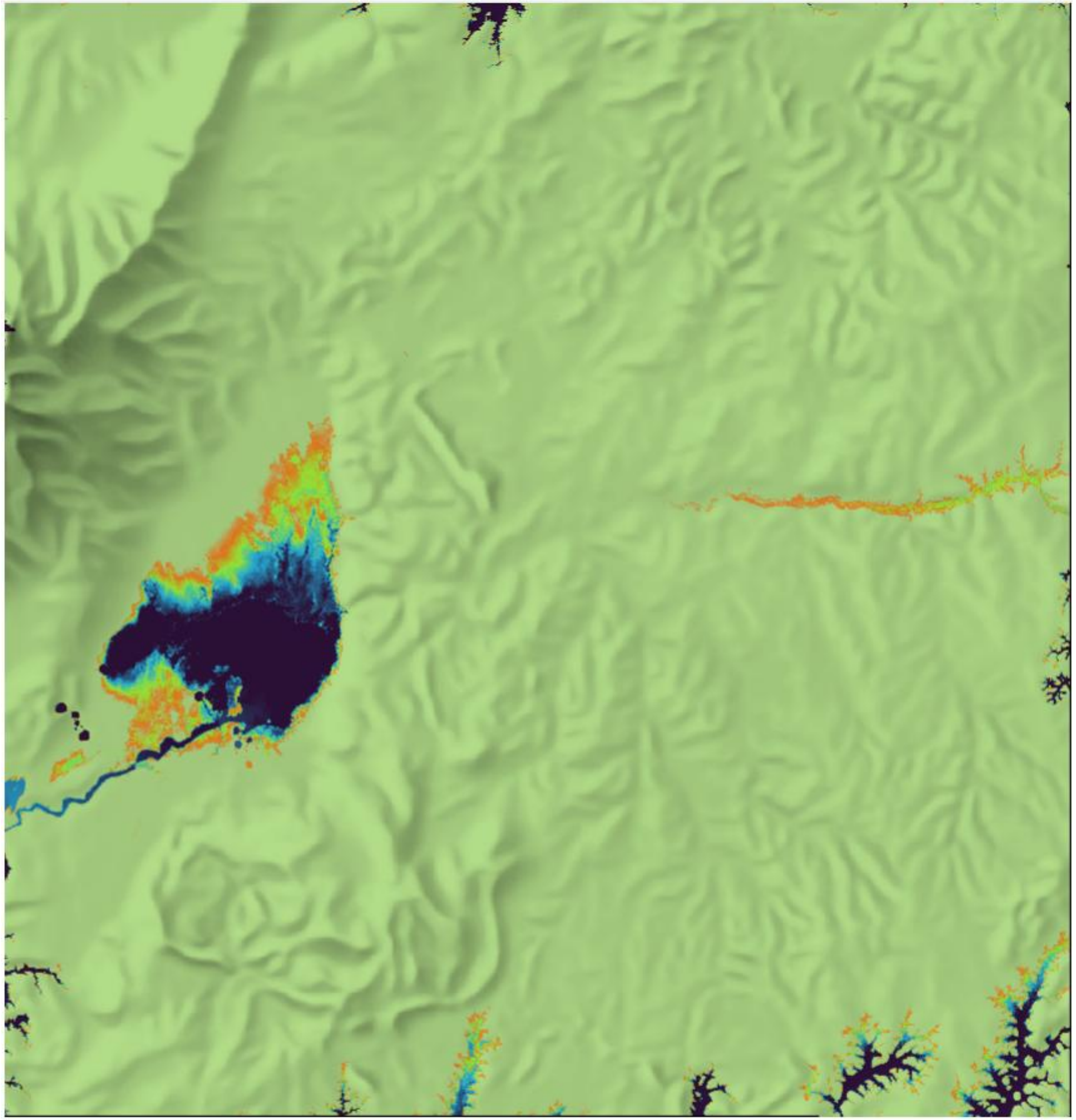
Using the Tool in Whitebox Workflows

Reference: Lindsay J, Dhun K. 2015. Modelling surface drainage patterns in altered landscapes using LiDAR. International Journal of Geographical Information Science, 29: 1-15.

Fill/Breach

- Difference between Merit DEM (original) and Breached DEM (units in m)





Flow direction

- **Purpose:** Determine water flow paths from higher to lower elevations across terrain grids (raster datasets). 2 main types **Single-Flow-Direction (SFD)** & **Multiple-Flow-Direction (MFD)** Algorithms
- **D8 (Deterministic 8) (SFD):**
  - Method: Flow goes to one adjacent cell with steepest downslope
  - Limitations: Flow restricted to 8 cardinal/diagonal directions (45° increments)
  - Result: Can produce unrealistic parallel flow patterns
  - Used in: ArcGIS and most standard GIS platforms
  - Reference: O'Callaghan, J. F. y Mark D.M. The extraction of drainage networks from digital elevation data. Computer Vision, Graphics and Image Processing 28: 323–44. 1984
- **Rho8 (SFD):**
  - Method: Similar to D8 but adds probabilistic element
  - Advantage: Breaks up parallel flow patterns on flat surfaces
  - Process: Selection probability proportional to slope gradient. Steeper slopes exert stronger "attraction" on the flow allocation.
  - Reference: Fairfield, J.; Leymarie P. Drainage networks from grid digital elevation models. Wat. Resour. Res. 27(5):709–717, 1991)
- **D-infinity (D∞) (MFD):**
  - Method: Flow can split between one or two downslope neighbors
  - Advantage: Precise flow direction as azimuth (0-360°)
  - Benefit: More realistic in areas with complex topography
  - Reference: Tarboton, D.G.; Shankar, U. (1998), The Identification and Mapping of Flow Networks from DigitalElevation Data, Invited Presentation at AGU Fall Meeting, San Francisco, 1998
- **FD8 (MFD):**
  - Method: Water flows to all downslope cells
  - Distribution: Flow proportion weighted by slope gradient
  - References: Freeman, T. G. (1991). Calculating catchment area with divergent flow based on a regular grid. Computers and Geosciences, 17(3), 413-422; Quinn, P.F.; Beven, K.J.; Chevallier, P.; Planchon, O.; The prediction of hillslope flow paths for distributed hydrological modelling using digital terrain models, Hydrological Processes, 5: 59–79. 1991

[See also Hydrology with a GIS, for dummies: calculation of flow(1) | GIS & Territories Blog (sigterritoires.fr)]

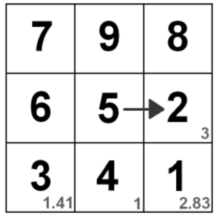
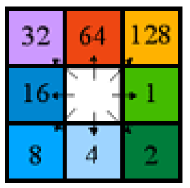


Figure 1. The SFD8 algorithm. The large numbers denote the elevations, the small numbers denote the slope from the central cell, and the arrow represents the determined flow direction.

D8 flow pointers Direction coding



.	.	.
64	128	1
32	0	2
16	8	4

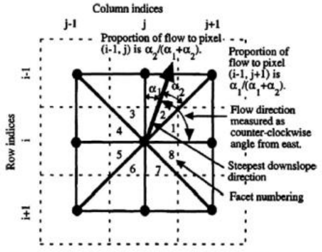


Figure 4. Flow direction on planar triangular facets in a block-centered grid (from Tarboton, 1997)

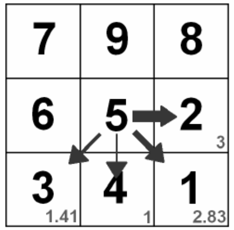
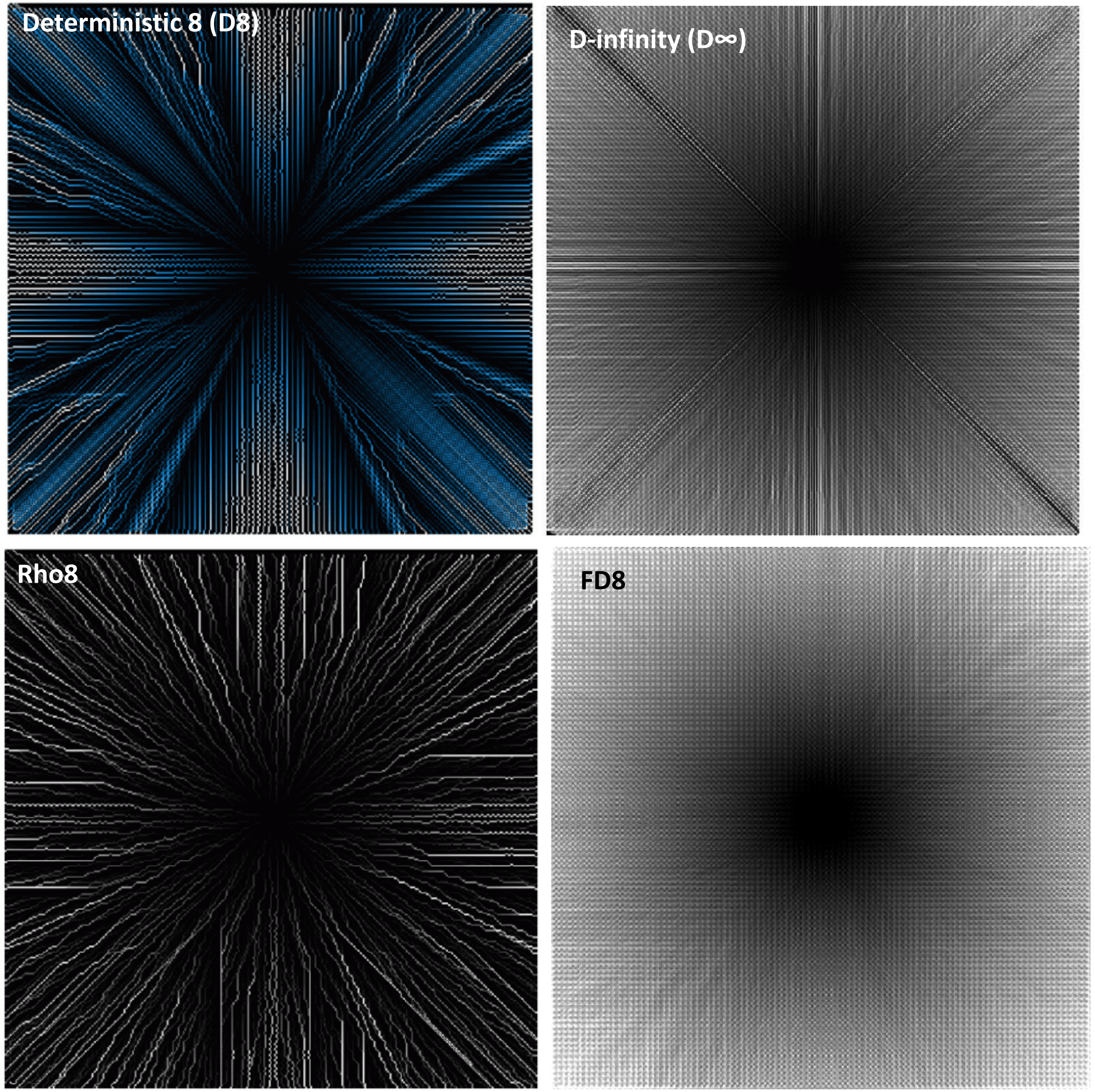
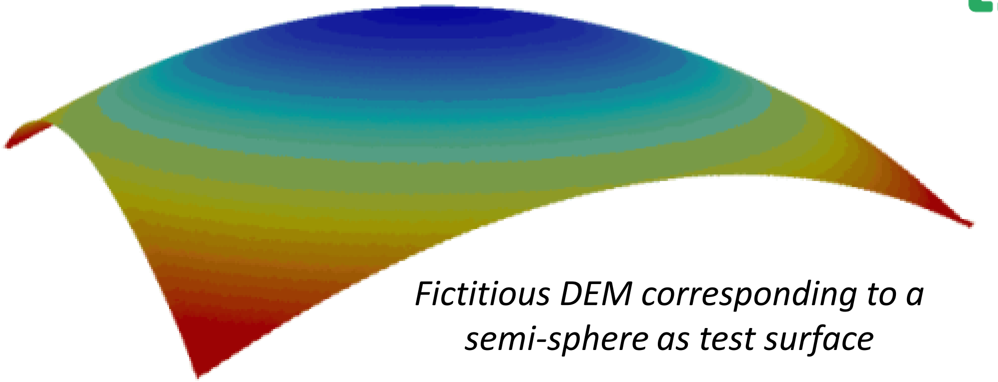


Figure 2. The MFD8 algorithm. The thickness of the arrows symbolizes the proportion of flow falling on the particular neighbour.

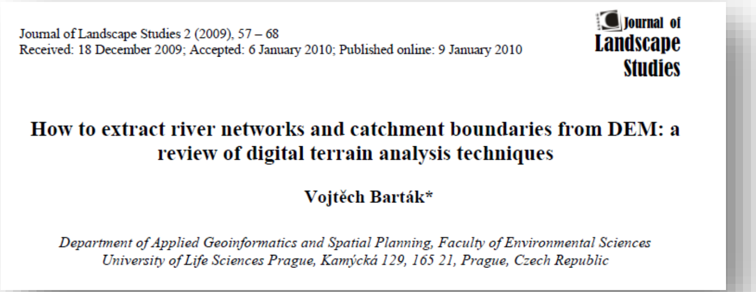
Flow direction





Fictitious DEM corresponding to a semi-sphere as test surface

See literature on BOKUlearn
(1) General review on methods
(2) Influence of different algorithms on simulations



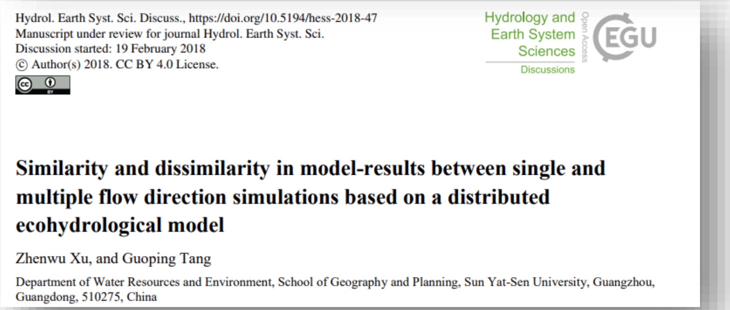
Journal of Landscape Studies 2 (2009), 57 – 68
Received: 18 December 2009; Accepted: 6 January 2010; Published online: 9 January 2010

Journal of Landscape Studies

How to extract river networks and catchment boundaries from DEM: a review of digital terrain analysis techniques

Vojtěch Barták*

Department of Applied Geoinformatics and Spatial Planning, Faculty of Environmental Sciences University of Life Sciences Prague, Kamýcká 129, 165 21, Prague, Czech Republic



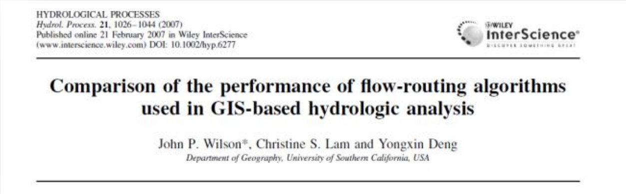
Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2018-47
Manuscript under review for journal Hydrol. Earth Syst. Sci.
Discussion started: 19 February 2018

Hydrology and Earth System Sciences Discussions

Similarity and dissimilarity in model-results between single and multiple flow direction simulations based on a distributed ecohydrological model

Zhenwu Xu, and Guoping Tang

Department of Water Resources and Environment, School of Geography and Planning, Sun Yat-Sen University, Guangzhou, Guangdong, 510275, China



HYDROLOGICAL PROCESSES
Hydrol. Process. 21, 1026–1044 (2007)
Published online 21 February 2007 in Wiley InterScience
(www.interscience.wiley.com) DOI: 10.1002/hyp.6277

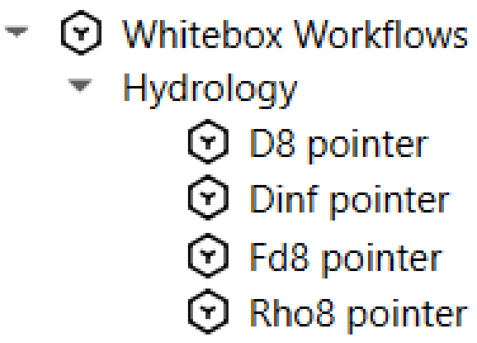
Comparison of the performance of flow-routing algorithms used in GIS-based hydrologic analysis

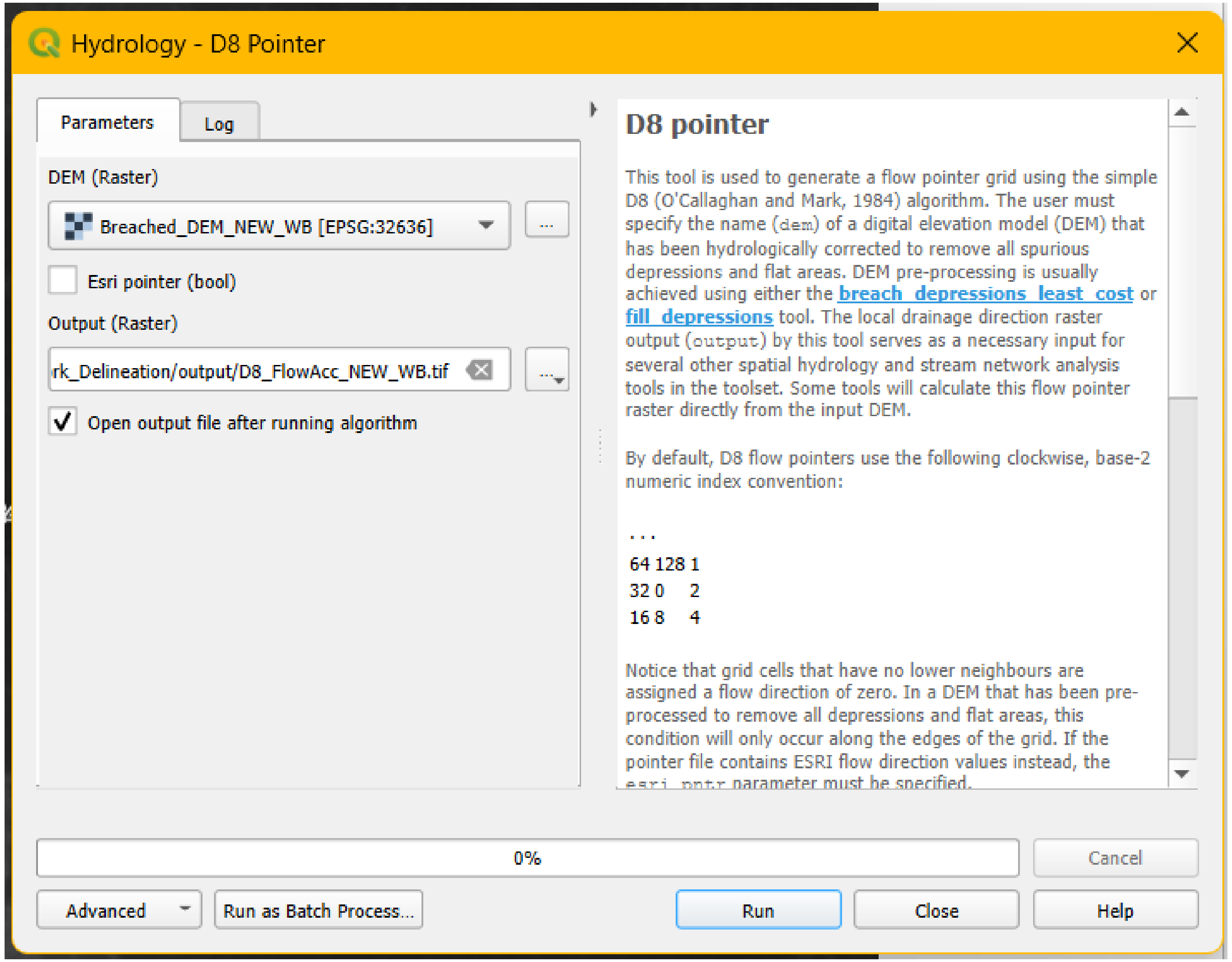
John P. Wilson*, Christine S. Lam and Yongxin Deng
Department of Geography, University of Southern California, USA

Source: Hydrology with a GIS, for dummies (that we are): calculation of flow(1) | GIS & Territories Blog (sigterritoires.fr)

Flow direction using D8

- Access the D8Pointer Tool
- Define input (use the BreachDepressionsLeastCost-DEM) and output (see screenshot)
- Here, we use D8. You can also try other flow direction methods





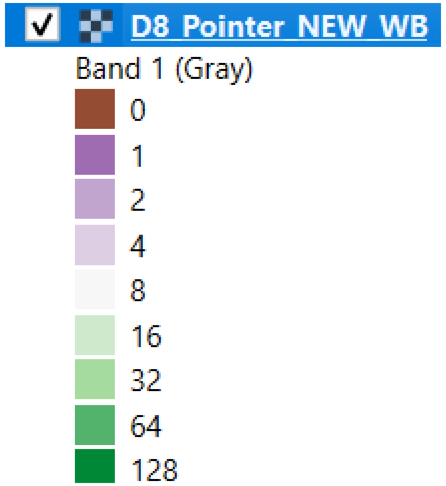
We use D8 here, you can also try other flow direction methods

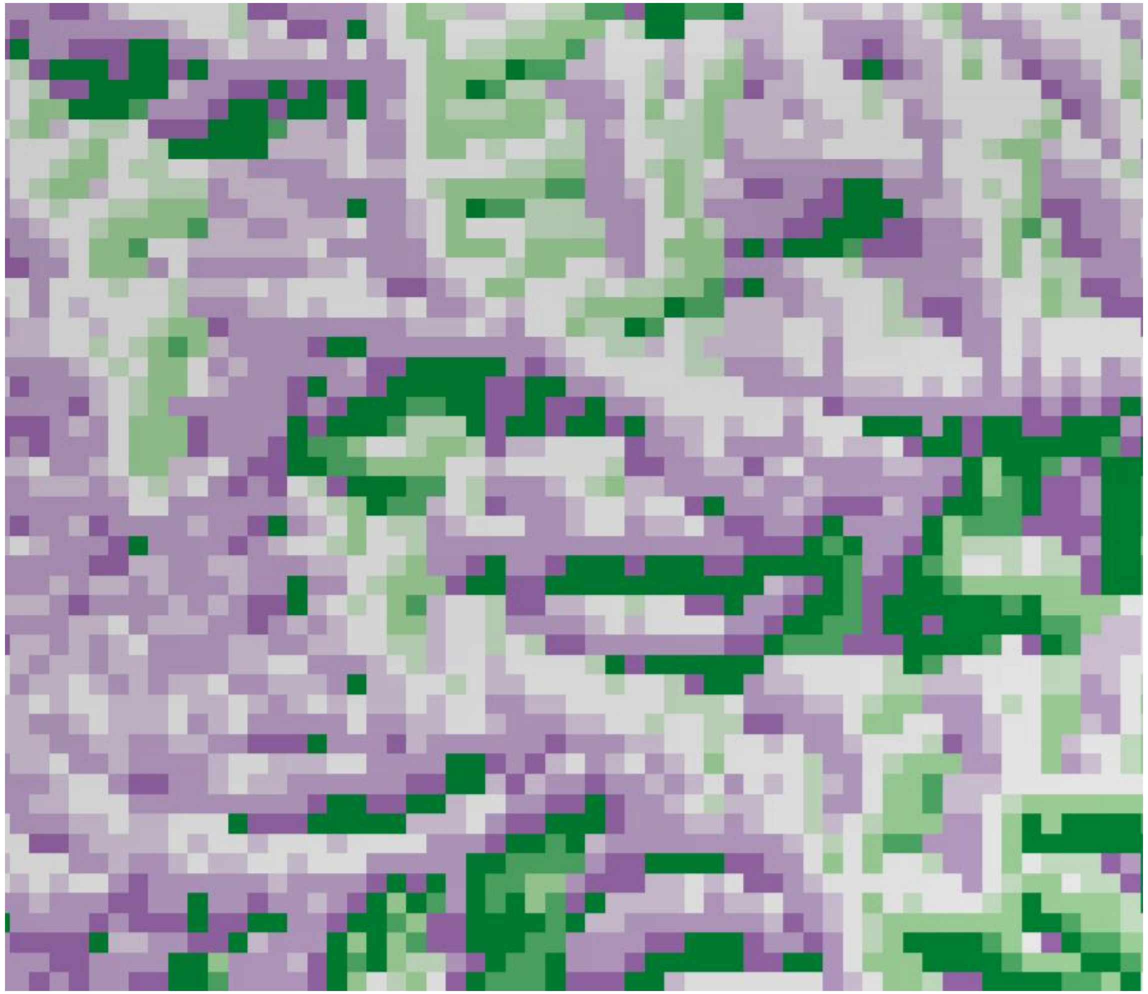
Flow direction using D8

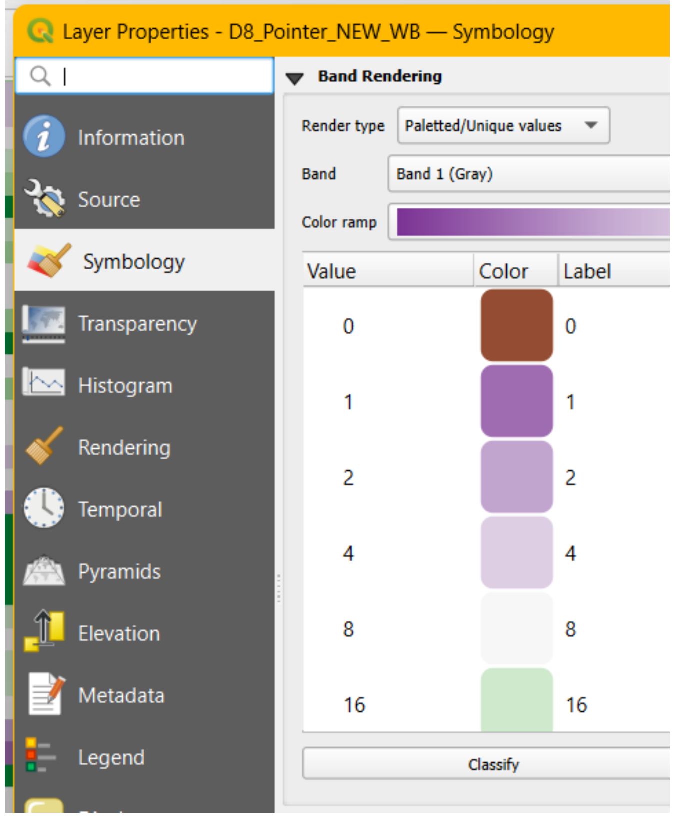
- The resulting raster indicates, in which direction water flows

.	.	.
64	128	1
32	0	2
16	8	4

D8 flow pointers Direction coding







We use D8 here, you can also try the other ones

Flow direction using D8

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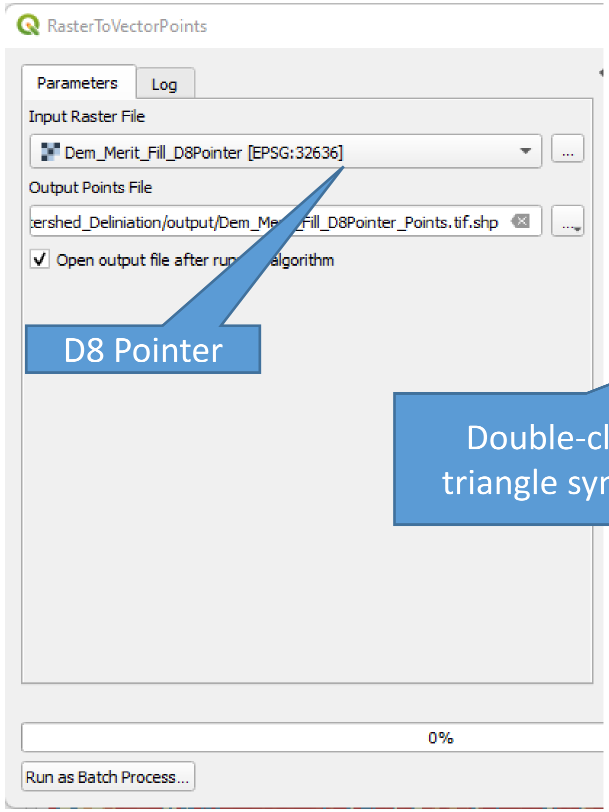
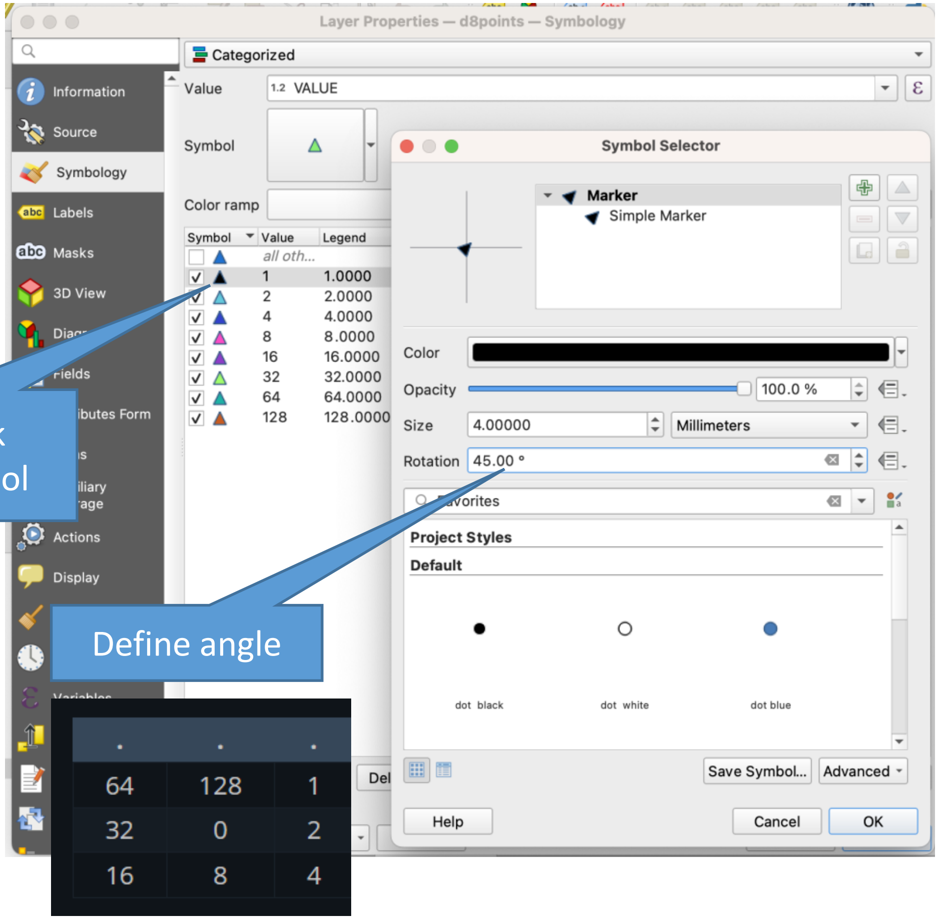
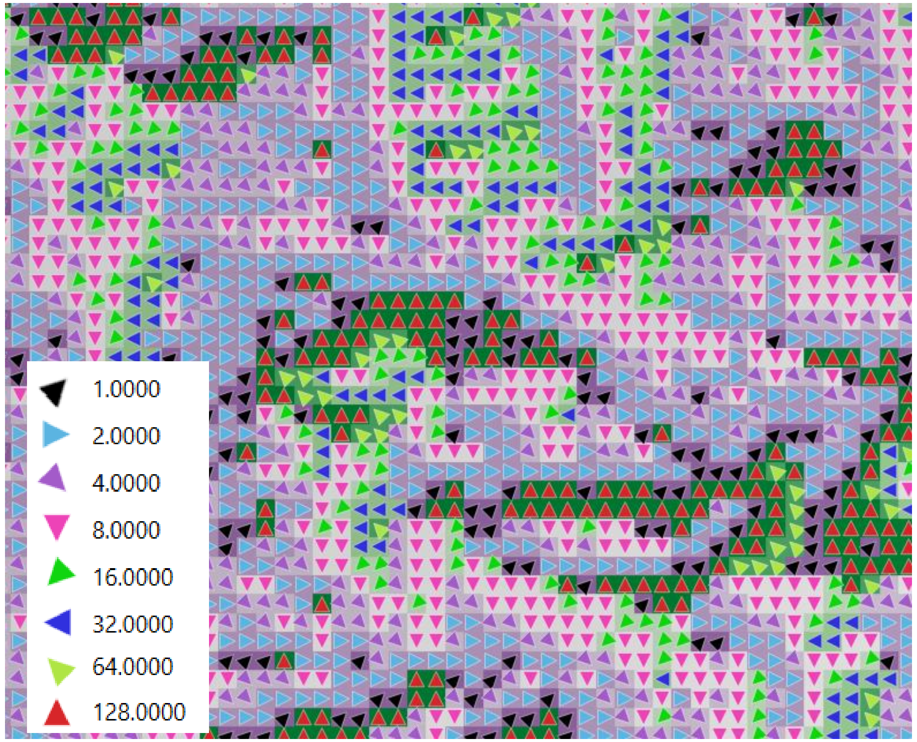
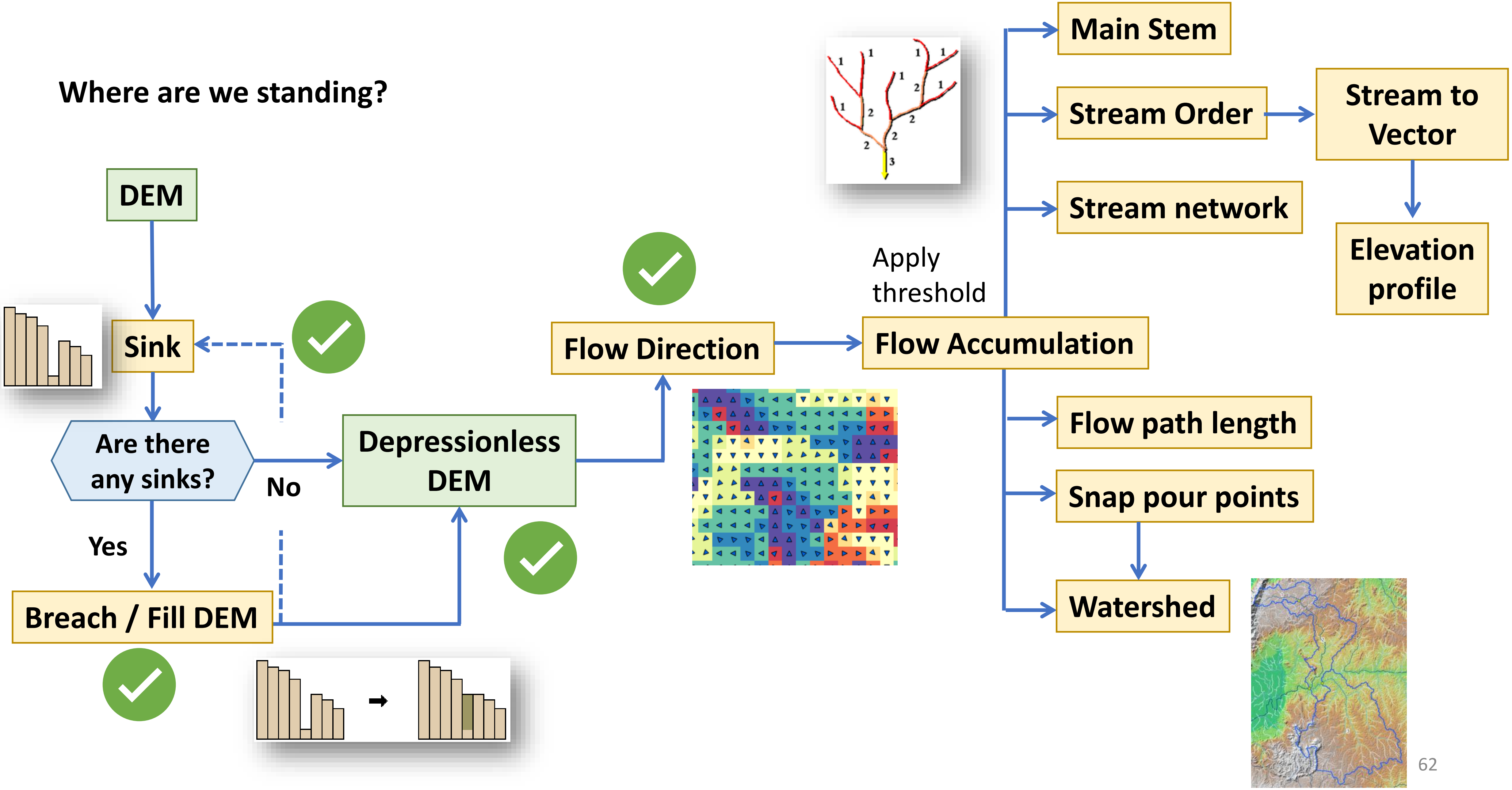
- Visualisation example using arrows (D8_Pointer: Raster pixels to point -> Adopt symbology of points as a function of the flow pointer coding (change rotation of triangle))





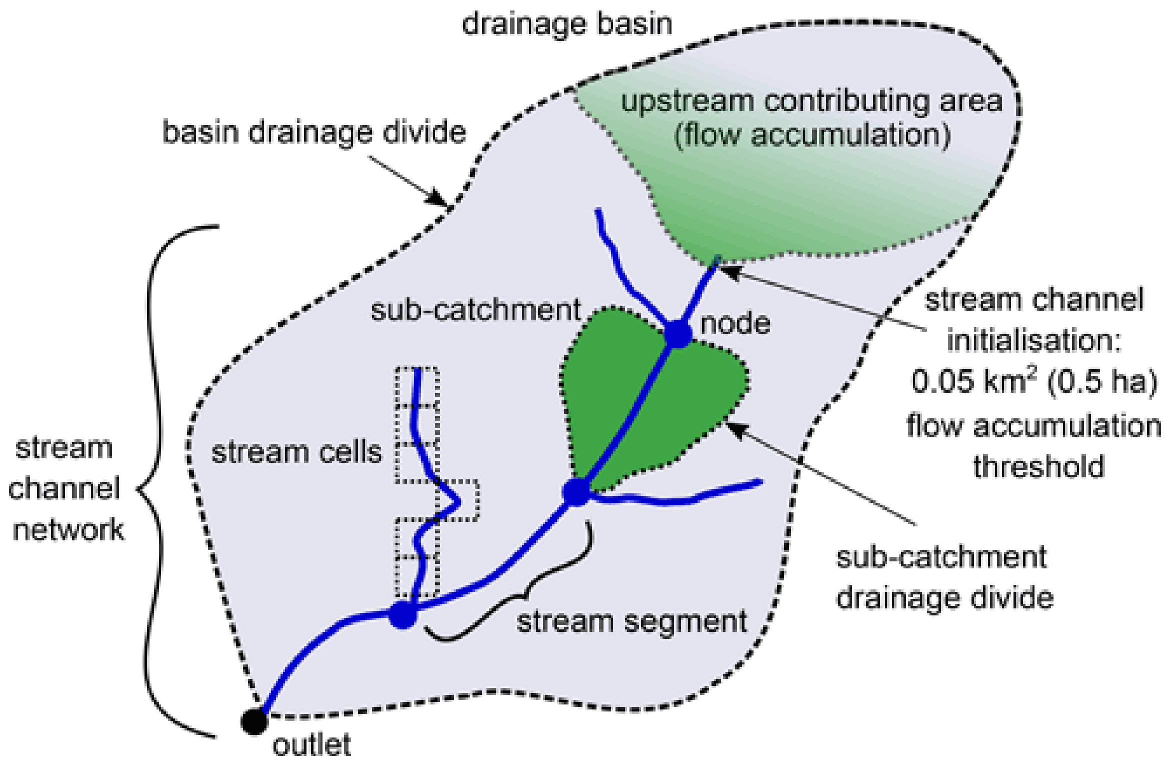


Catchment and stream network delineation



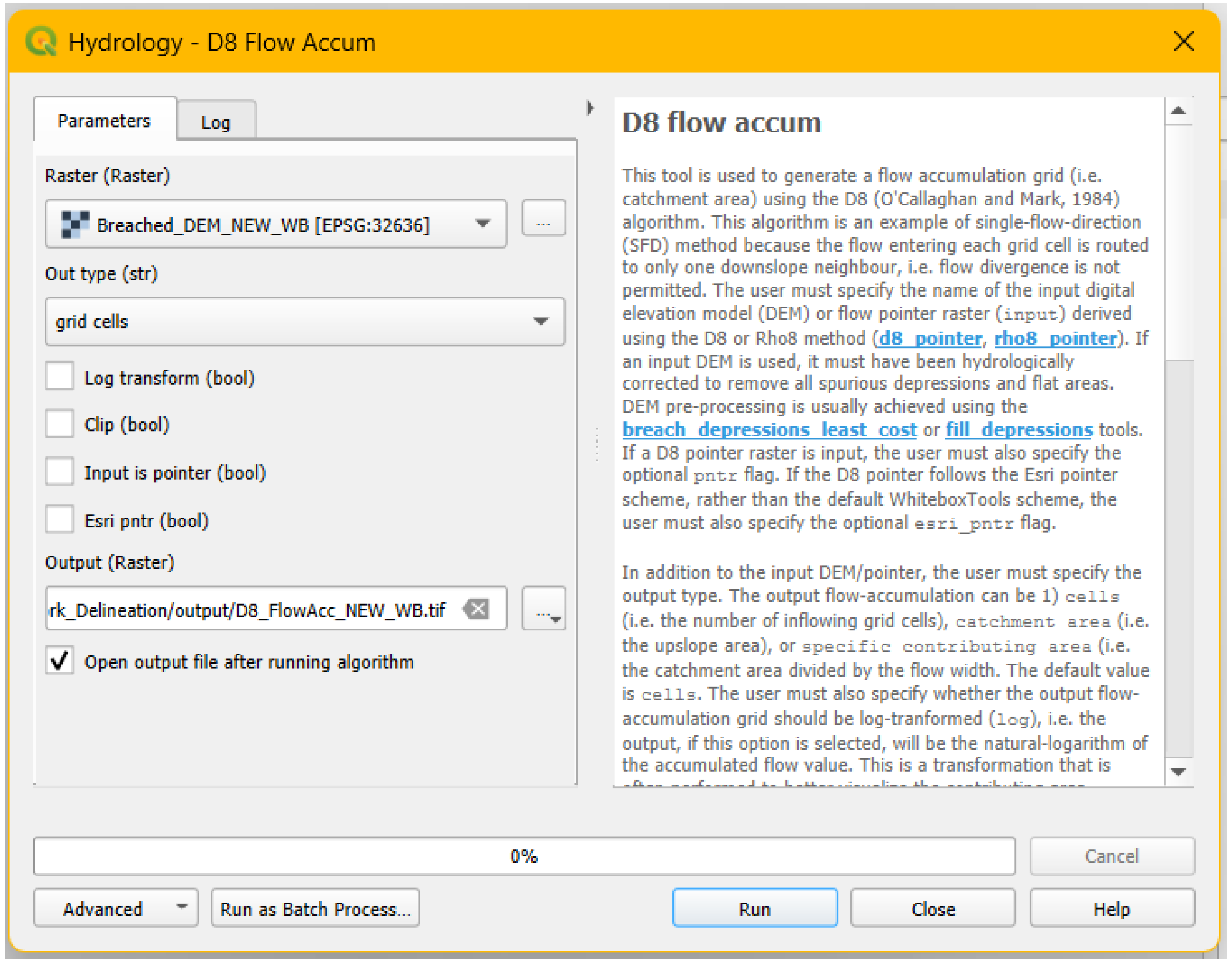
Flow Accumulation

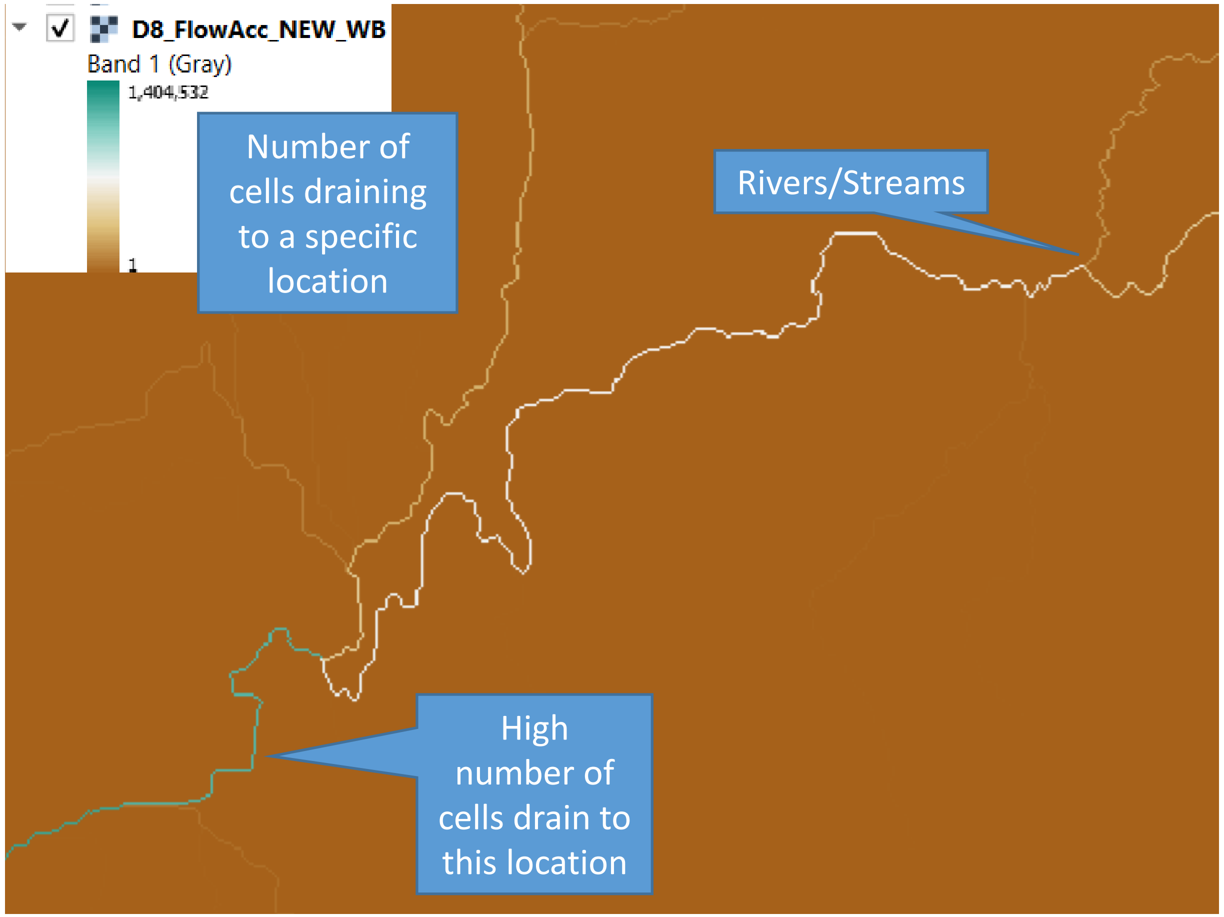
- Flow accumulation represents the **total number of upstream cells (or area)** that **drain** or contribute to the flow of water in a **given cell**
- Flow accumulation is used to identify areas of **concentrated water flow**, such as **streams or rivers**.
- Higher values indicate areas where more water would accumulate
- Flow accumulation is used as a precursor to other hydrological analyses, such as **stream network or and watershed delineation**.



Amatulli, G., Garcia Marquez, J., Sethi, T., Kiesel, J., Grigoropoulou, A., Üblacker, M. M., Shen, L. Q., and Domisch, S.: Hydrography90m: a new high-resolution global hydrographic dataset, Earth Syst. Sci. Data, 14, 4525–4550, https://doi.org/10.5194/essd-14-4525-2022, 2022.

Flow Accumulation





The flow accumulation grid is a raster where each cell is the number of cells that drains to that cell

Flow Accumulation – Testing different thresholds

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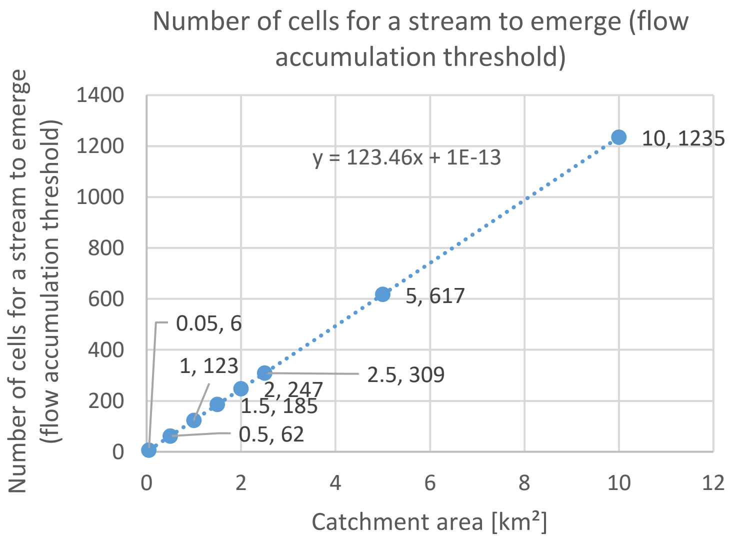
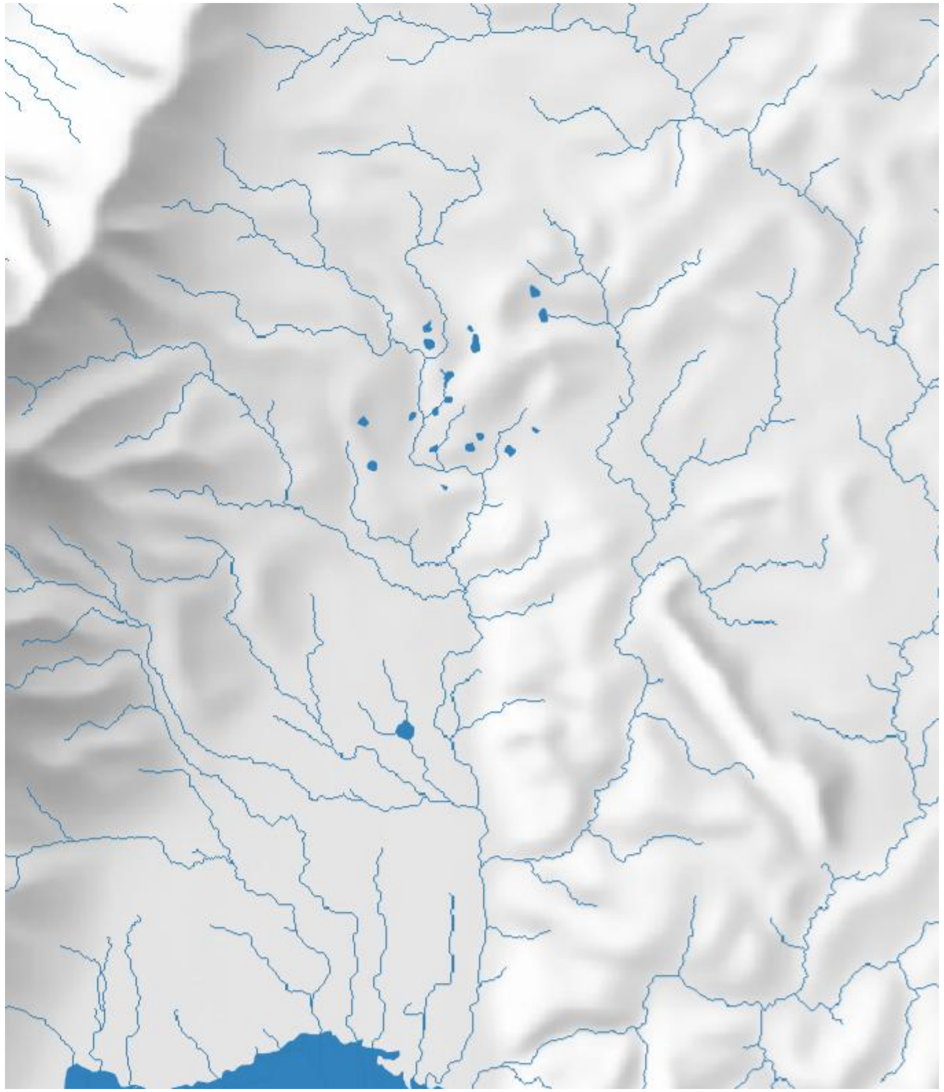
- Because the flow accumulation shows the number of cells (or area) that drain to a particular cell, it can be used to **define a stream**.
  - It is assumed that a stream **is formed when a certain area (threshold) drains to a point**.
- This threshold can be defined by using the number of cells in the flow accumulation grid. If we assume an area of "CatchArea" (in km²) as the threshold to create a stream, the number of cells (NCells) corresponding to this threshold area is (with the cell size of the raster CellSize (x, y) (in m)):

$$NCells = \frac{CatchArea\ [km^2] * 10\hat{}6}{CellSize(x) * CellSize(y)[m^2]}$$

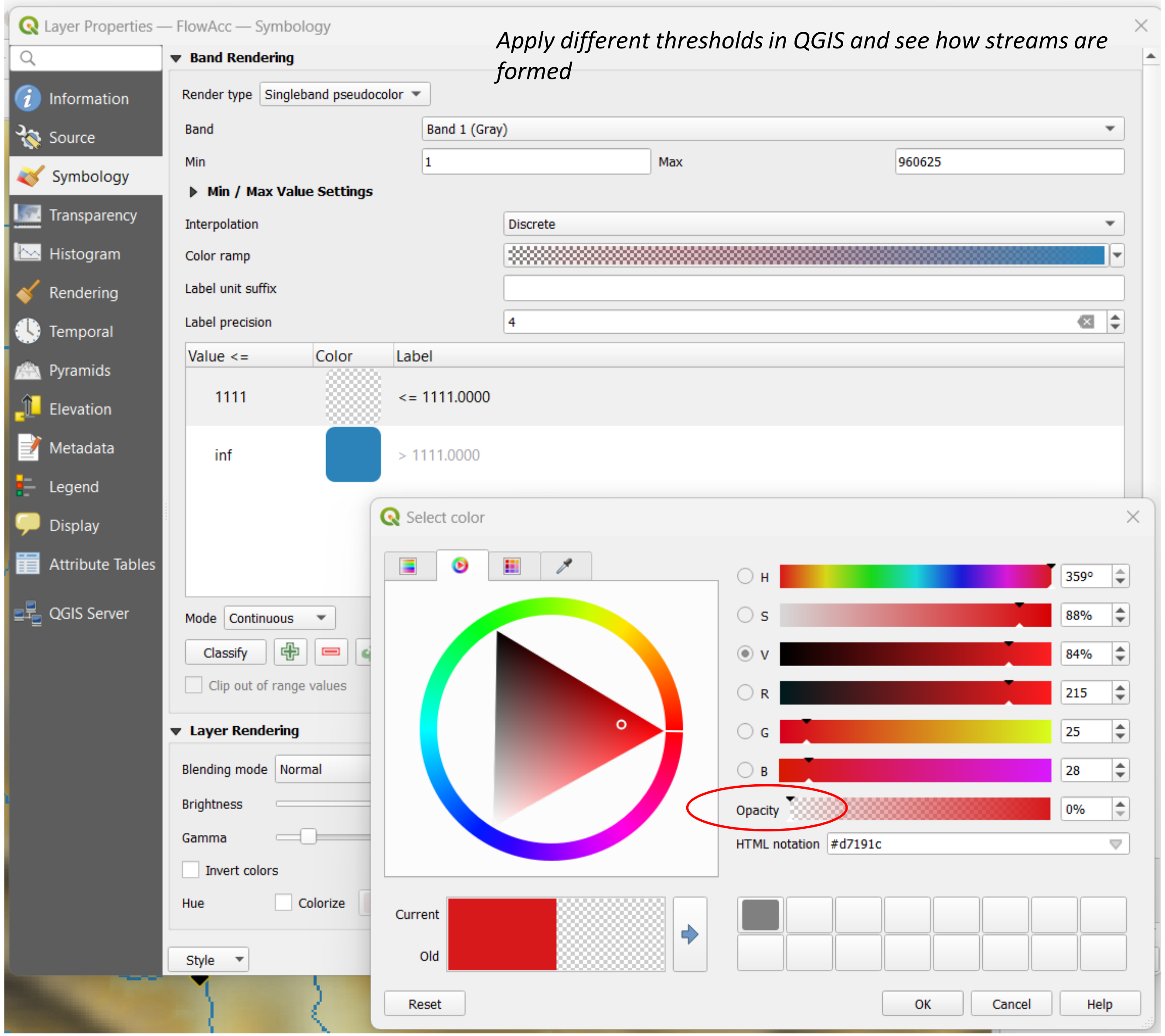


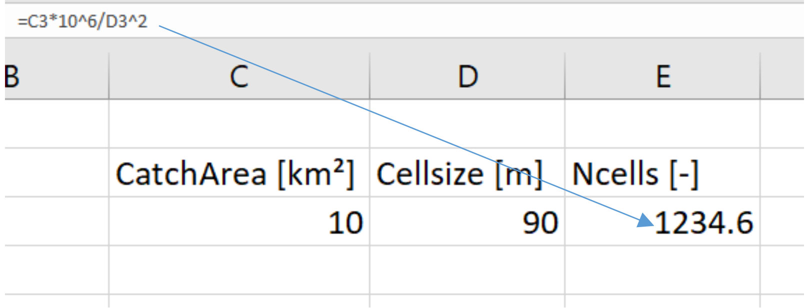
Catchment area [km²]	Raster Cell Size	Number of cells for a stream to emerge (flow accumulation threshold)
0.05	90	6
0.5	90	62
1	90	123
1.5	90	185
2	90	247
2.5	90	309
5	90	617
10	90	1235



Flow Accumulation – Testing different thresholds

Apply different thresholds in QGIS and see how streams are formed

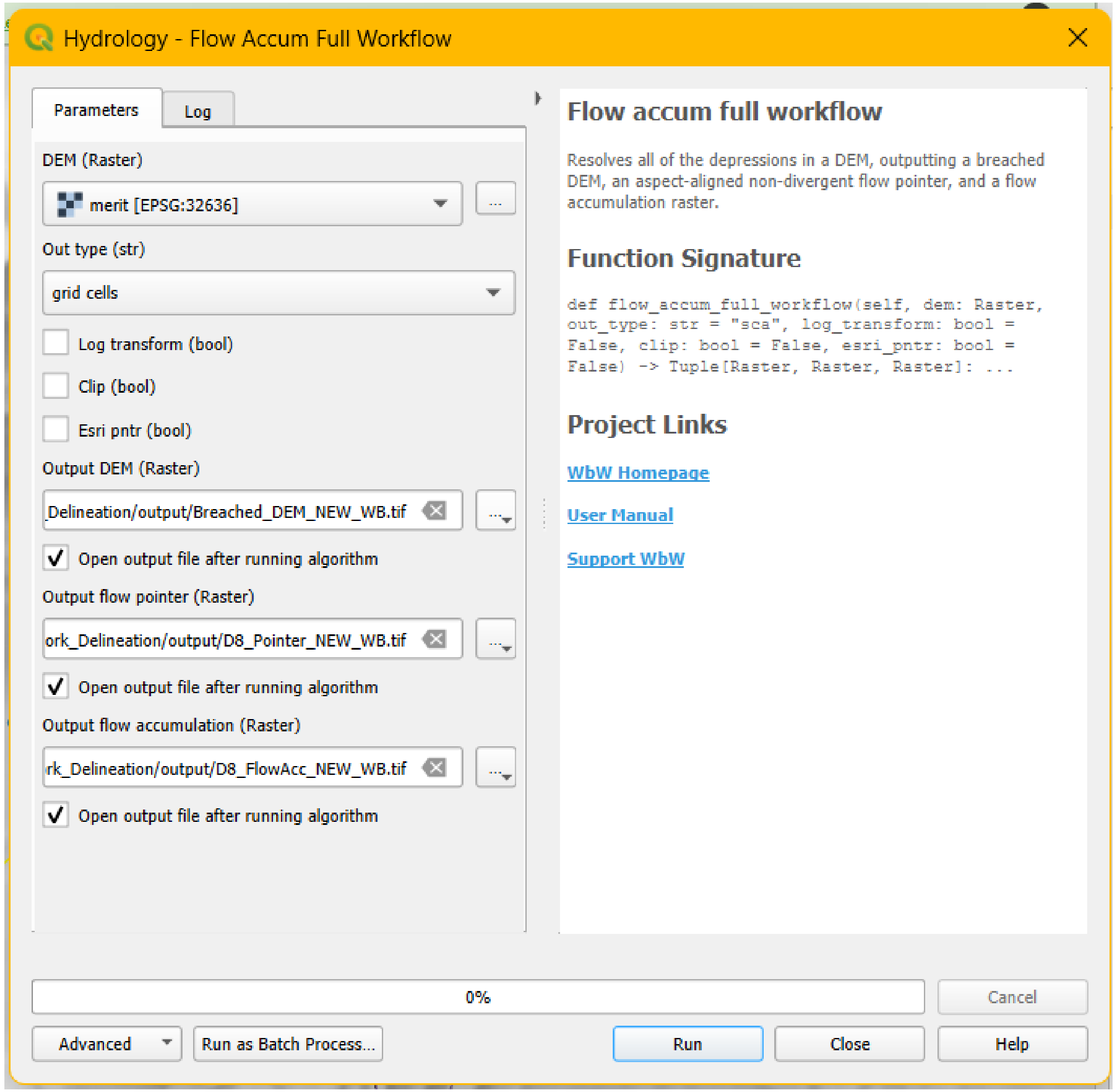




Catchment area [km²]	Raster Cell Size	Number of cells for a stream to emerge (flow accumulation threshold)
0.05	90	6
0.5	90	62
1	90	123
1.5	90	185
2	90	247
2.5	90	309
5	90	617
10	90	1235

Flow Accum Full Workflow

- The "**Flow Accumulation Full Workflow**" tool in streamlines hydrological analysis by combining multiple processing steps into a single operation.
- Rather than running individual tools sequentially (depression filling/breaching, flow direction calculation, and flow accumulation), this tool executes the complete workflow automatically.



Stream network

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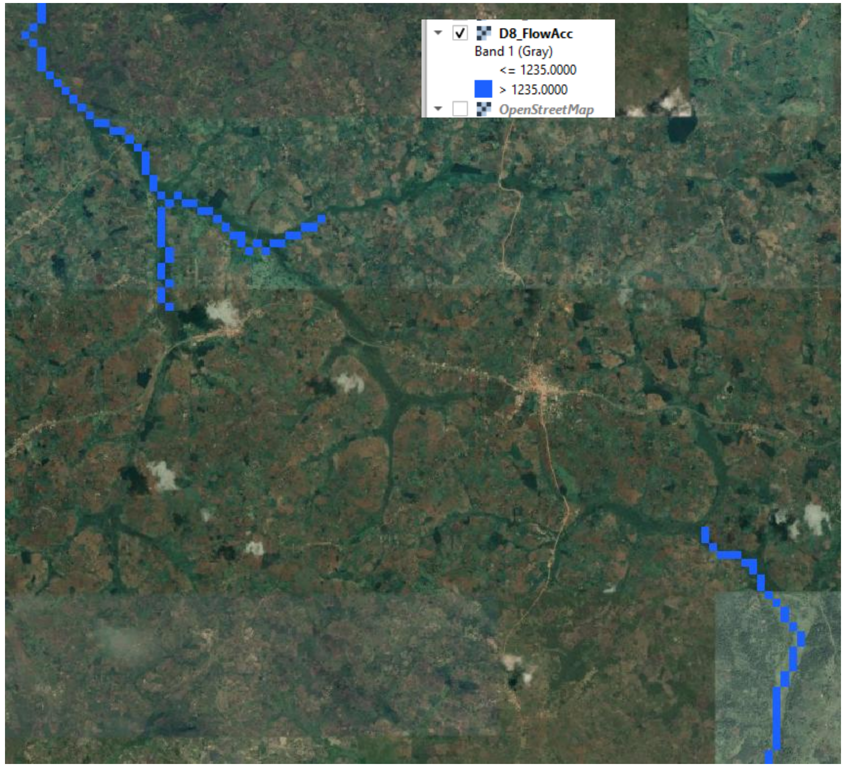
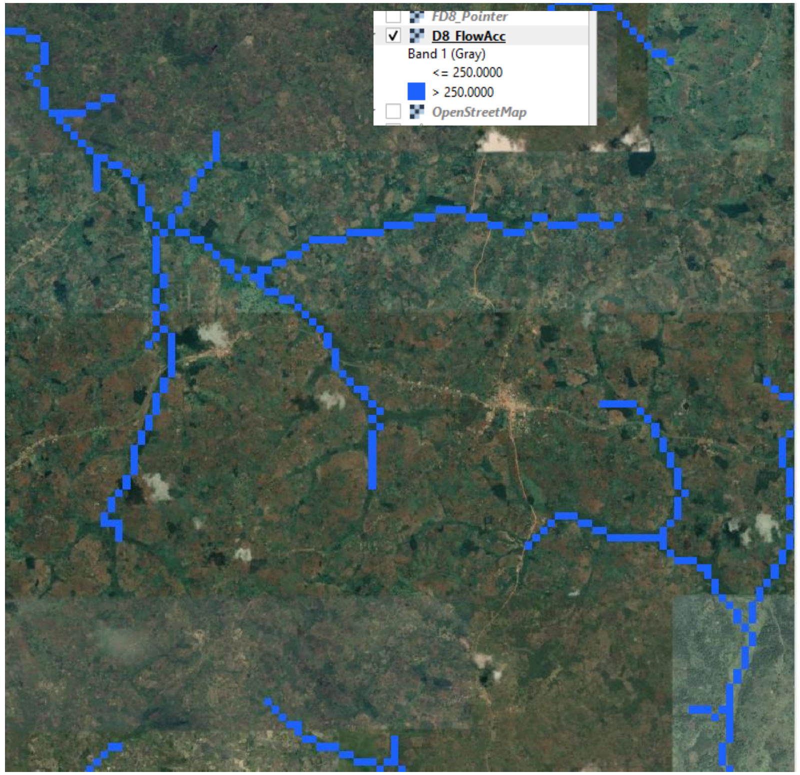
- Choice of threshold value (CatchArea or NCells) depends on local hydrological, meteorological and hydrogeological conditions.
- It should be defined based on local knowledge or the consultation of (high resolution) satellite imagery (e.g. here shown with google satellite in the background), topographic maps or OSM maps

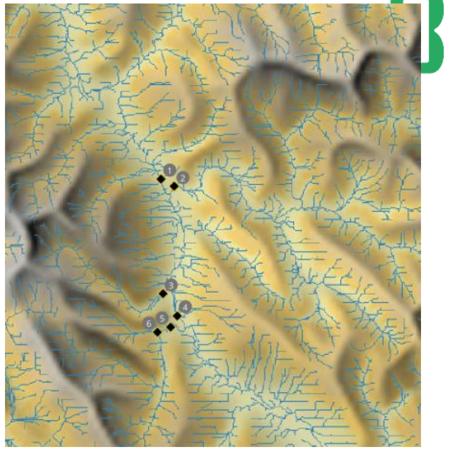


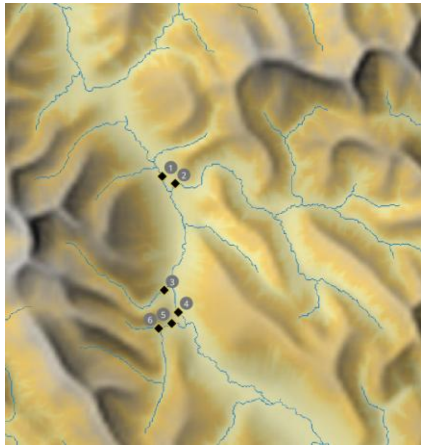
10 km² or 1235 cells may be too large for a threshold

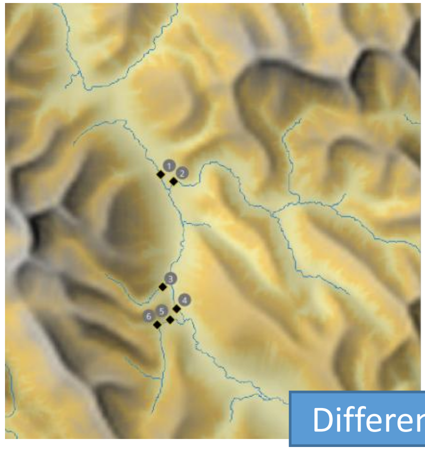


2 km² or ~250 cells seems reasonable (at least for the given area)

$$NCells = \frac{CatchArea\ [km^2] * 10^6}{CellSize(x) * CellSize(y)[m^2]}$$



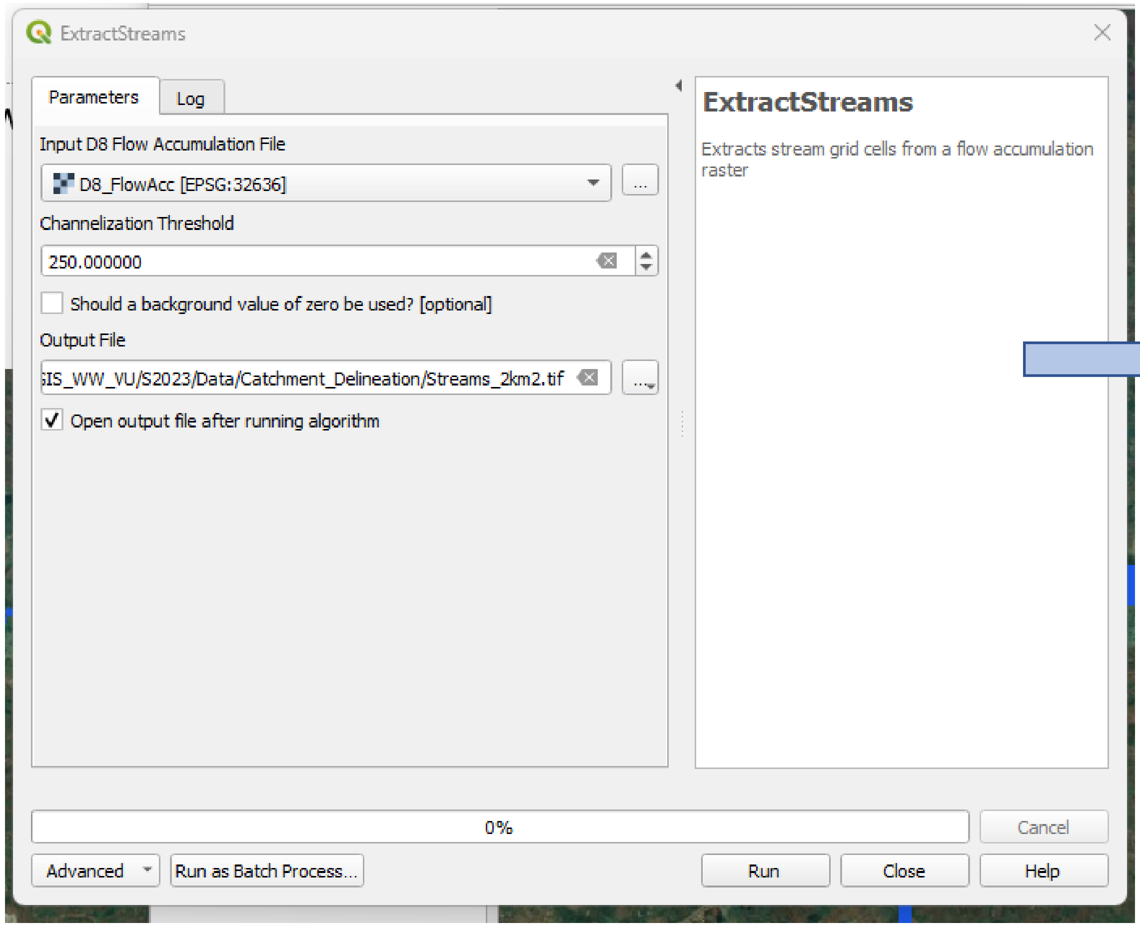


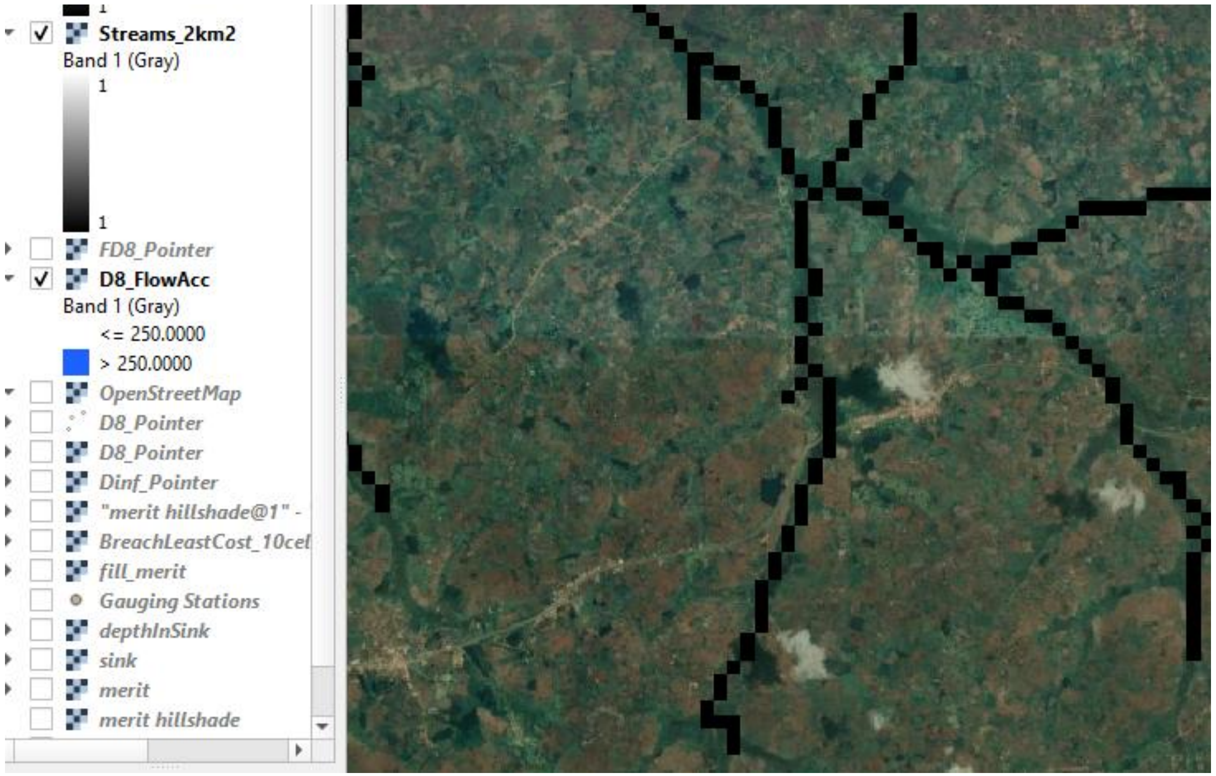


Different example

Stream network

- If satisfied with the threshold value -> Extract streams using “ExtractStream” from the WBT





Resulting raster with values of “1” showing streams

Stream network

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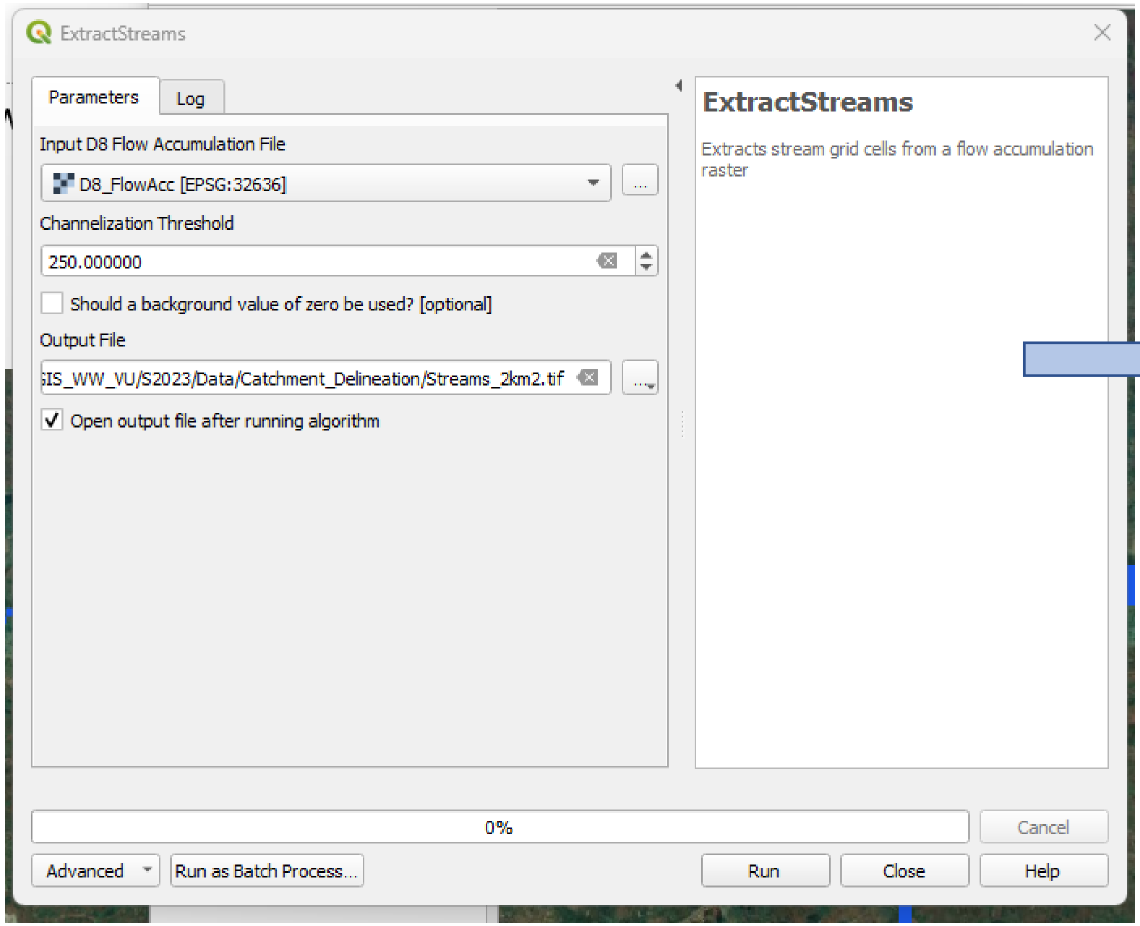
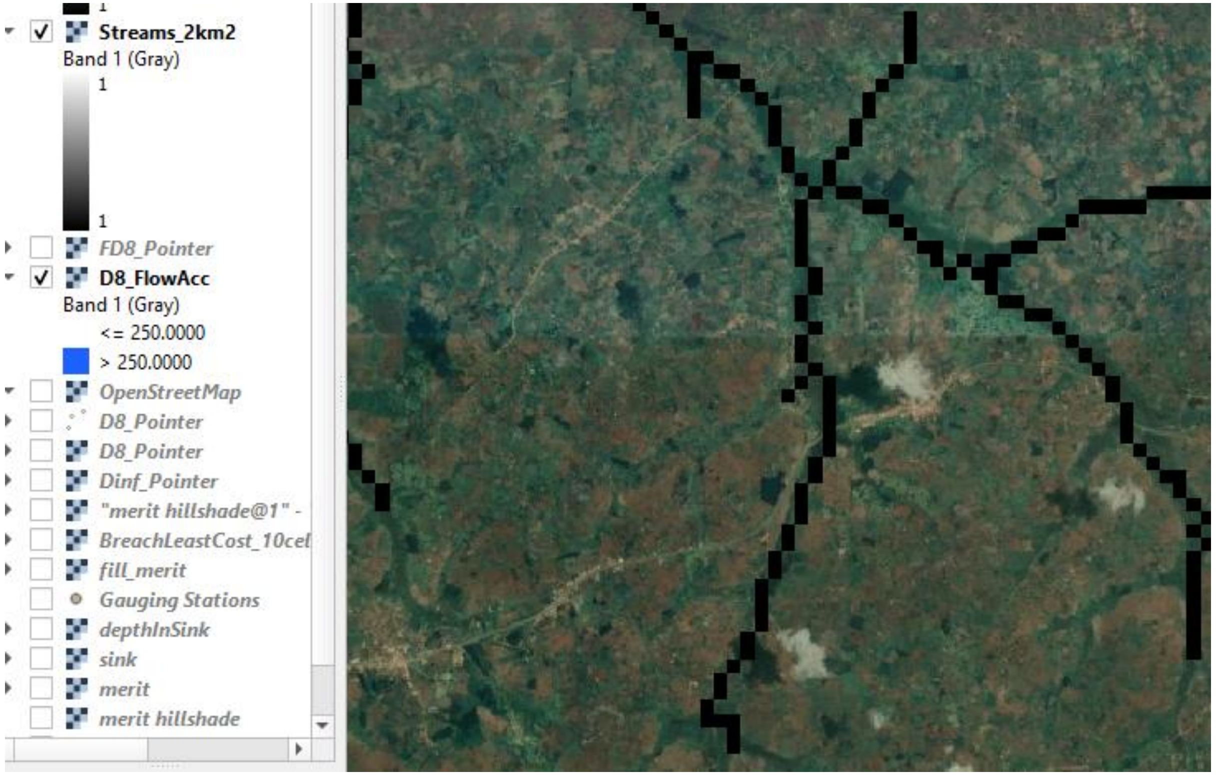
- If satisfied with the threshold value -> Extract streams using “ExtractStream” from the WBT

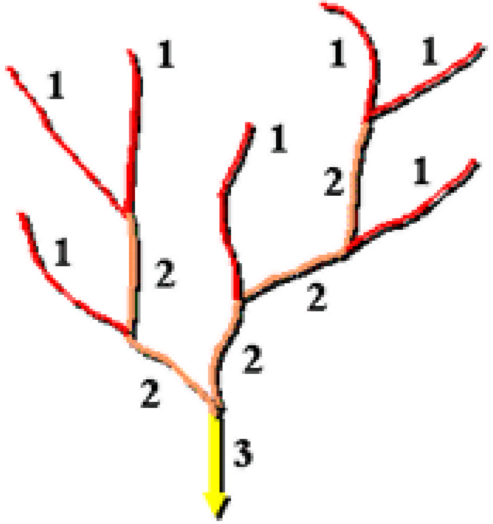




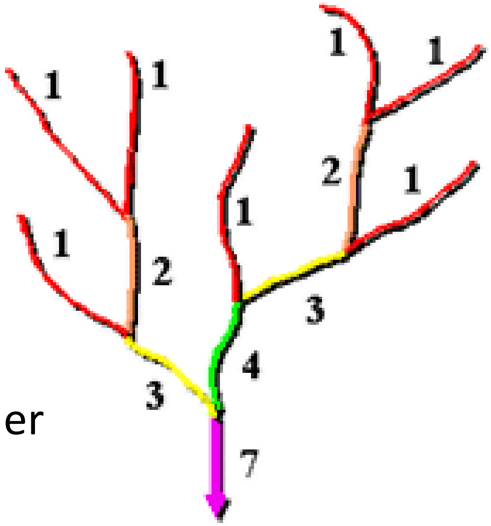
Resulting raster with values of “1” showing streams

Stream order

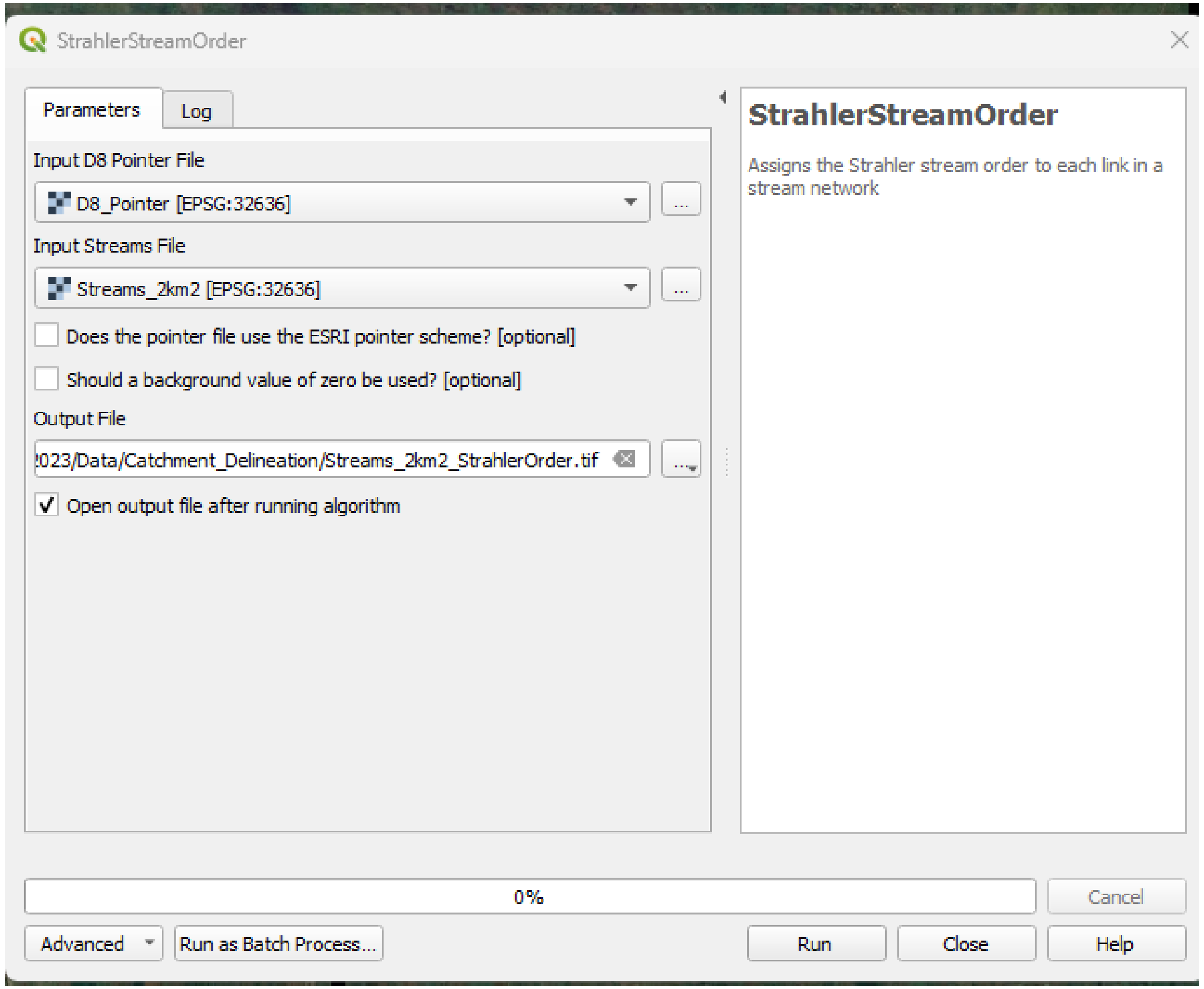
- Creates a stream order for the stream network (use the Strahler method)



Strahler (1957) order

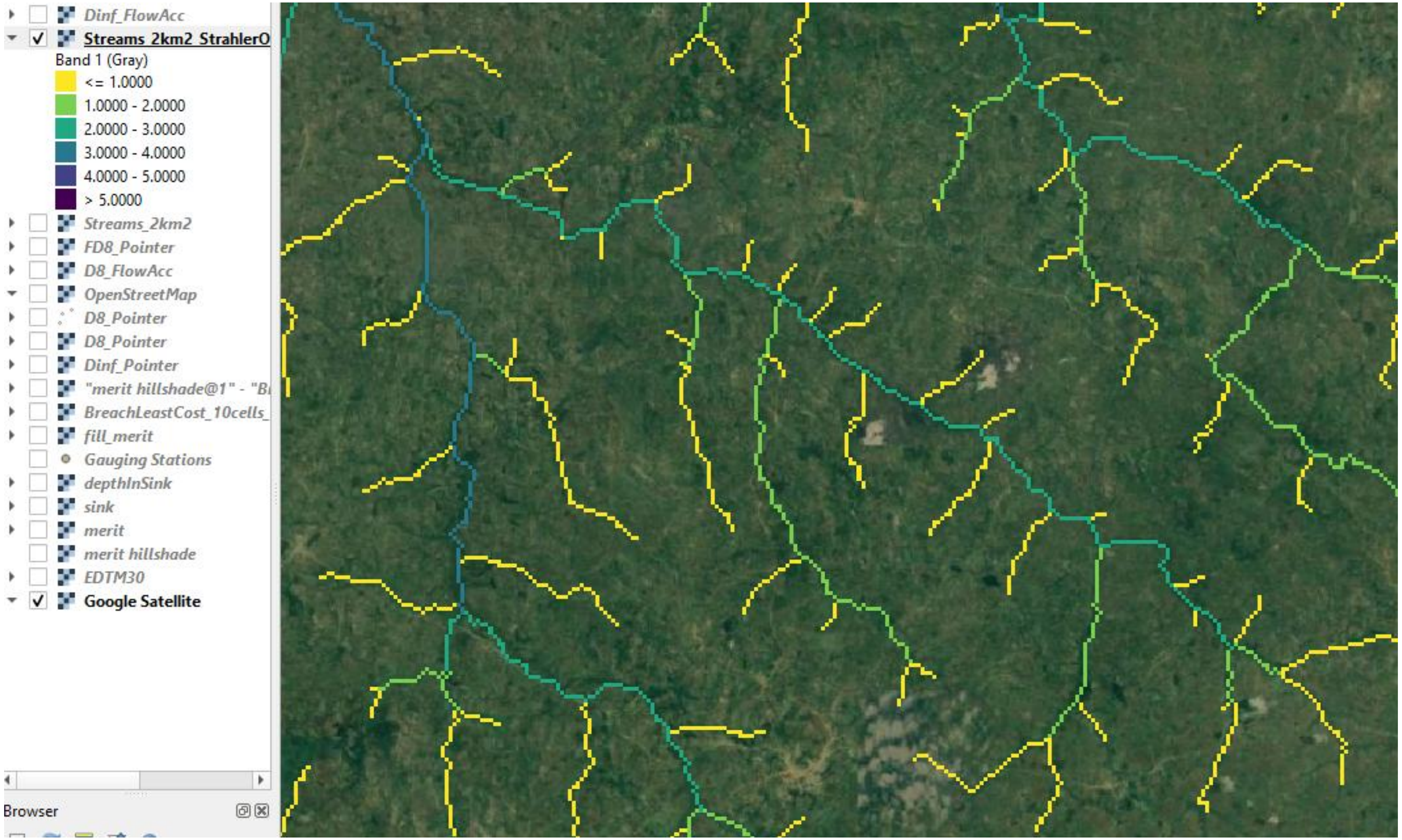


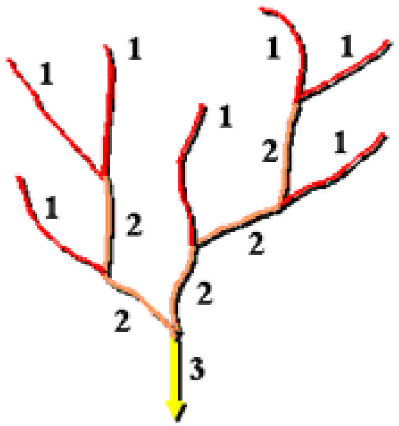
Shreve (1966) order



Stream order

- Creates a stream order for the stream network





Strahler (1957) order

Find main stem of river network

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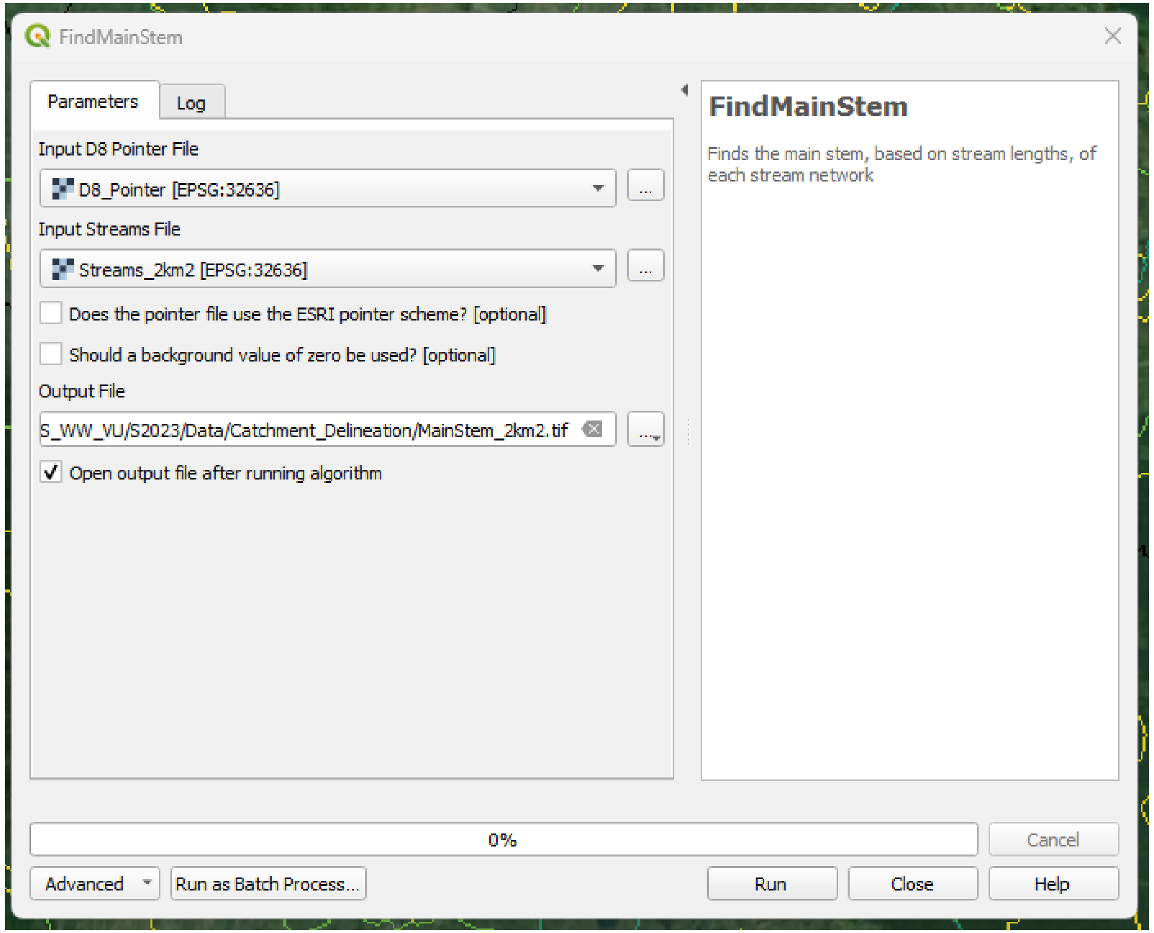

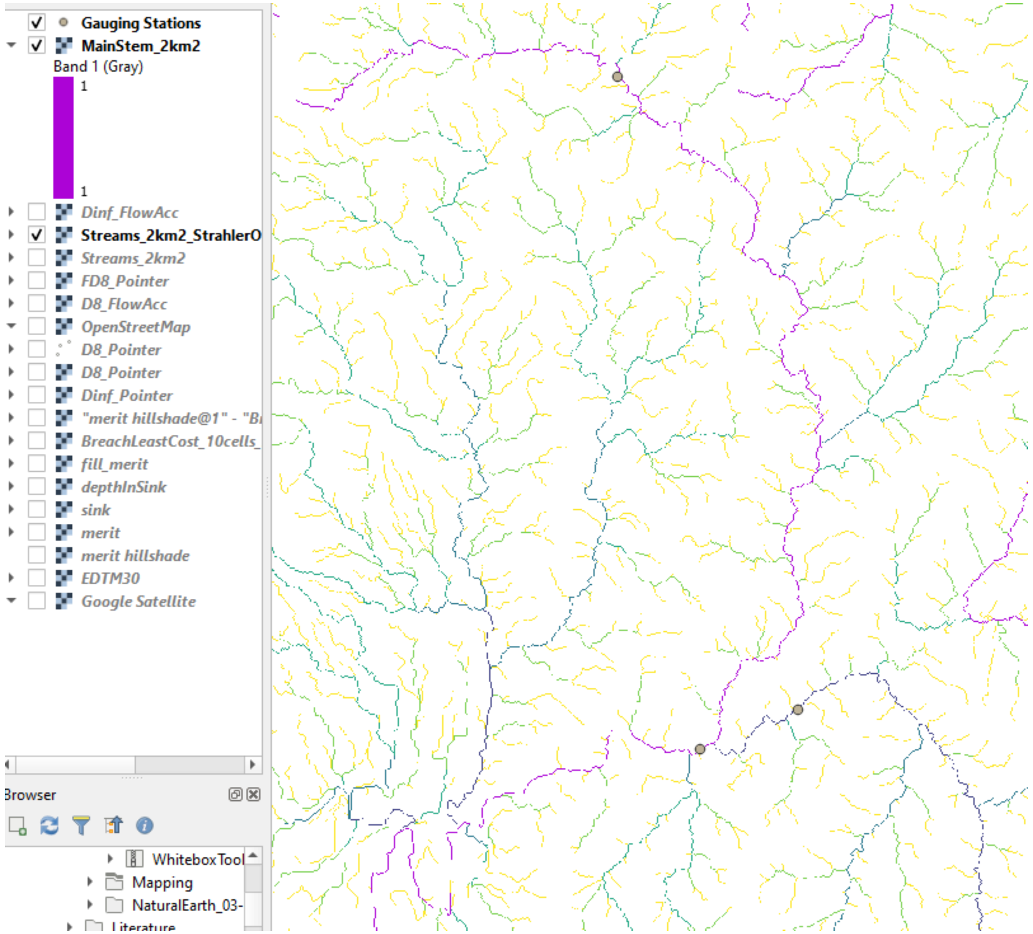

Stream to Vector (1)

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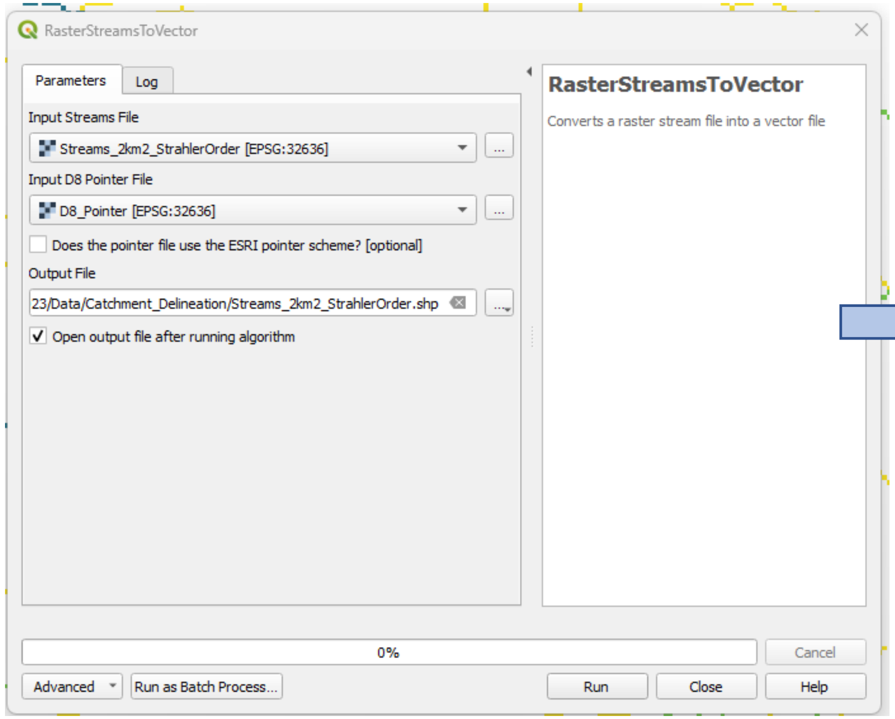
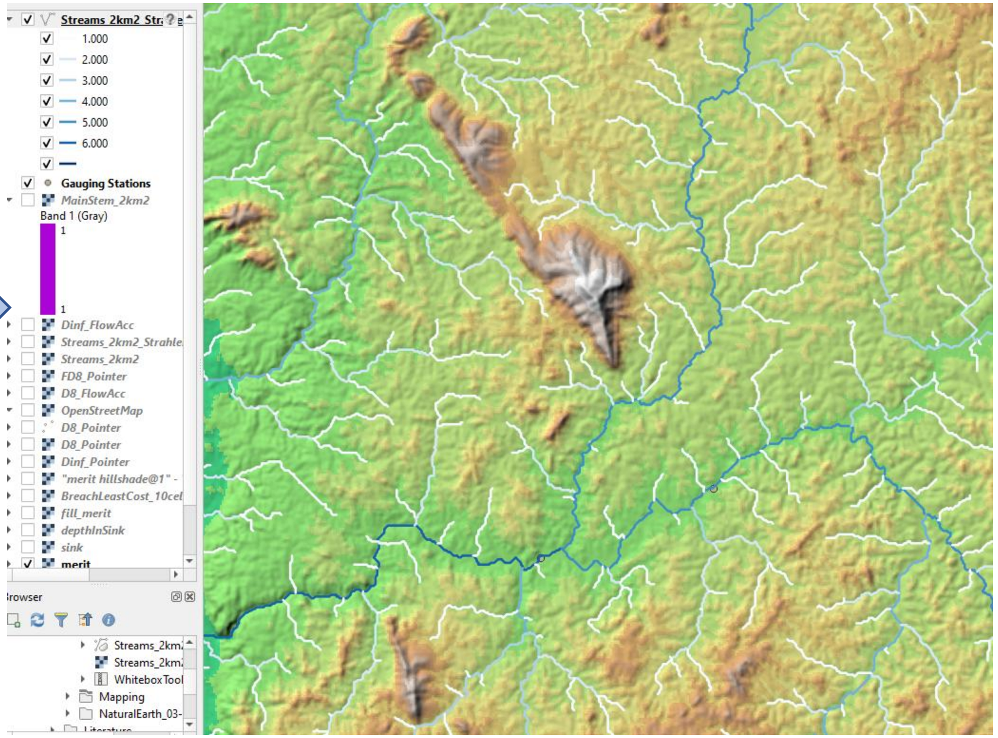
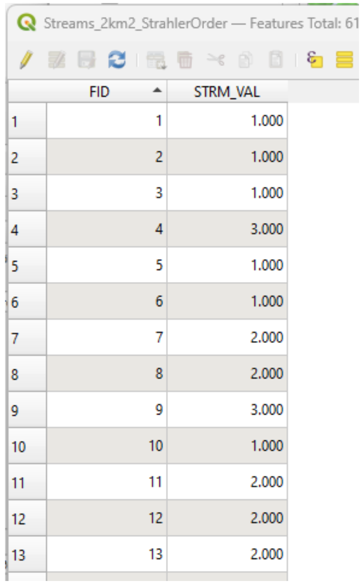
- This tool converts the **stream raster** to a polyline feature class







Streams_2km2_StrahlerOrder — Features Total: 61

	FID	STRM_VAL
1	1	1.000
2	2	1.000
3	3	1.000
4	4	3.000
5	5	1.000
6	6	1.000
7	7	2.000
8	8	2.000
9	9	3.000
10	10	1.000
11	11	2.000
12	12	2.000
13	13	2.000

Since we used the Input Streams File depicting the Strahler Order, the values in the attribute table show the Strahler Order (STRM_VAK)

Stream to Vector (2)

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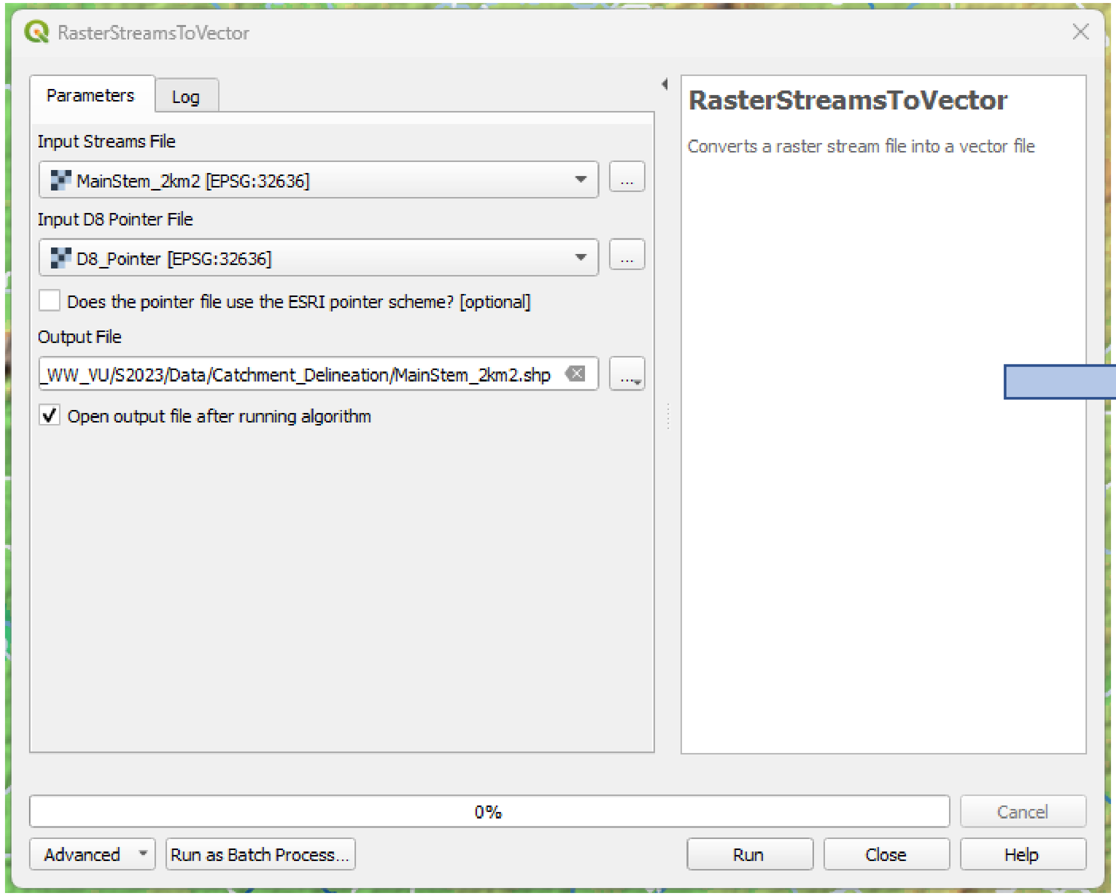
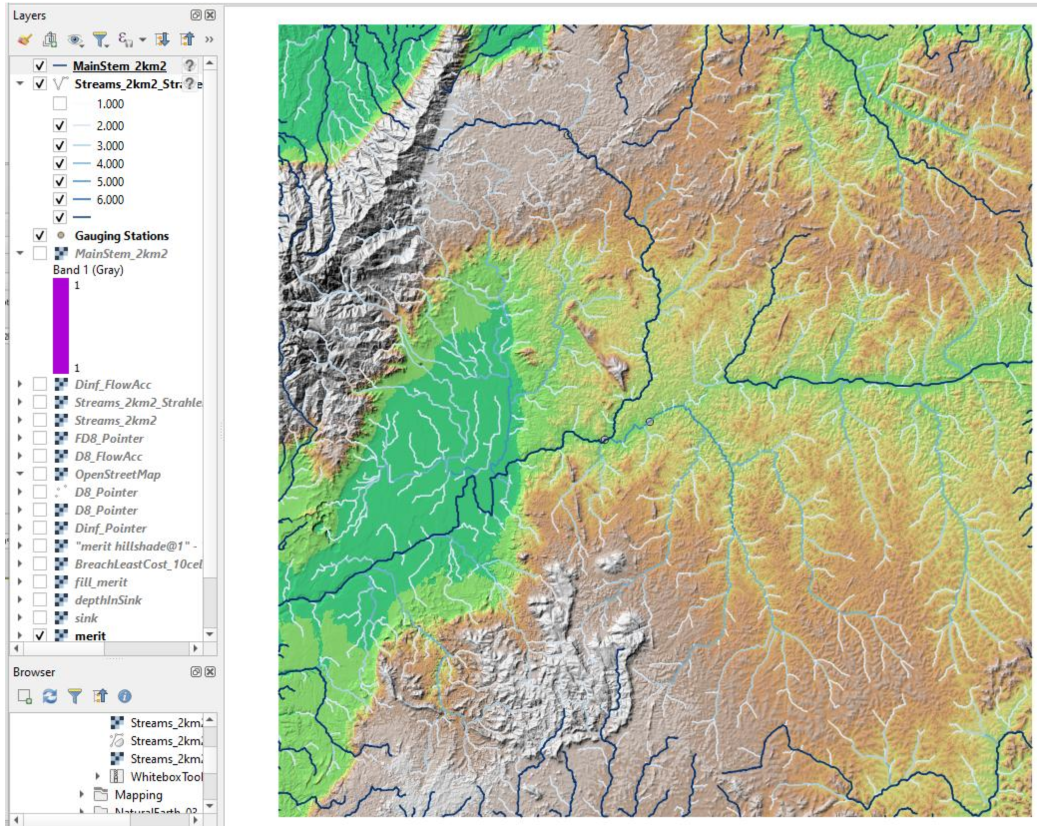
- Do the same for the **main stem**

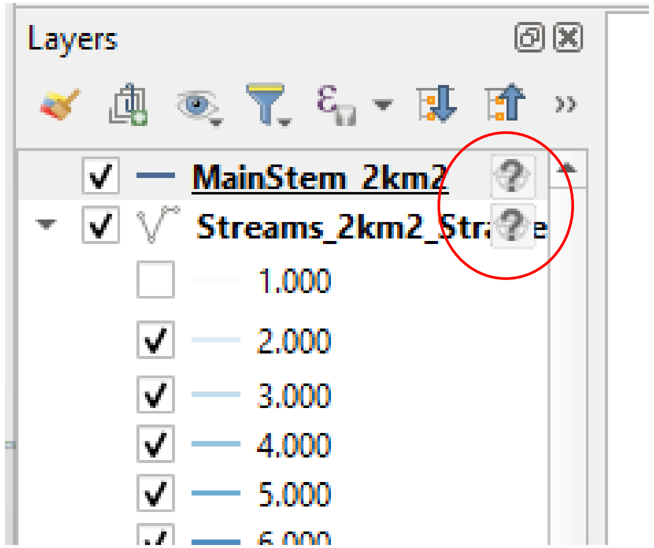


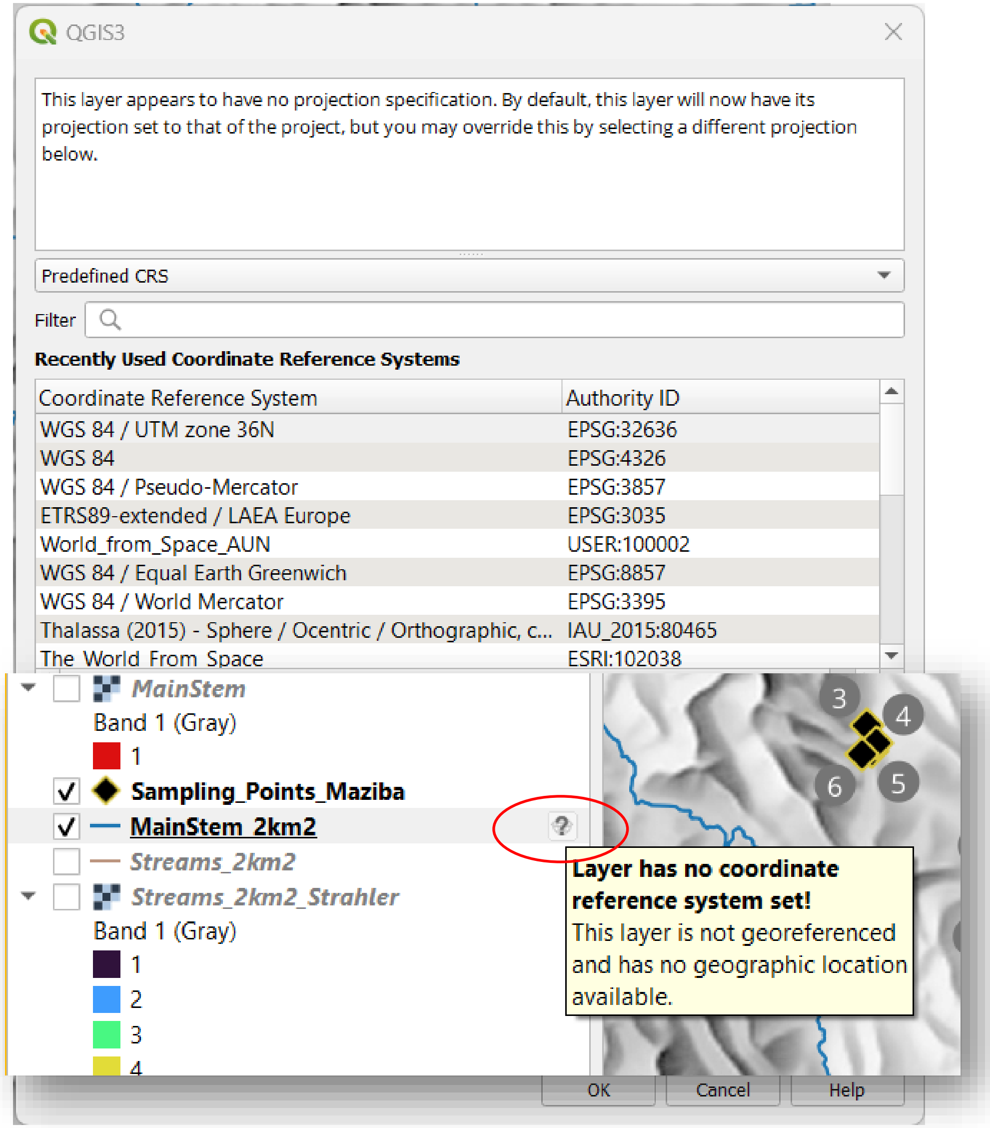


Can be helpful for visualization purposes

Stream to Vector – resolving issue with CRS

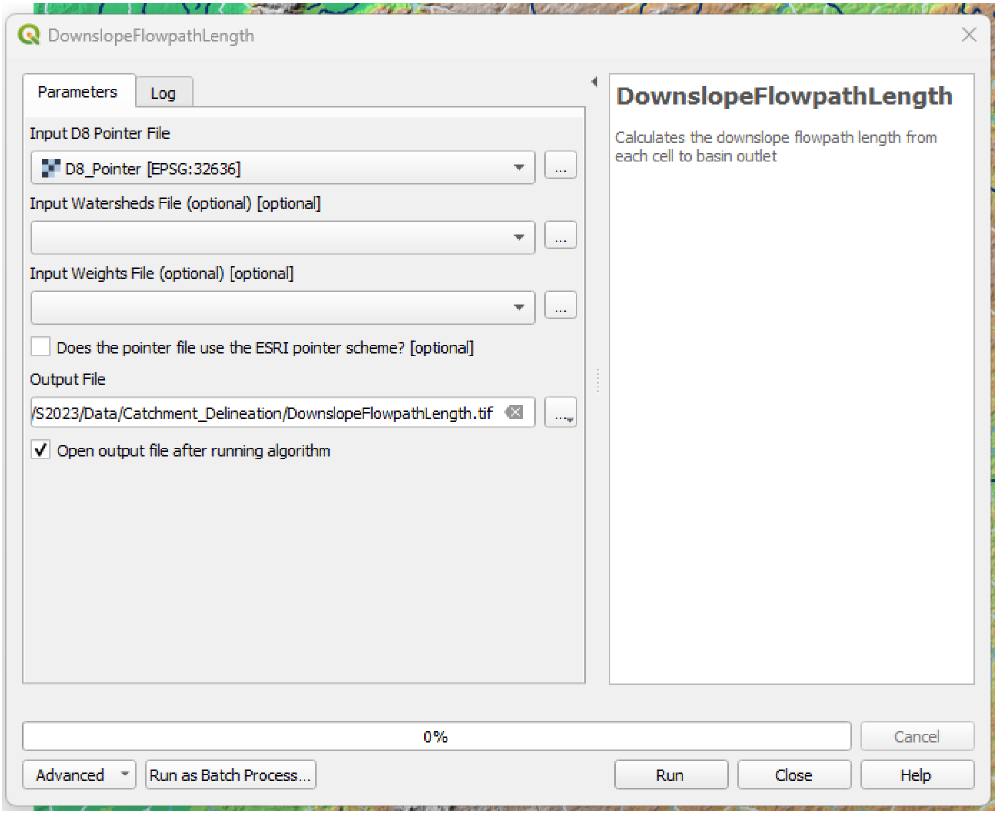
The resulting Layer has an issue with the CRS -> click on the “?” and select EPSG:32636 to resolve the issue

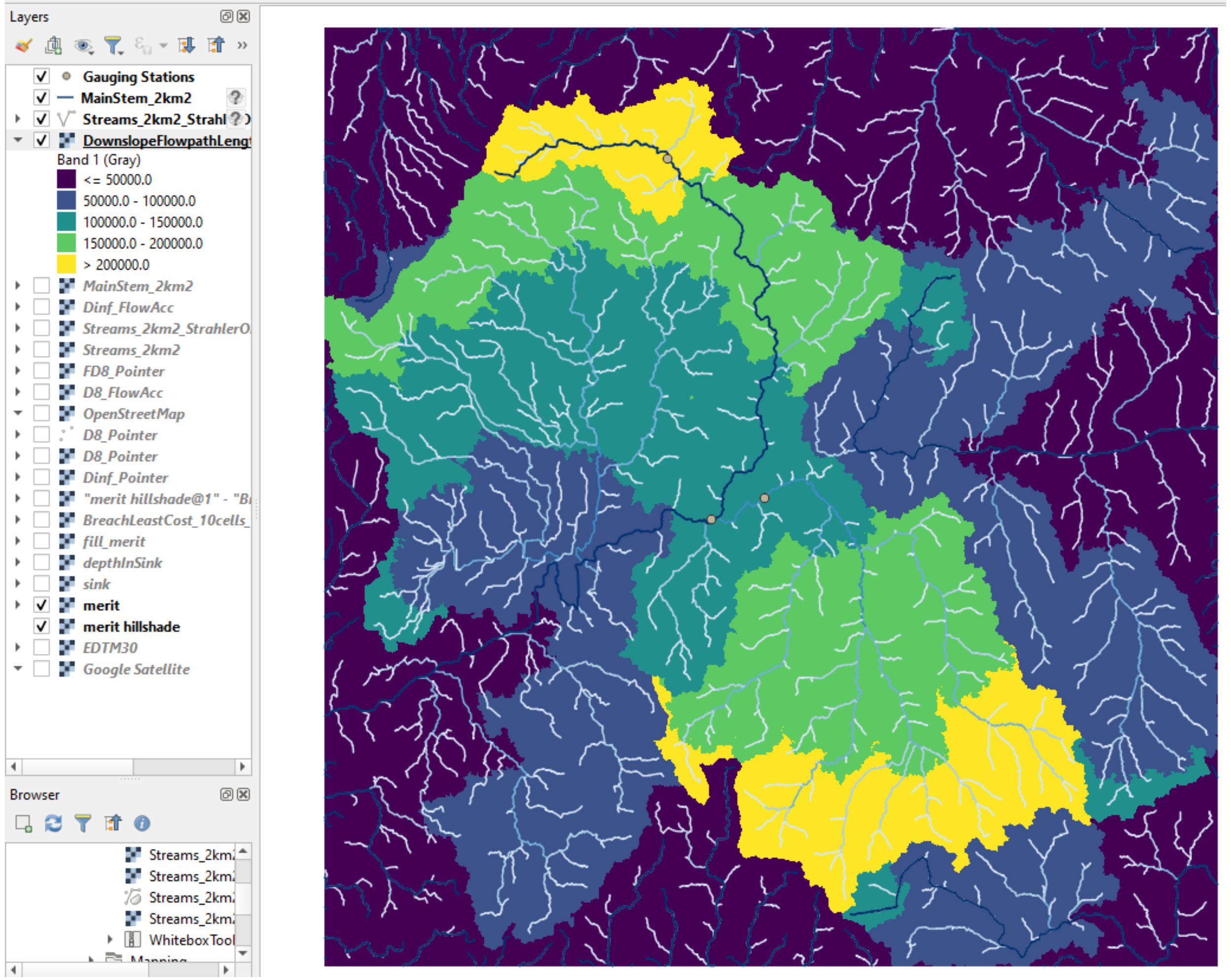




Flow path length

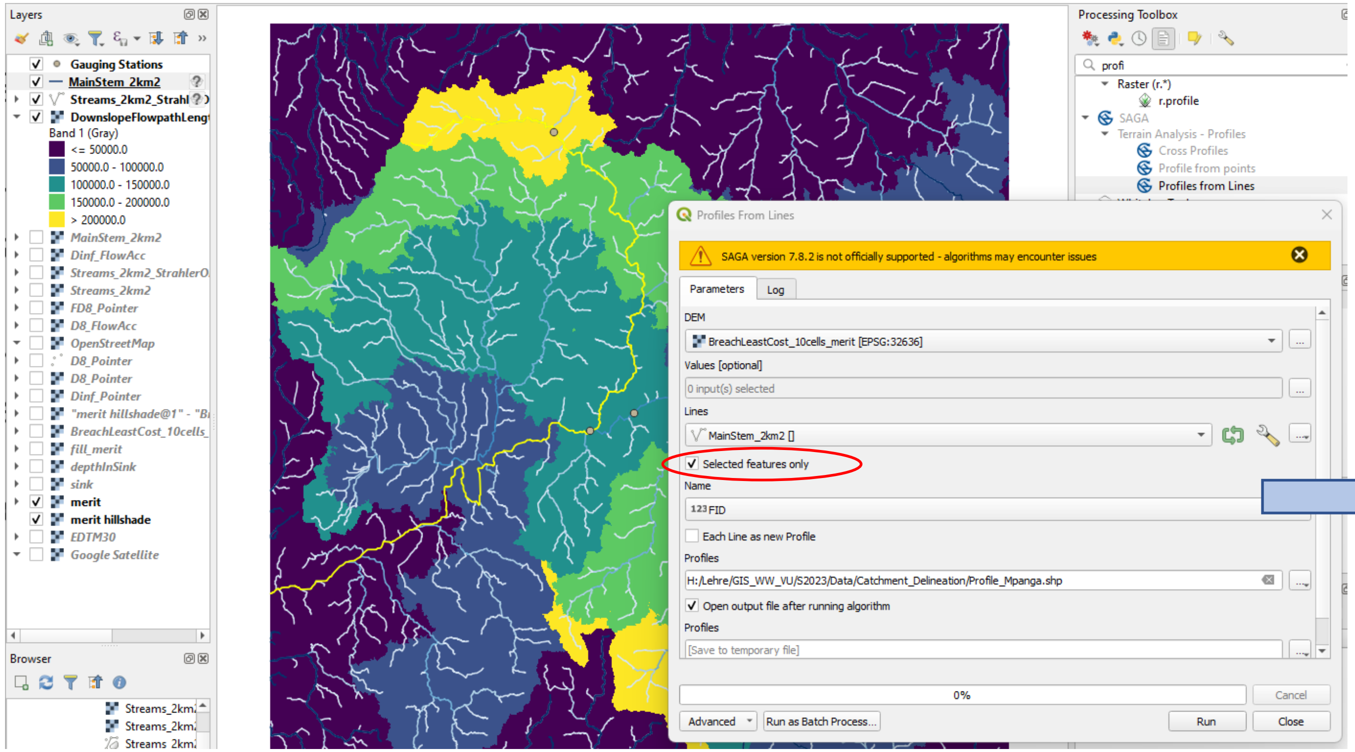
- This tool computes the flow distance or length from each cell to the most downstream or upstream cell



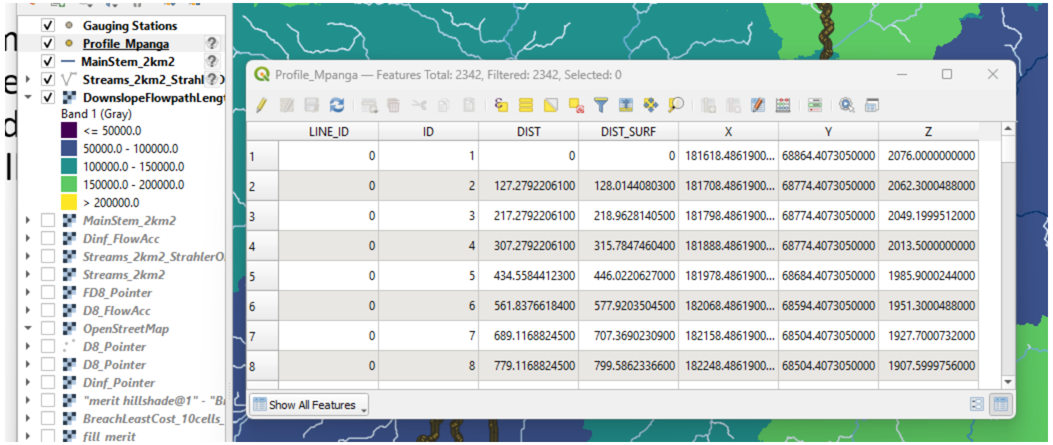


Note that the symbology of the new raster was adopted. Units are [m]

Elevation Profile for main Mpanga Stem



You may need to install the “Processing Saga NextGen Provider” plugin to access the Tool



Profile From Lines Tool (SAGA) – note that you need to select the Mpanga river first and to tick “Selected features only”

Points are generated along the main Stem, which include Elevation (Z)

Elevation Profile for main Mpanga Stem

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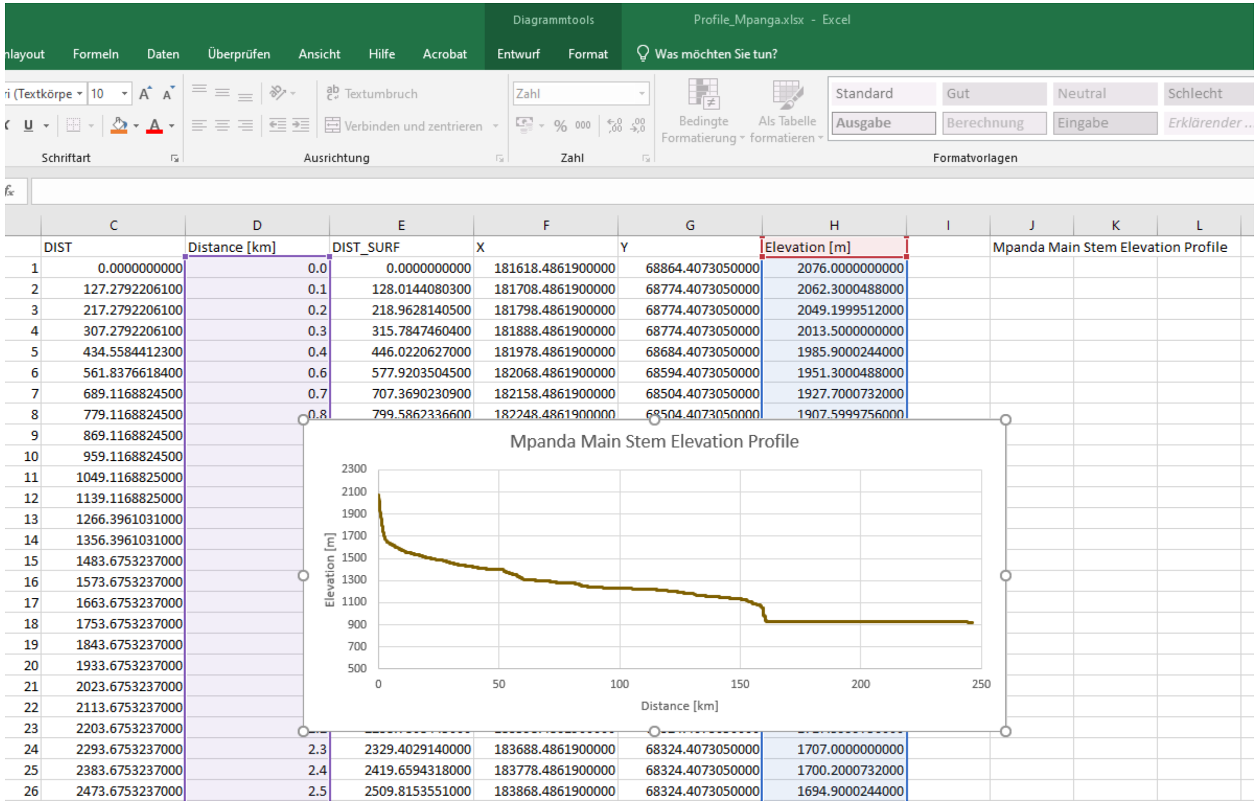
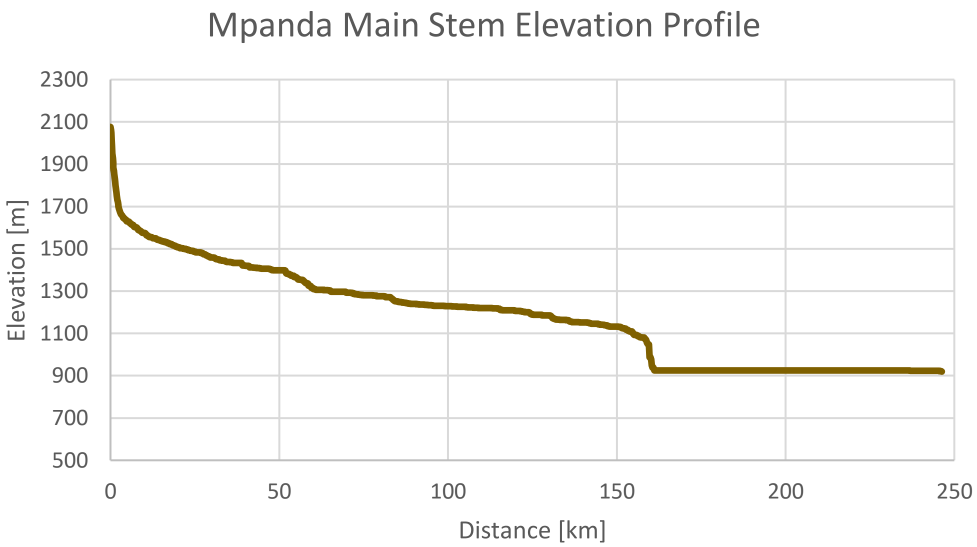
The dbf-file of the Elevation points shape-file can be opened in Excel and a Elevation profile can be generated

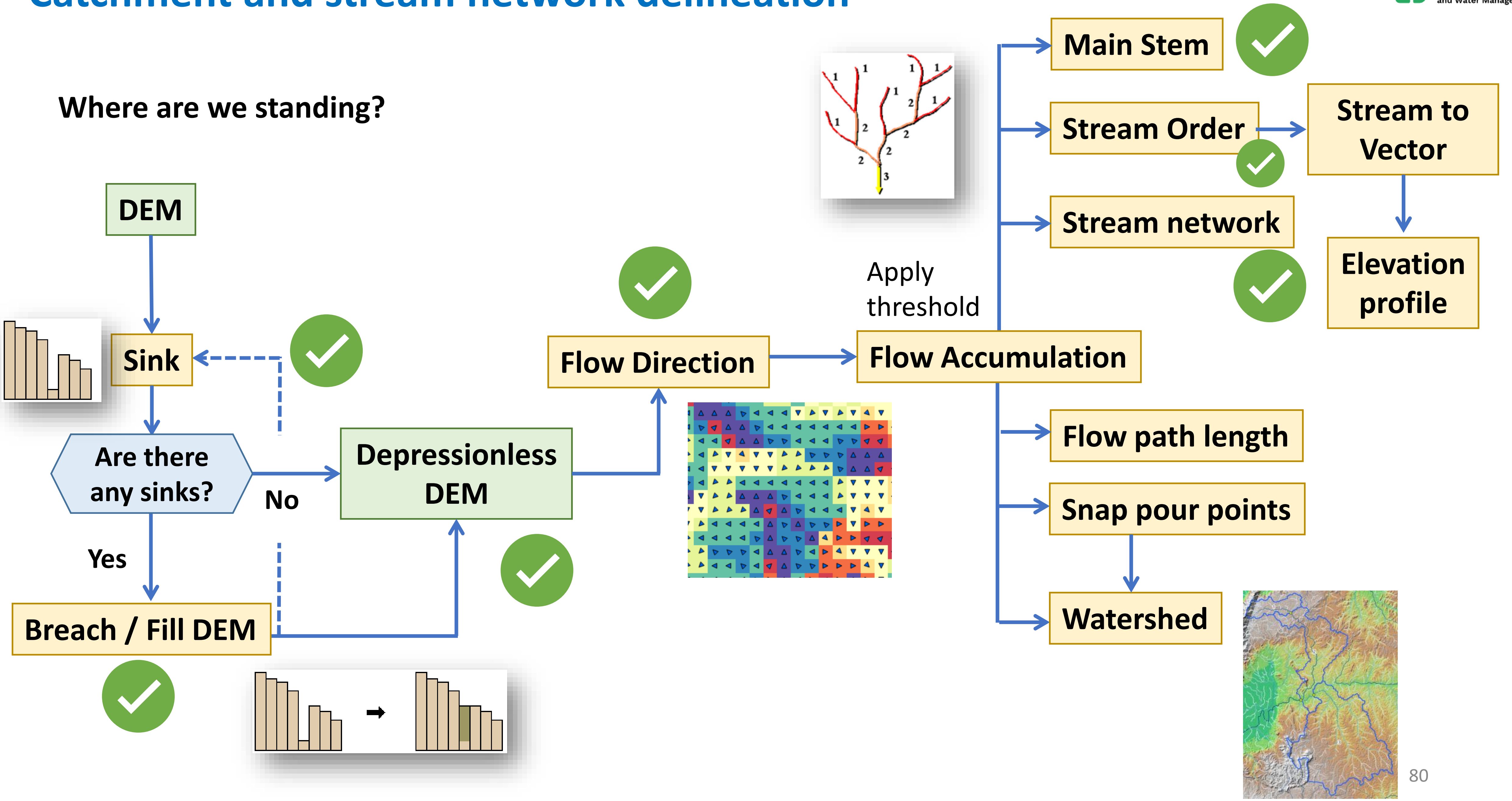


	DIST	Distance [km]	DIST_SURF	X	Y	Elevation [m]
1	0.0000000000	0.0	0.0000000000	181618.4861900000	68864.4073050000	2076.0000000000
2	127.2792206100	0.1	128.0144080300	181708.4861900000	68774.4073050000	2062.3000488000
3	217.2792206100	0.2	218.9628140500	181798.4861900000	68774.4073050000	2049.1999512000
4	307.2792206100	0.3	315.7847460400	181888.4861900000	68774.4073050000	2013.5000000000
5	434.5584412300	0.4	446.0220627000	181978.4861900000	68684.4073050000	1985.9000244000
6	561.8376618400	0.6	577.9203504500	182068.4861900000	68594.4073050000	1951.3000488000
7	689.1168824500	0.7	707.3690230900	182158.4861900000	68504.4073050000	1927.7000732000
8	779.1168824500	0.8	799.5862336600	182248.4861900000	68504.4073050000	1907.5999756000
9	869.1168824500					
10	959.1168824500					
11	1049.1168825000					
12	1139.1168825000					
13	1266.3961031000					
14	1356.3961031000					
15	1483.6753237000					
16	1573.6753237000					
17	1663.6753237000					
18	1753.6753237000					
19	1843.6753237000					
20	1933.6753237000					
21	2023.6753237000					
22	2113.6753237000					
23	2203.6753237000					
24	2293.6753237000	2.3	2329.4029140000	183688.4861900000	68324.4073050000	1707.0000000000
25	2383.6753237000	2.4	2419.6594318000	183778.4861900000	68324.4073050000	1700.2000732000
26	2473.6753237000	2.5	2509.8153551000	183868.4861900000	68324.4073050000	1694.9000244000



Catchment and stream network delineation

Where are we standing?



Watersheds– (1) Snap Pour Point

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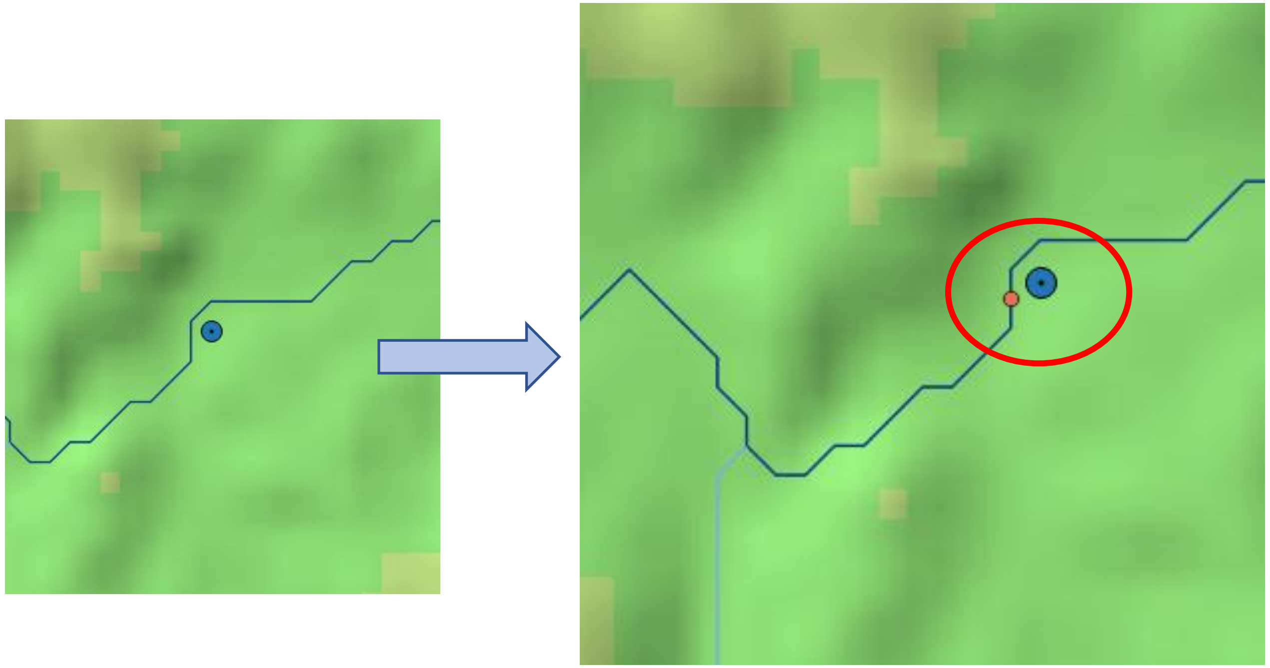
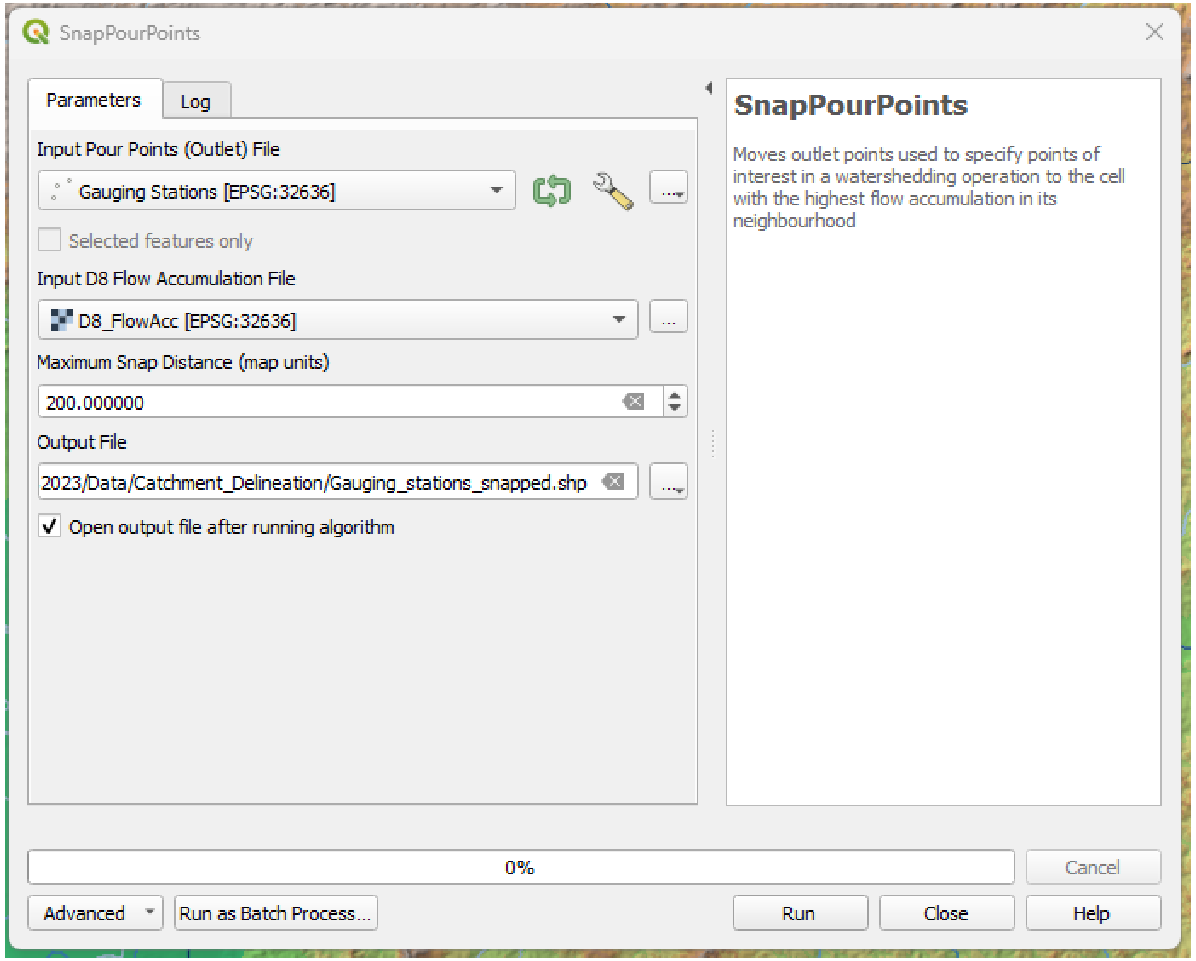
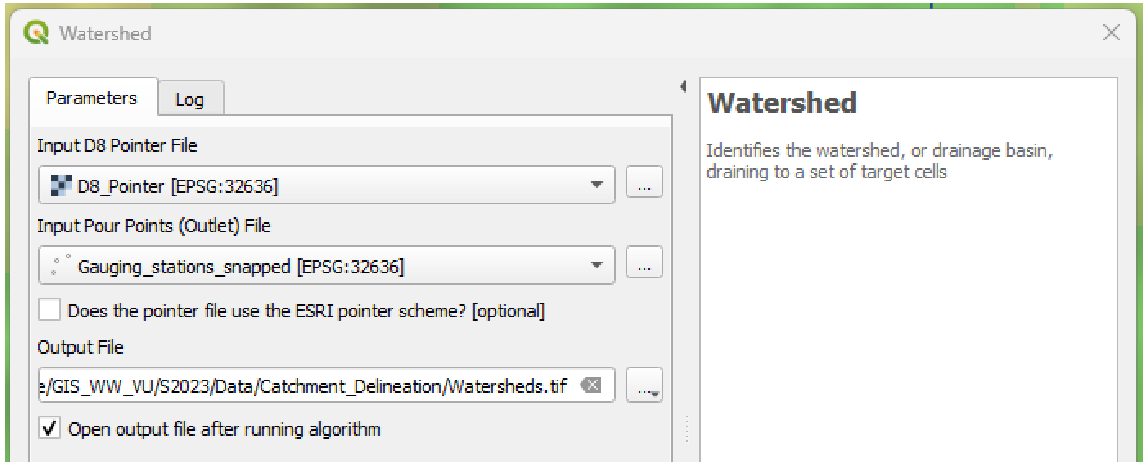
- Not all gauges are not located on the streams
- To derive the watersheds for the gauging station we therefore need to apply the “SnapPourPoints” tool.
- It snaps the pour points (our gauging stations) to the cell of highest flow accumulation
- Always check if the point is snapped to the correct stream
- Note, that a manual shift of the points is also possible

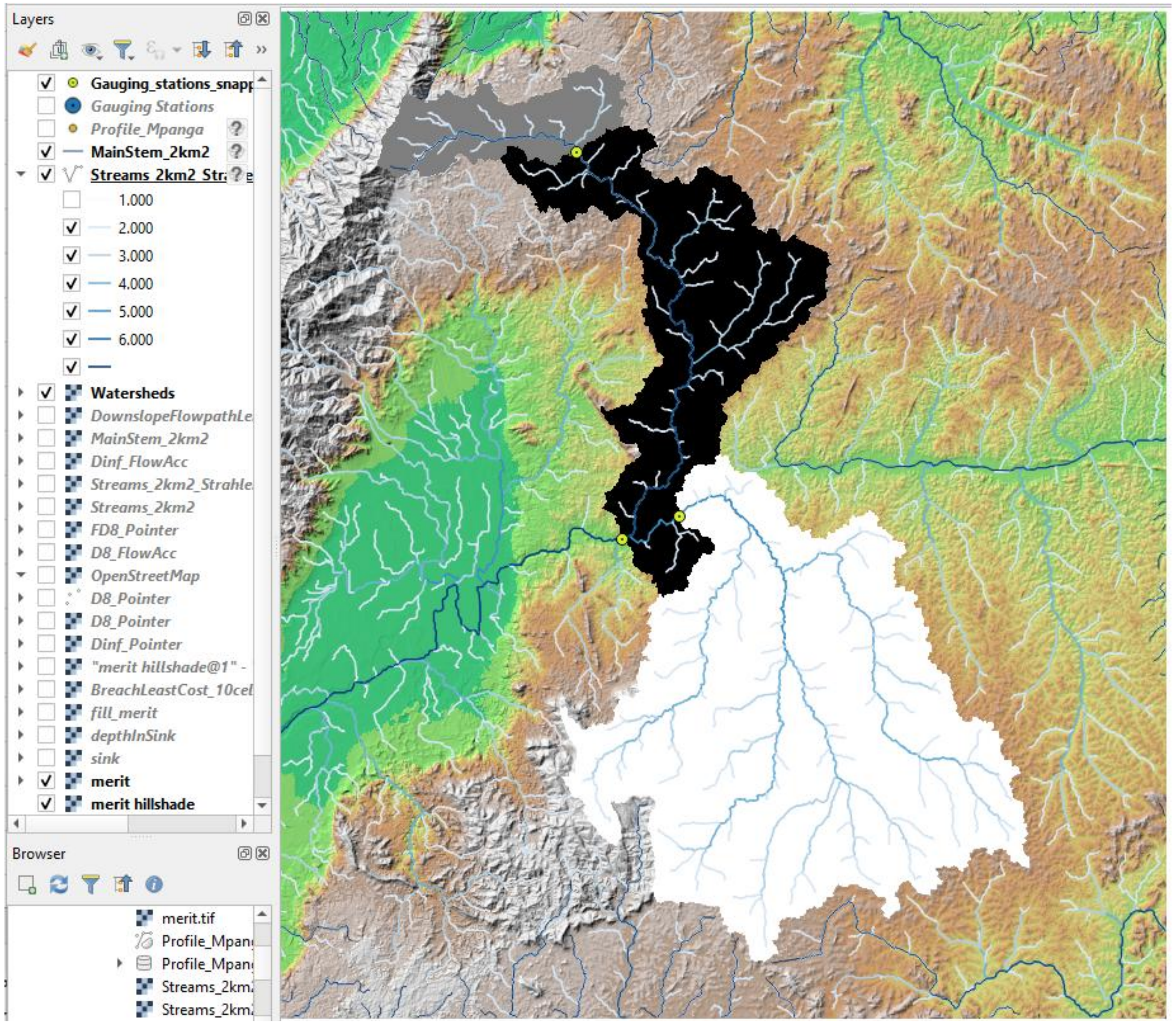




Watersheds – (2) Watershed

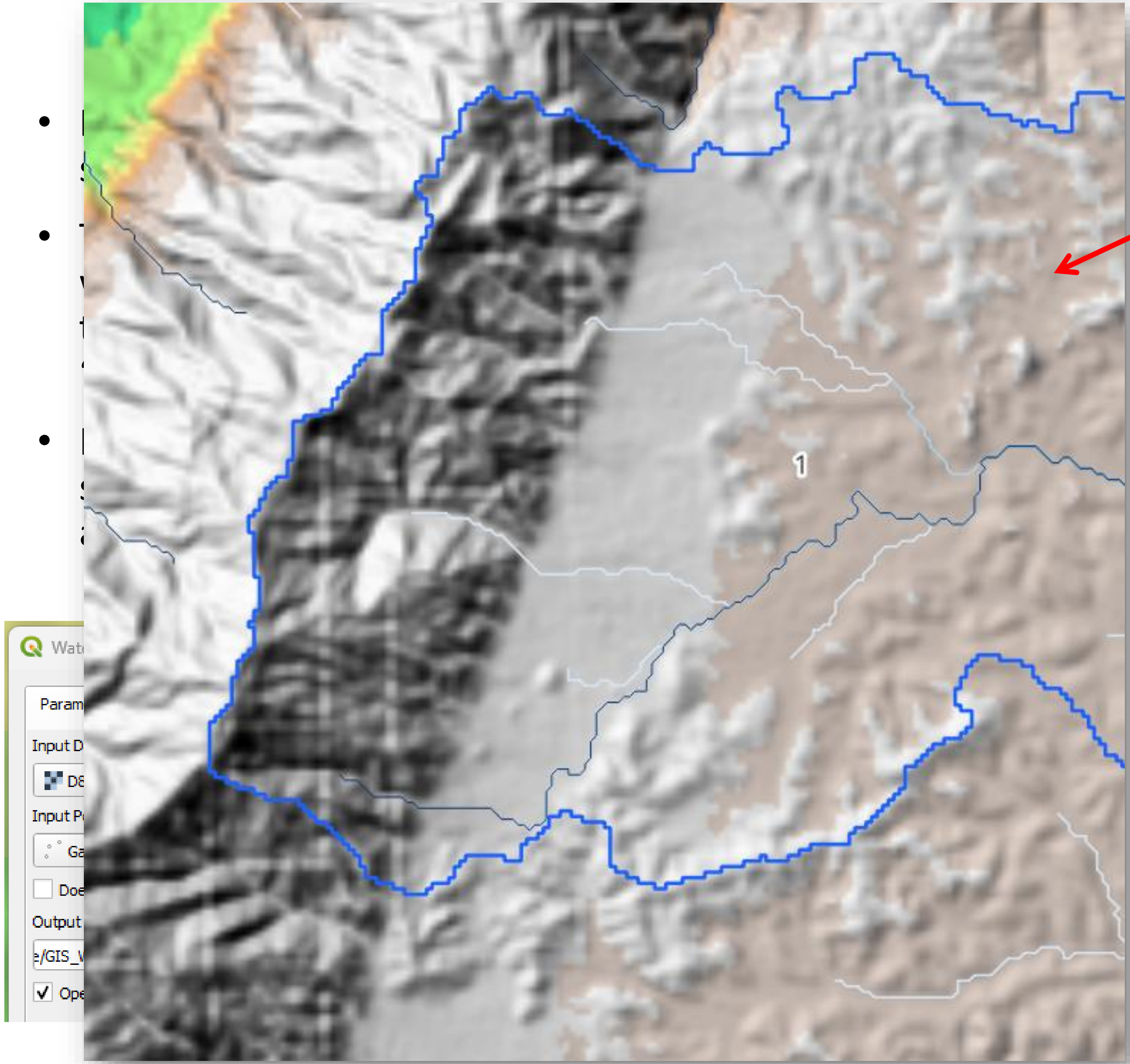
- Determines the contributing area above a set of cells in a raster
- Watershed is the area that drains to a set of target cells (i.e. pour points or in our case the sampling stations)

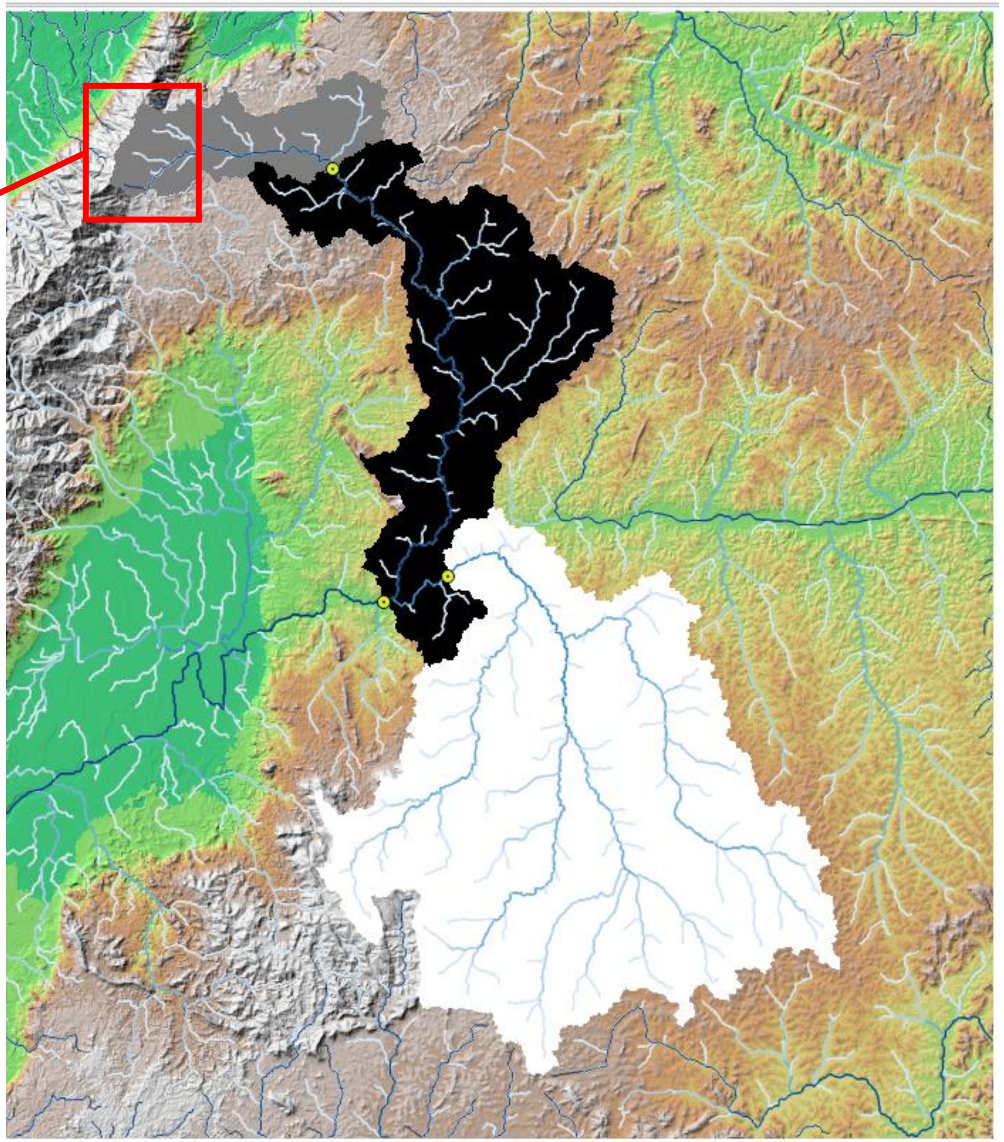




Resulting Watersheds & Stream-network

Watersheds – (2) Watershed

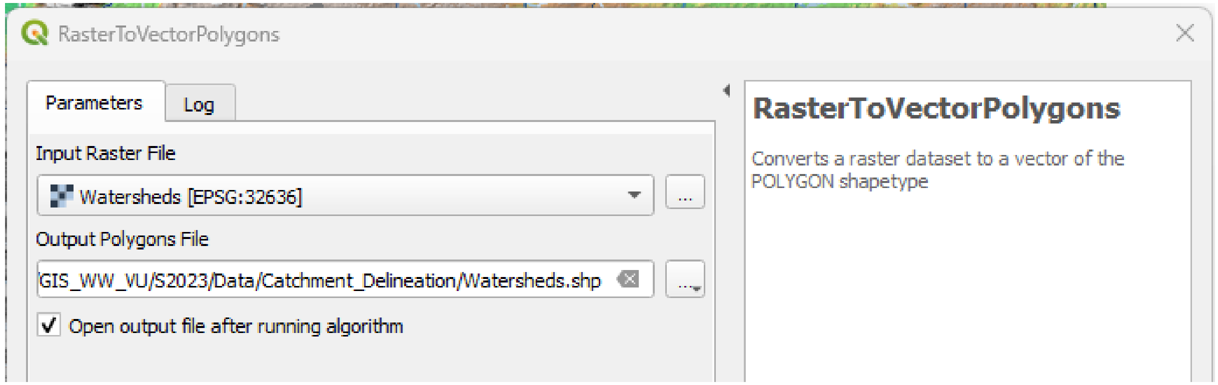


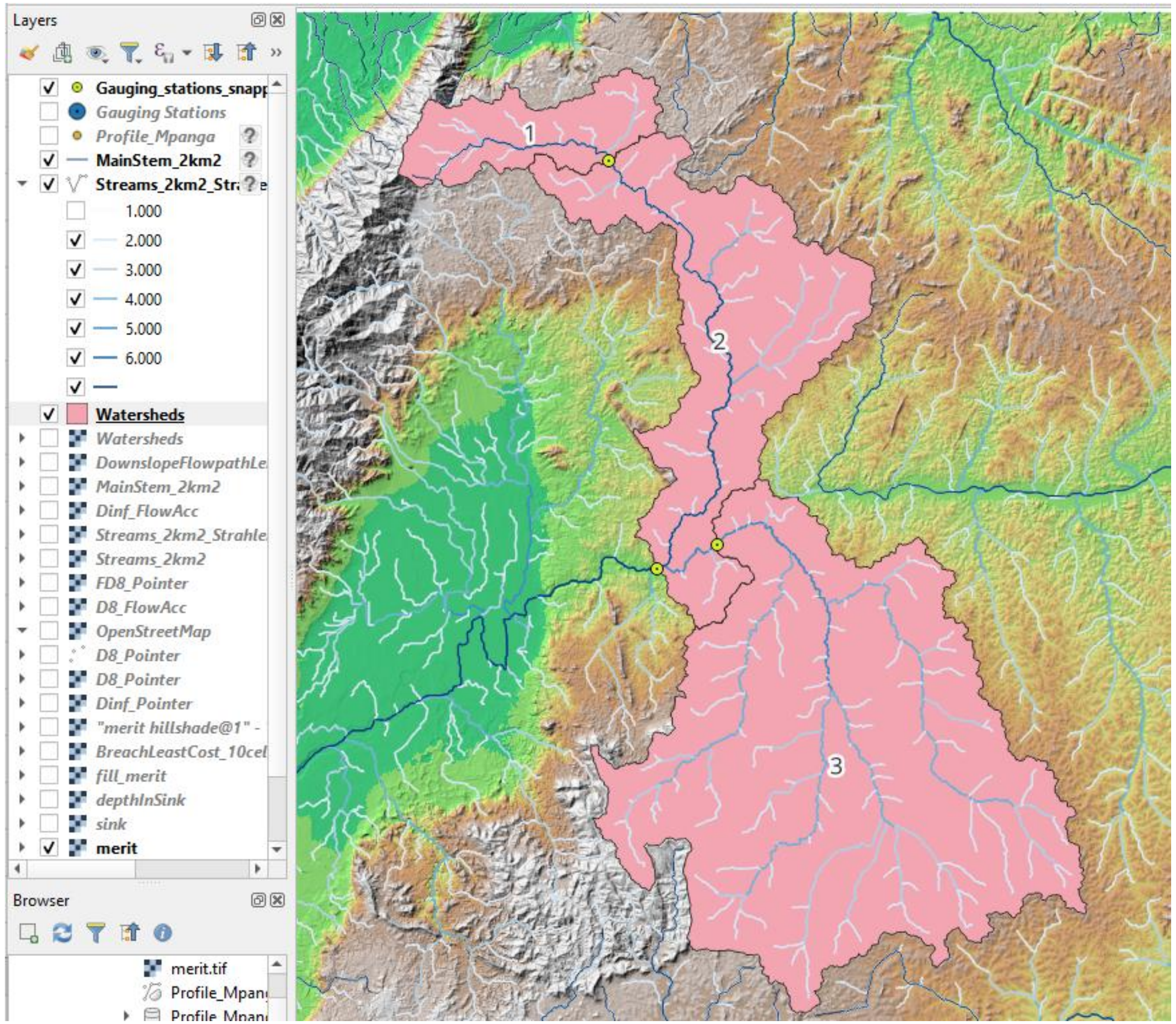


Resulting Watersheds & Stream-network

Raster to Polygon

- The watersheds are stored as a raster and should be converted into a polygon for more convenience





Calculating area of sub-watersheds

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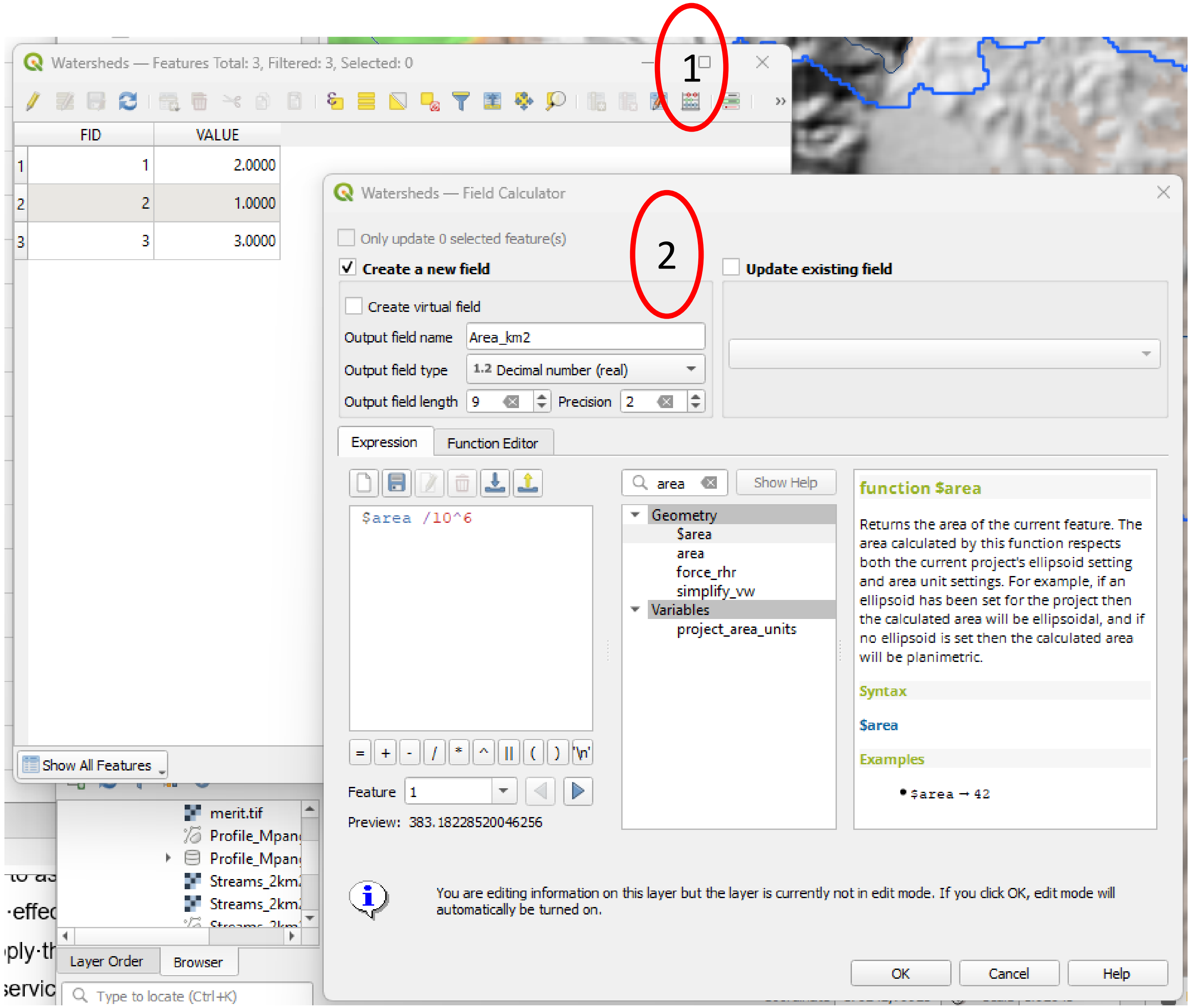
- Calculating the polygon areas of the watersheds



- *Open attribute table and open field calculator (1)*
- *Adopt settings and fields in Field calculator as shown (2)*

Calculating area of sub-watersheds

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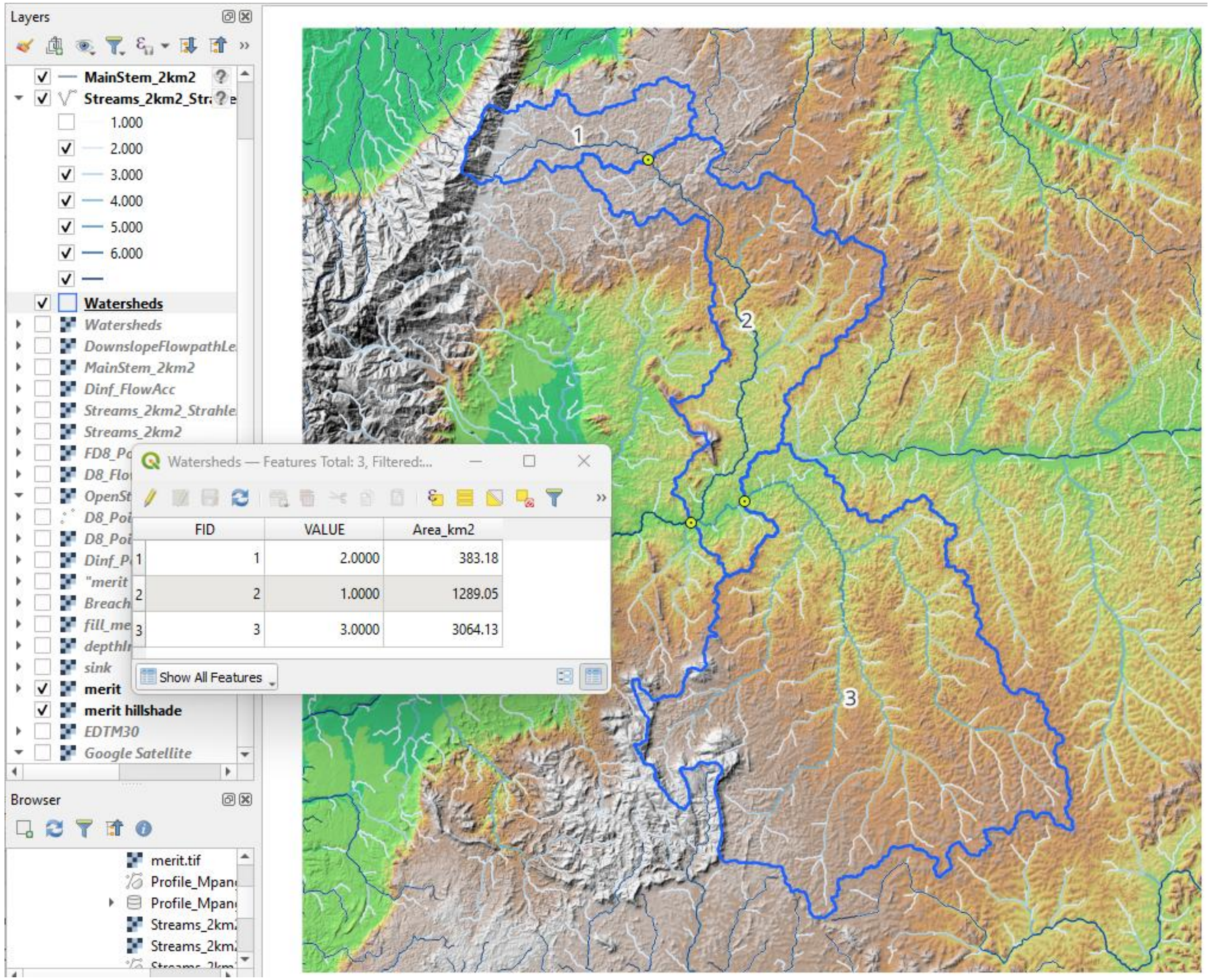
- Calculating the polygon areas of the watersheds



Resulting area of the sub-watersheds in km²

Thank you for your attention!