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The past is the key to the future – considering Pleistocene subglacial erosion for the minimum depth of a radioactive waste repository

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This document provides a workflow for extracting thalweg lines from a contoured depth map and assigning them the respective depth from the original map. Some of the specifics of the individual processing steps depend on the source data and the file type. This step-by-step outline can be used as a 'cookbook'.

The aim of this workflow is to extract channel-like topographic structures from digital elevation data using geoinformation systems (GIS/ArcMap) to provide different thalweg lines as line shapes, which also have the depth position as a z-value derived from the input data. In our study, we used this workflow to extract the thalwegs of Pleistocene tunnel valleys from contoured depth maps that represent the base of the Quaternary.

Input data:

- Depth contour maps (.shp)
- Gocad surfaces (.ts)

Software used:

- ArcMap (version 10.8.2)
  - Spatial Analyst Extension
  - ArcScan Extension

Data preparation:

In order to have the same input data format, the contoured depth maps (.shp) need to be converted to raster data in ArcMap using the *'Topo to Raster*' tool. The modelled 3D surfaces (.ts) are exported from Gocad as point data and imported into ArcMap 'Display XYZ' and converted into raster data by using the '*Point to Raster*' tool.

The input data should all be in the same coordinate system.

Step-by-step description:

Thalweg line calculation from raster data:

The GIS workflow (Fig. S1) starts with the '*Flow Direction*' tool of the Spatial Analyst extension of ArcMap. The applied D8 method models the flow direction from each cell to its steepest downslope neighbour based on the elevation / depth raster (Fig. S2A).

Select the raster data created in the data preparation as input data.

'ArcToolbox' > 'Spatial Analyst Tools' > 'Hydrology' > 'Flow Direction'

The Spatial Analyst's '*Flow Accumulation*' tool was used to identify the thalweg lines of the tunnel valleys. It uses the newly calculated 'Flow Direction' grid as an input dataset and calculates how many grid cells drain into or flow out of each grid cell. The cells with high accumulation are areas of increased runoff and may represent channels. Cells with zero accumulation are topographic highs and may represent ridges (Fig. S2B).

Select the newly calculated raster grid 'Flow Direction' as input file.

'ArcToolbox' > 'Spatial Analyst Tools' > 'Hydrology' > 'Flow Accumulation'

Conversion to a true-false raster:

A grid consisting of the values "zero" (TRUE) and "one" (FALSE) is calculated; "zero" corresponds to the channels or valleys and "one" to all other areas (Fig. S2C). This is done using the '*Conditional (Con)*' function of the Raster Calculator.

The grid resulting from the flow-accumulation calculation ('FlowAcc_raster'*)* is used as input data for the further calculation (Fig. S1).

'ArcToolbox' > 'Spatial Analyst Tools' > 'Map Algebra' > 'Raster Calculator'

Outrast = Con("FlowAcc_raster" <= 0, 0, 1)

Deriving thalweg lines from the true-false grid:

The next step is to process the data using the ArcScan extension and the ArcScan toolbar (Fig. S1). This requires the 'Con grid', which consists

only of zeros and ones, and an initially blank line shapefile. With these two inputs, the ArcScan Toolbar is activated and the cleaning of the raster can begin. With the ArcScan extension, it is possible to select connected cells and save them in a new selection. This excludes isolated raster cells that are not in the areas of the channels. By modifying the input parameters of the '*Selection*' tool, it is possible to improve the automatic selection of cells in order to simplify and clean up the grid. The selection of connected cells is an iterative process and can be repeated several times. It is also possible to manually select cells that were not included in the automatic selection.

Select the newly calculated raster 'Con Raster' as the input raster and an empty line shapefile.

'Extension ArcScan' > 'Raster Toolbar' > 'Cell Selection' > 'Select connected cells'

The next step is to use the '*Raster Cleanup*' tool (Fig. S1) from the Raster Painting toolbar to remove the unselected cells and save the new selection in a new raster (Fig. S2D).

'Extension ArcScan' > 'Raster Toolbar' > 'Raster Cleanup' > 'Start Cleanup'
'Extension ArcScan' > 'Raster Toolbar' > 'Cell Selection' > 'Save Selection as…'

The '*Vectorization*' tool then converts the connected raster cells into lines that are saved in the previously created shapefile. The spatial pattern of the thalweg lines can be controlled here and a new selection can be made if necessary. '*Polygons*' was selected as the setting style for the procedure with a gap closure tolerance of five (Figure S2E).

Select the former calculated grid '*Selection Raster*' and the empty line shapefile as input.

'Extension ArcScan' > 'Raster Toolbar' > 'Vectorization' > 'Vectorization Settings' > 'Show Preview' > 'Generate Features'

The selection grid now available shows the spatial pattern of the tunnel-valley thalwegs, but there is still no information about the depth of the data. Therefore, the next step is to assign the respective depth value to the grid cells.

Assigning the depth

The depth values need to be extracted from the grid showing the base of the Quaternary and assigned to the selection grid. This is done in two steps: first, it is necessary to define which cells are to be assigned depth values (Fig. S1). This can be done using the '*Reclass*' toolset. In this step, the values "zero" (thalweg) are set equal to "one". In addition, all areas of the raster are reclassified to 'NoData'.

Select the '*Selection Raster*' as the input file.

'ArcToolbox' > 'Spatial Analyst Tools' > 'Reclass' > 'Reclassify'

The second step is to use the '*Extract by Mask*' tool. This uses the base Quaternary raster as the input raster and the reclassified raster as the mask raster (Fig. S1). All raster cells containing a value other than 'NoData' will be assigned the value from the base Quaternary raster.

Select the original grid 'Base Quaternary' and the 'Reclass Raster' as input data.

'ArcToolbox' > 'Spatial Analyst Tools' > 'Extraction' > 'Extract by Mask'

Converting thalweg grid to thalweg lines

The final result should be a shapefile containing the thalweg lines rather than a raster dataset. The first step is to convert the existing float grid into an integer grid. This is done by eliminating the

descending digits by multiplying them by a multiple of 10. The next step is to use the '*Int*' tool to convert the grid.

Select the newly calculated 'Mask Raster' as input data.

'ArcToolbox' > 'Spatial Analyst Tools' > 'Map Algebra' > 'Raster Calculator'

'ArcToolbox' > 'Spatial Analyst Tools' > 'Math' > 'Int'

The '*Raster to Polyline*' tool can then be used. Note that the depth values have also been changed by the previous multiplication by a multiple of 10. Therefore, the depth values need to be divided by the previously used value and written to a new column in the attribute table.

Select the newly created integer raster as input data.

'ArcToolbox' > 'Conversion Tools' > 'From Raster' > 'Raster to Polyline'

The lines converted from the raster need to be edited using the advanced editing tool '*Planarize lines*' (Fig. S1) and any missing parts need to be corrected manually. The result are the tunnel-valley thalwegs as a line shapefile containing the depth values of the map showing the base of the Quaternary (Fig. S2F).

Select the newly created line Shapefile as input file.

'Table of Contents' > 'Editing' > 'Start Editing' > 'Editor Toolbar' > 'More Editing Tools' > 'Advanced Editing' > 'Planarize Lines'

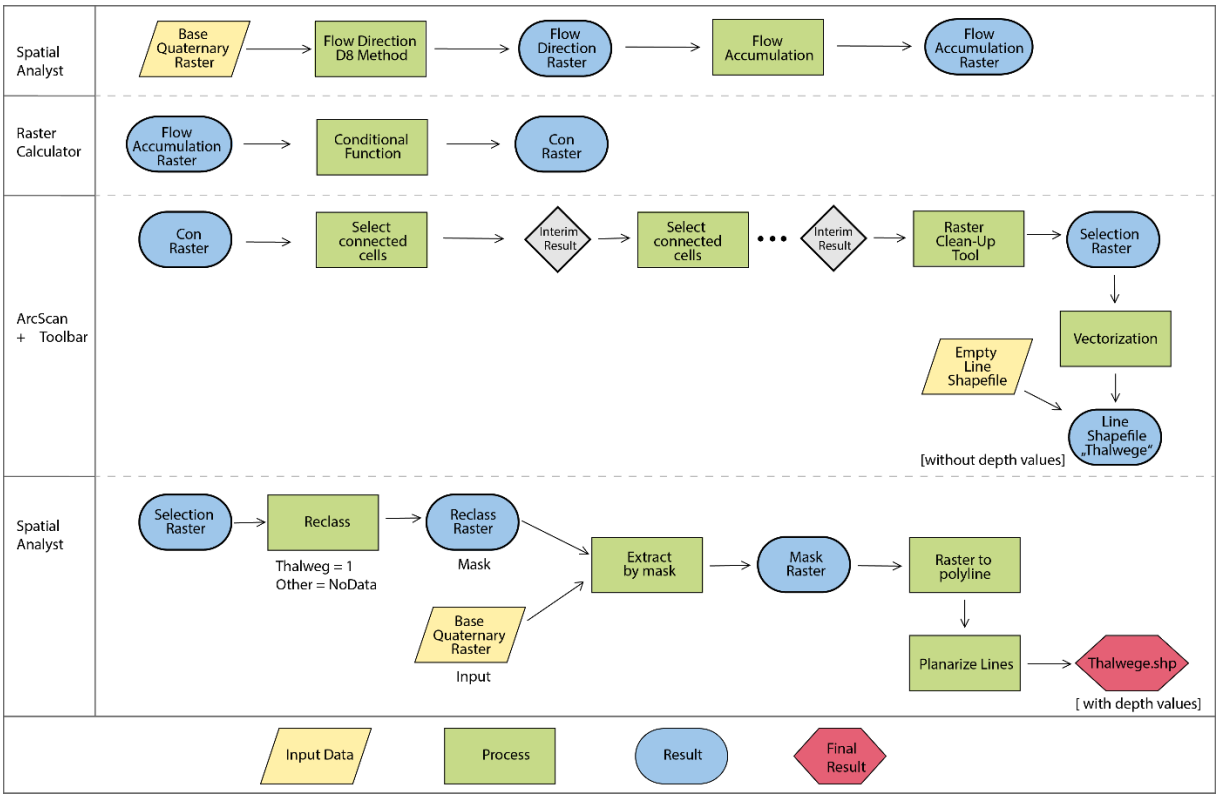

Fig. S1: The flowchart shows the steps in ArcGIS needed to derive the thalweg lines and their depths.

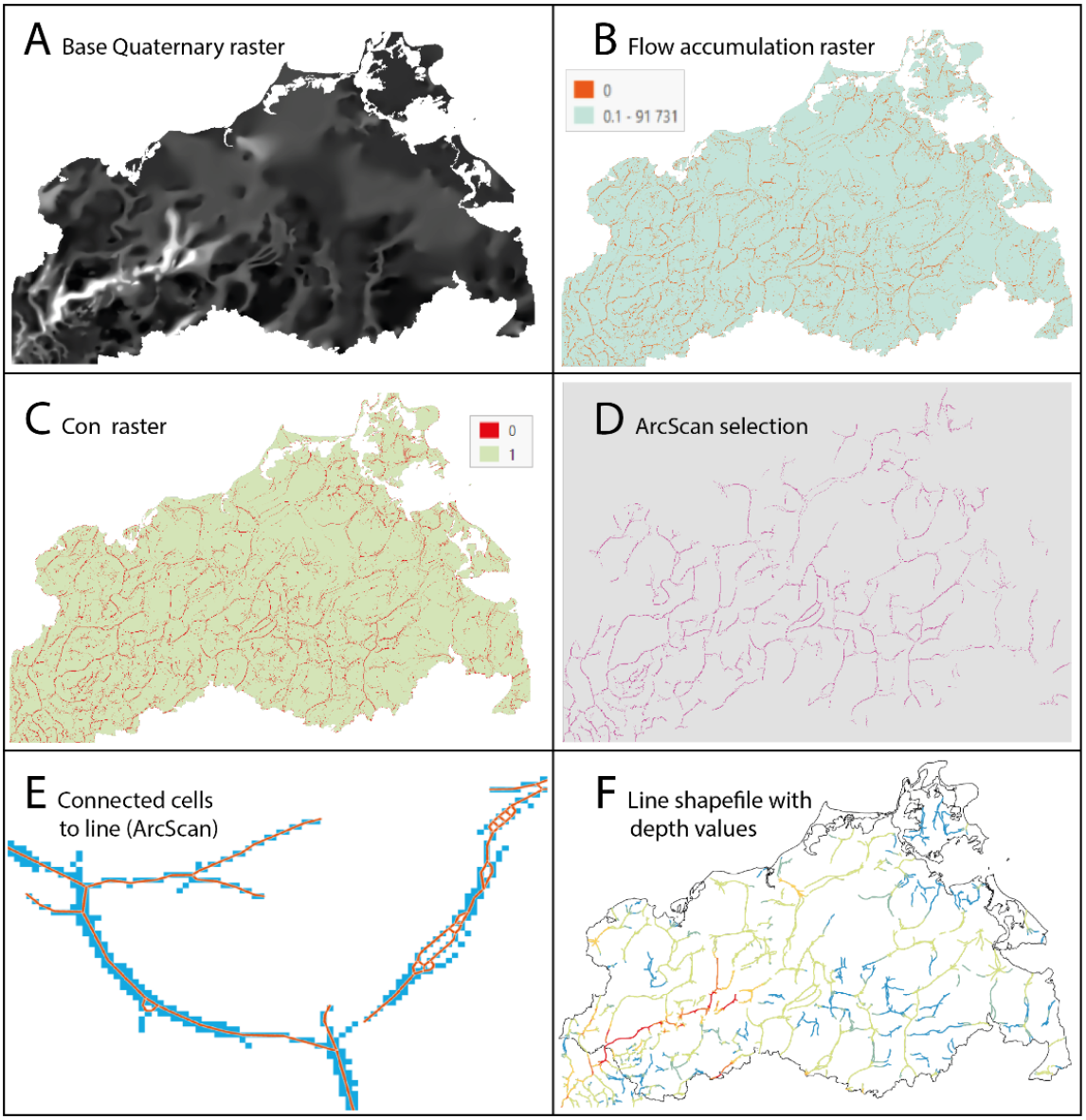

Fig. S2: The illustration exemplifies the process of thalweg extraction based on the federal state of Mecklenburg-Pomerania. A shows the base quaternary grid calculated from the line shapefile; B displays the calculated flow accumulation grid, which here can reach values between 0 (tunnel valley lows) and 91731 (main accumulation); C illustrates the calculated Con raster in which values ≥ 0 from the flow accumulation raster are set to 1; D shows the result of the ArcScan selection, in which only contiguous raster cells are saved in a new selection; E illustrates an enlarged section of the data when the connected cells to line function is executed; F displays the final result of the Thalweg calculations as a line shapefile with the corresponding depth values from the base Quaternary raster.