Illini Drainage Tools

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The ***Illini Drainage Tools*** *[IDTs]* are a series of "one-click QGIS processing" plugins being developed in the Department of Agricultural Engineering at the University of Illinois. These tools were developed to simplify the design of subsurface drainage systems and have been placed in the public domain to make them available to a broad audience. They also reduce the level of technical or GIS expertise required for designing a drainage system. These easy-to-use tools have been successfully used to optimize the design and layout of subsurface drainage systems at the University of Illinois South Farm. They are free, are compatible with all versions of QGIS3, and are available for download from the official QGIS Plugin Repository - (https://plugins.qgis.org/plugins/illini_drainage_tools/). They can also be accessed from the Illinois Drainage Guide - (https://publish.illinois.edu/illinoisdrainageguide/illini-drainage-tools/). The GUI for all the routines in the IDTs is comprised of a main window with two different input sections (A, B) and a usage information window (C), which are organized using tabs. In the main window, Section A contains the input parameters that are essential for the tools to work, while Section B defines the output data files resulting from running the tools. For the optimal benefit of these routines, we recommend that you do not use them in isolation as each precedes the next one: "A to P".

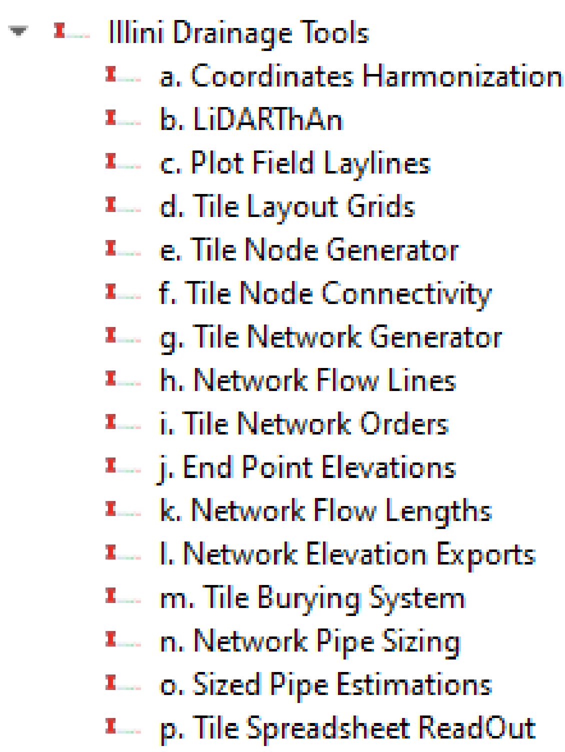

Figure 1. QGIS Table of Content for the Illini Drainage Tools

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a. Coordinates Harmonization:

This routine – **Coordinates Harmonization** – helps to ensure that the same coordinate system is applied to both datasets of vector and raster layers respectively. It creates two new layers with the exact same features and geometries. This routine can also be used to repair layers which have been assigned an incorrect projection. The user interface for this routine is shown in figure 2.

Input Data Requirements:

a. Select Raster DEM (LiDAR) Layer
b. Select any Vector Shapefile Layer (e.g., Boundary or/and line data)
c. Specify the Targeted CRS (Coordinate Reference System)

Output Datafiles (Optional):

a. New Raster DEM Layer
b. New Vector Shapefile Layer (e.g., Boundary or/and line data)

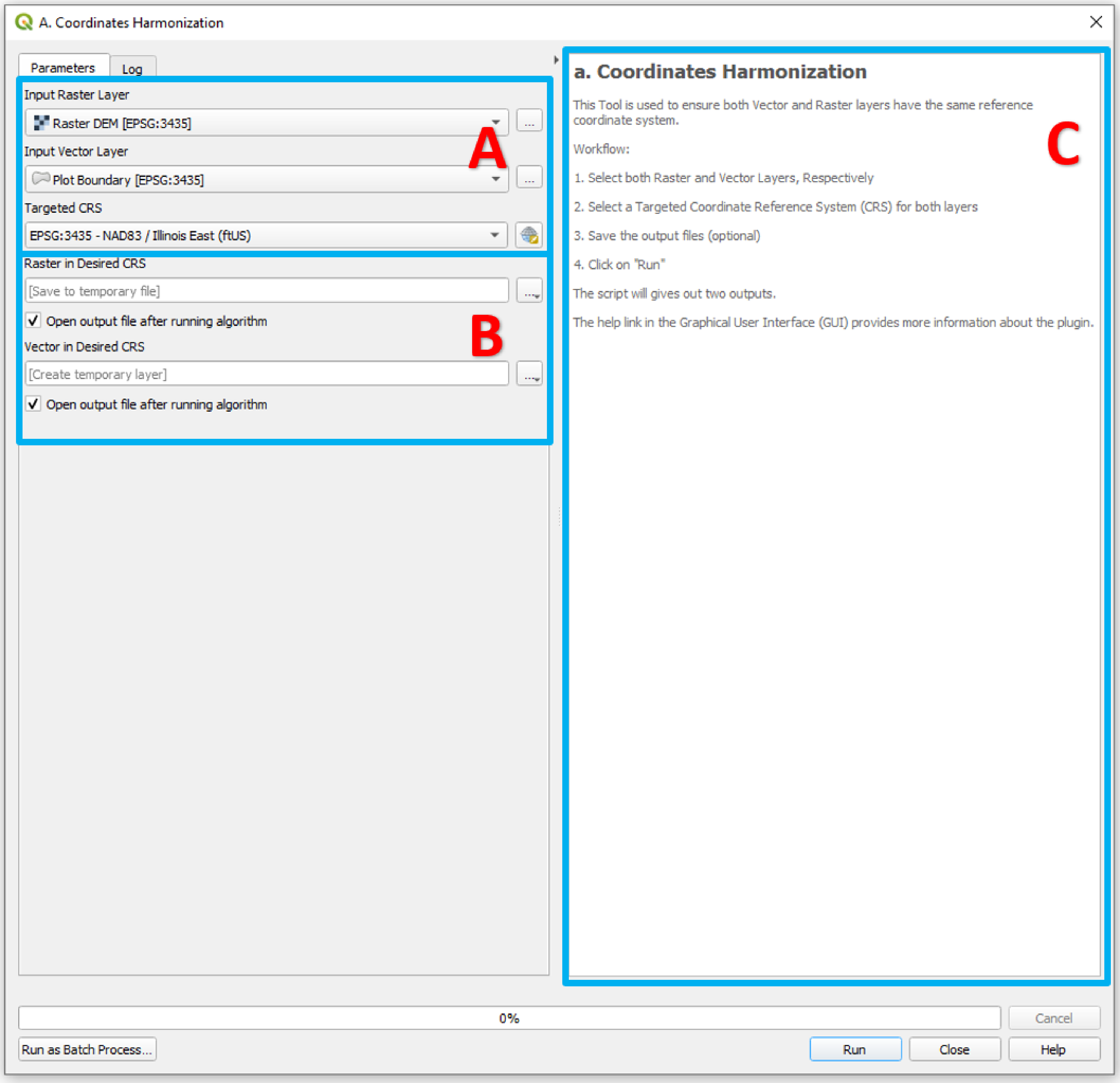


Figure 2. Graphical User Interface of the "Coordinates Harmonization" Routine

b. LiDARThAn:

Raster LIDAR data is now used for the design of many agricultural or conservation systems in the Midwest. One such use is for the design of drainage systems. LiDARThAn (**LiDAR Th**inning **An**alysis), the interface of which is shown in Figure 3, was developed to reduce the density of point cloud data based on a specified threshold spacing. This routine can be used for boundary extraction, DEM resampling, pixels point conversion, and the extraction of point-elevation data. The results from successfully testing the new routine (Figure 4) show both a LiDAR DEM thinned to the desired pixel size, and dots on and within the boundary of the extracted area. Each dot of the grid represents a point feature with spatial reference in a point sampling design.

Input Data Requirements:

a. Select Raster DEM (LiDAR) Layer
b. Select Polygon Vector Shapefile Layer (e.g., Boundary data)
c. Specify Desired Pixel Size (Ft)

Output Datafiles (Optional):

a. New Raster DEM Layer
b. Three New Point Vector Shapefile Layers

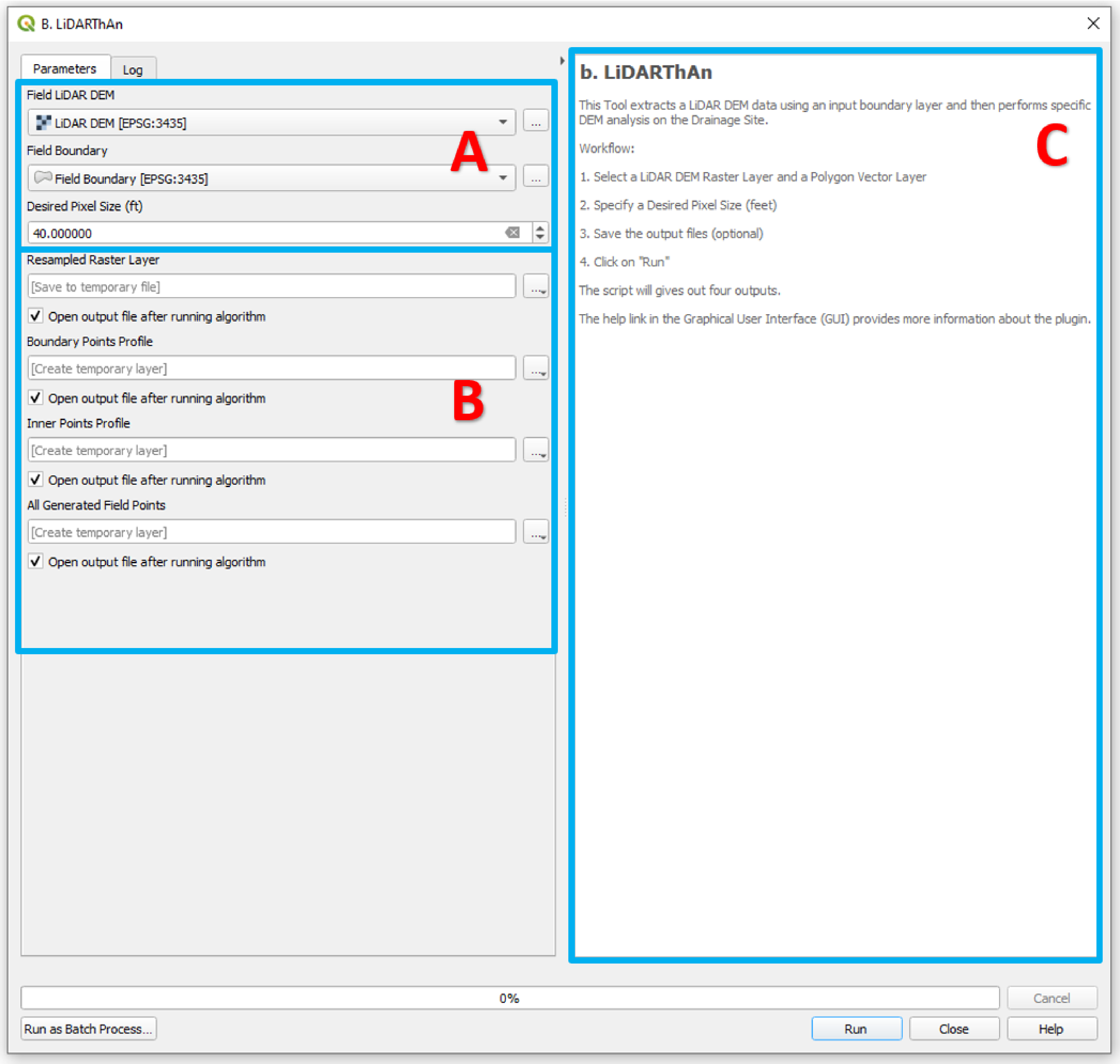


Figure 3. Graphical User Interface of the “LiDARThAn” Routine

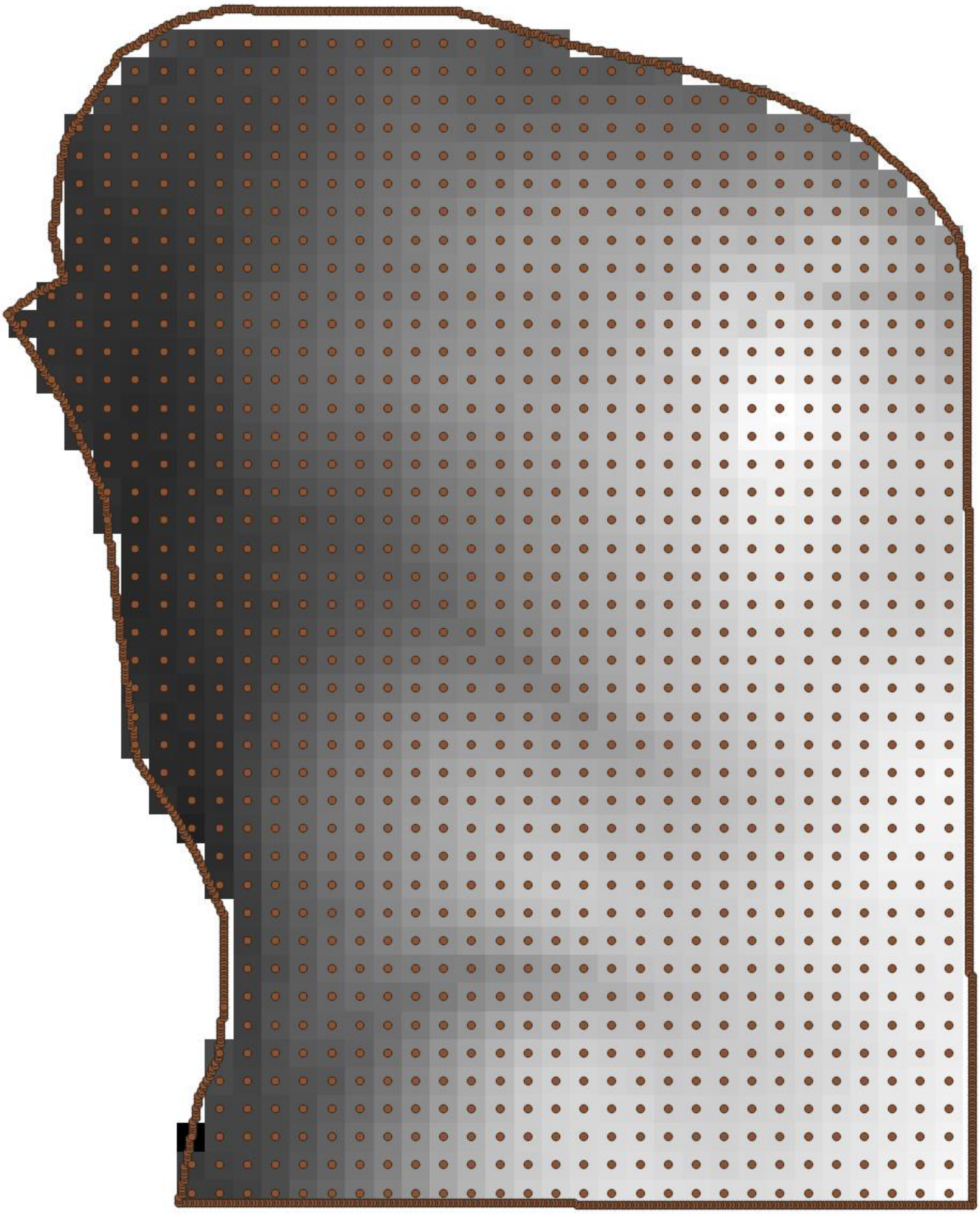


Figure 4. LiDARThAn Routine Result

c. Plot Field Laylines:

The use of LiDAR DEM data has facilitated watershed-based design, and the identification and sizing of run-on areas and depressions. Developing a drainage system layout traditionally includes the generation of contour lines from elevation data and the use of these contour lines to inform the layout of laterals and mains. Experienced designers can identify high points, plateaus, draws or depressions from contour lines, and incorporate these into system layout. However, drainage system layout is somewhat of an art and even experienced contractors can produce distinct design layouts using the same topographic data. Inexperienced contractors or producers may have difficulty visualizing surface features or flow pathways from contour lines. This routine - **Plot Field Laylines** - produces drainage nets, consisting of contour lines and surface flow pathways, herein called LAYLINES, to help visualize surface features, and thereby simplify drainage system layout, particularly for inexperienced designers. These drainage nets are analogous to flow nets, comprising equipotential lines and streamlines, that are used for steady-state subsurface flow visualization and flow determination, particularly in regions with irregular geometries. Like equipotential lines and streamlines, contour lines and LAYLINES are at right angles to each other. The interface for this routine is shown in Figure 5, and a drain net is shown in Figure 6.

Input Data Requirements:

a. Select the Original Raster DEM (LiDAR) Layer (e.g., 4 x 4-pixel size)
b. Select the Thinned Raster DEM (LiDAR) Layer (e.g., 40 x 40-pixel size)
c. Select a Polygon Vector Shapefile Layer (e.g., Boundary data)
d. Specify the Desired Contour Line Interval (Ft)
e. Specify the Investigating Raster Depth Difference (Ft)

Output Datafiles (Optional):

a. New Raster DEM Layer (a.k.a. Depression DEM)
b. Three New Line Vector Shapefile Layers

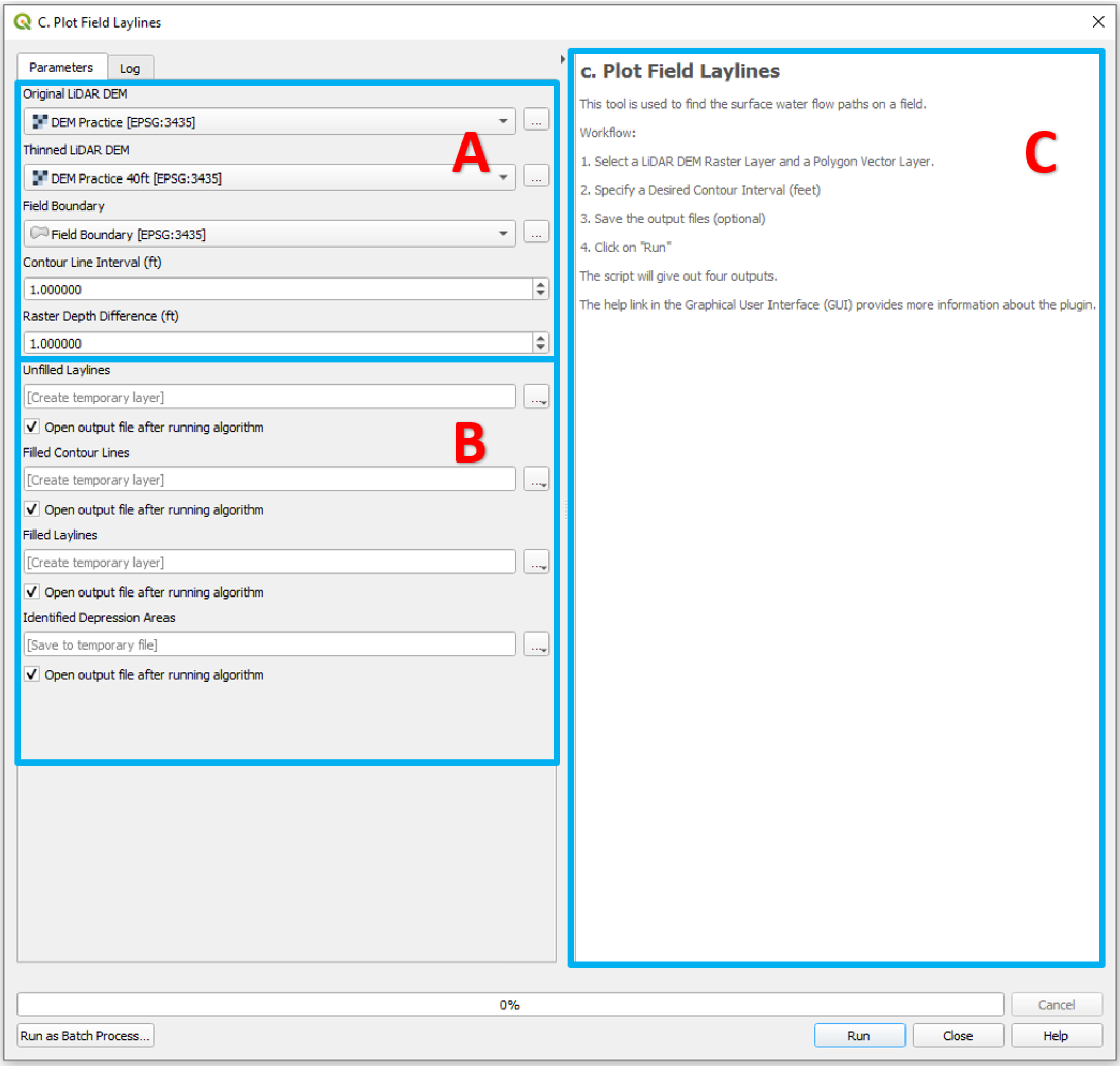


Figure 5. Graphical User Interface of the "Plot Field Laylines" Routine

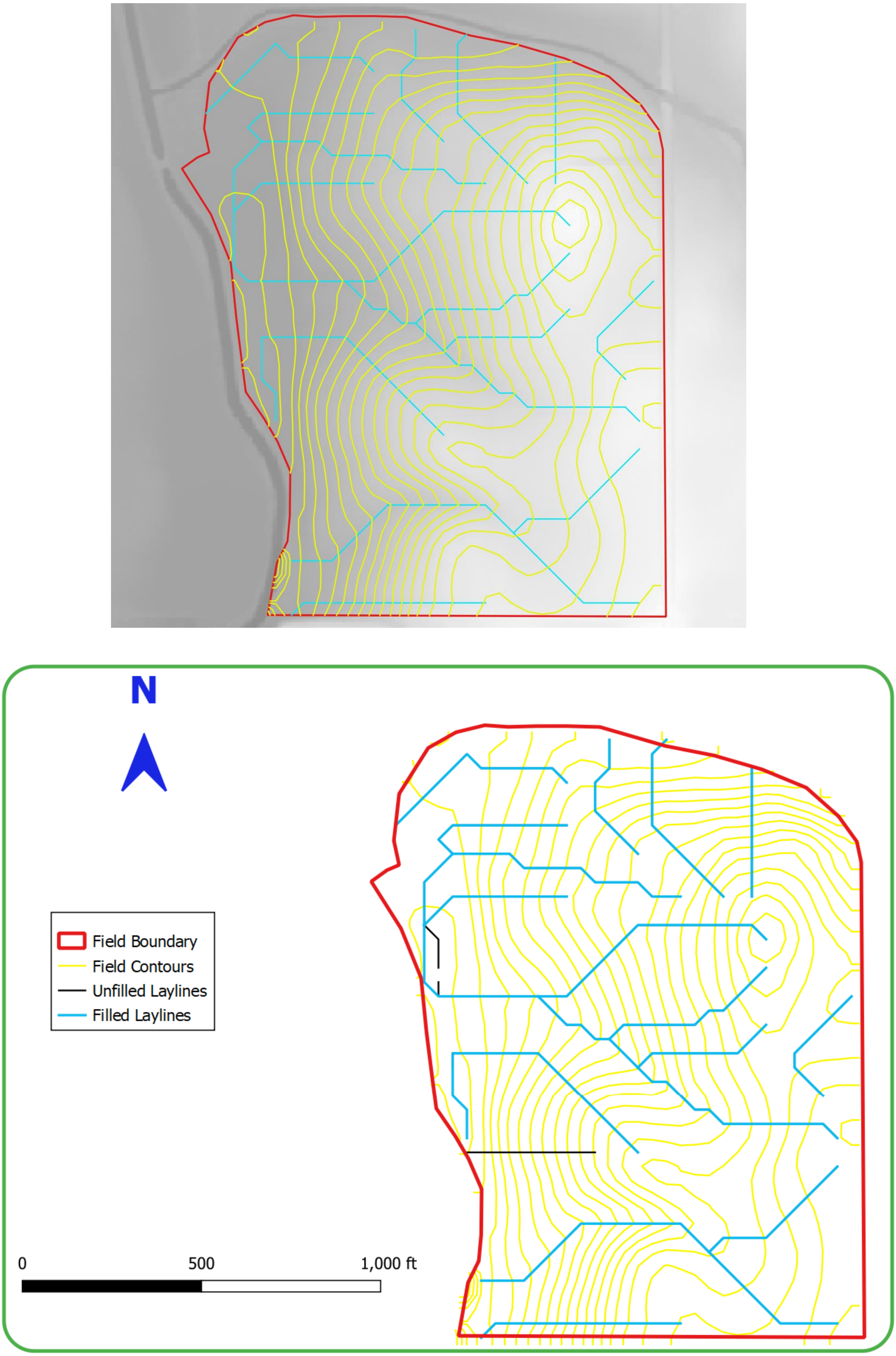


Figure 6. Plot Field Laylines Routine Result

Additionally, Figure 7 highlights the depression in the DEM resulting from the difference between the elevation details of both the thinned DEM and the DEM with filled sinks. The "White Area" within the boundary indicates the existence of depressions at specified depths in the field. With this information, surface inlet points can be located within the field boundary.

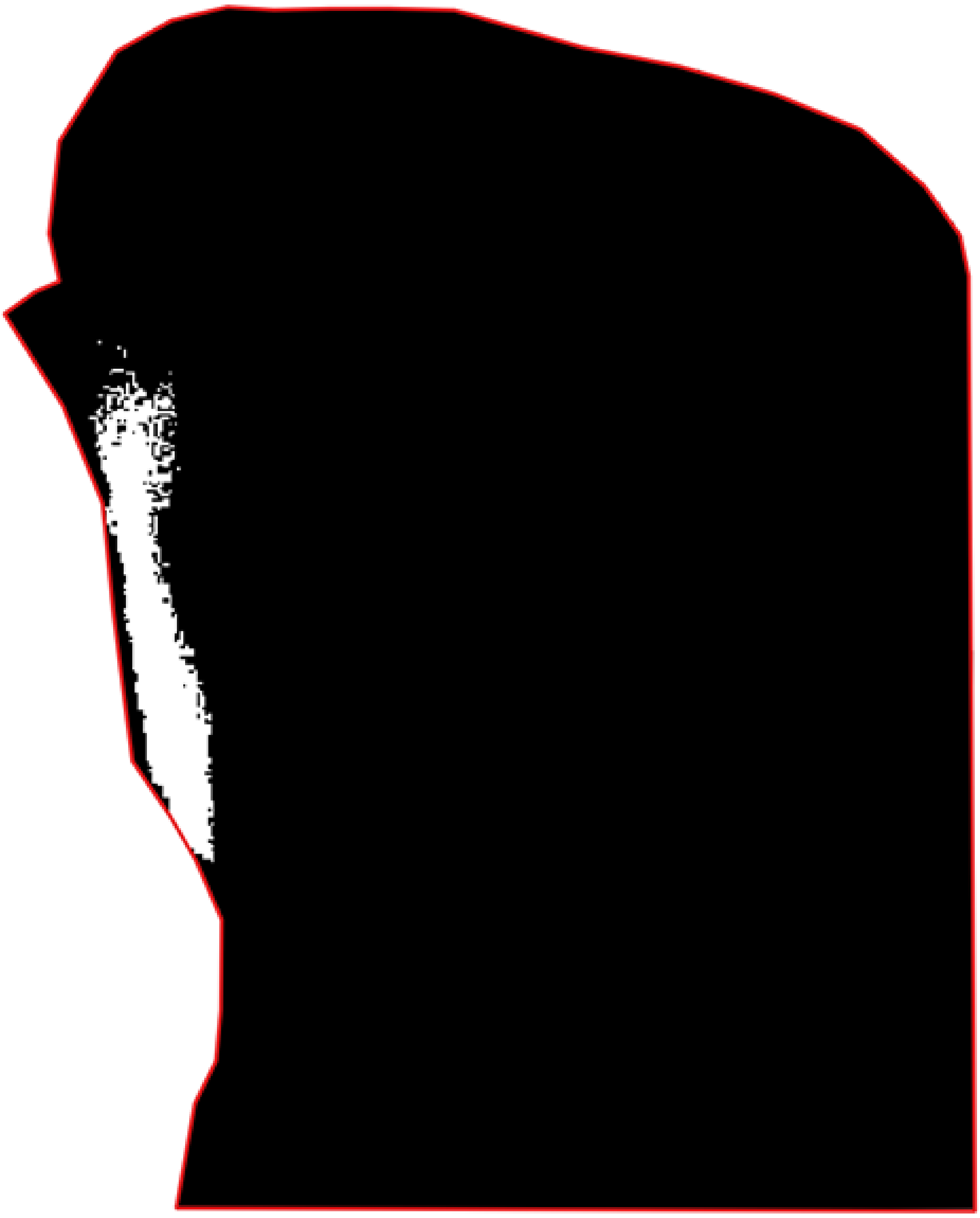


Figure 7. Raster DEM with Depression Areas in "White"

d. Tile Layout Grids:

This routine - **Tile Layout Grids** – produces guidelines, in the form of overlay-grids, to assist in drainage system layout. The line spacing and grid angle are user specified (Figure 8). An example output is given in Figure 9.

Input Data Requirements:

a. Zoom Out on the Map Canvas and Select the "Map Canvas Extent" Option
b. Select Targeted CRS (Coordinate Reference System)
c. Specify Drain Spacing (Horizontal and Vertical, in Ft)
d. Specify Rotation Angle for the Perpendicular Gridlines
e. Indicate the Grid Center on the Map Canvas

Output Datafiles (Optional):

a. Two New Vector Shapefile Layers (Grid Lines: Linear and Perpendicular)

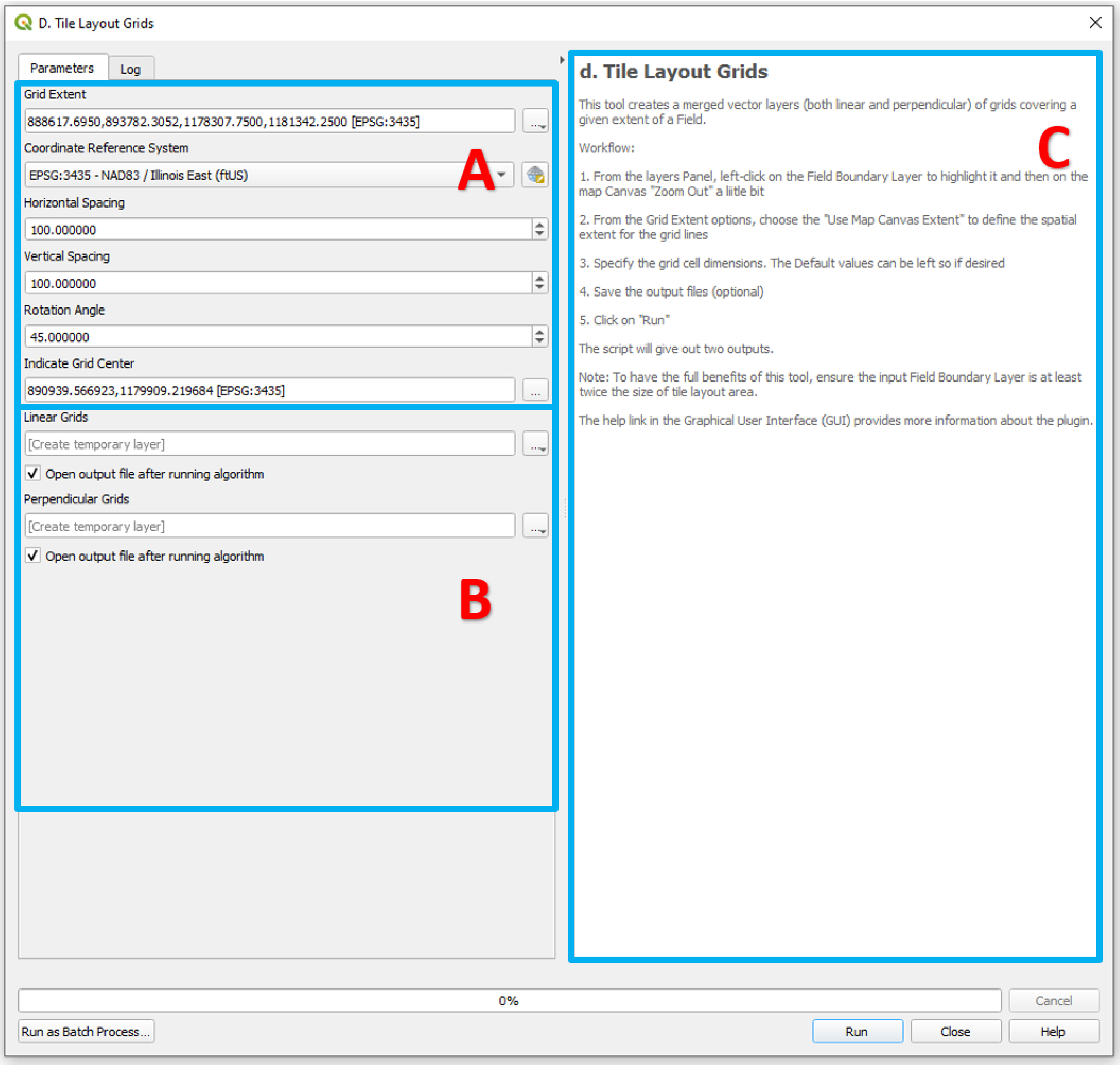
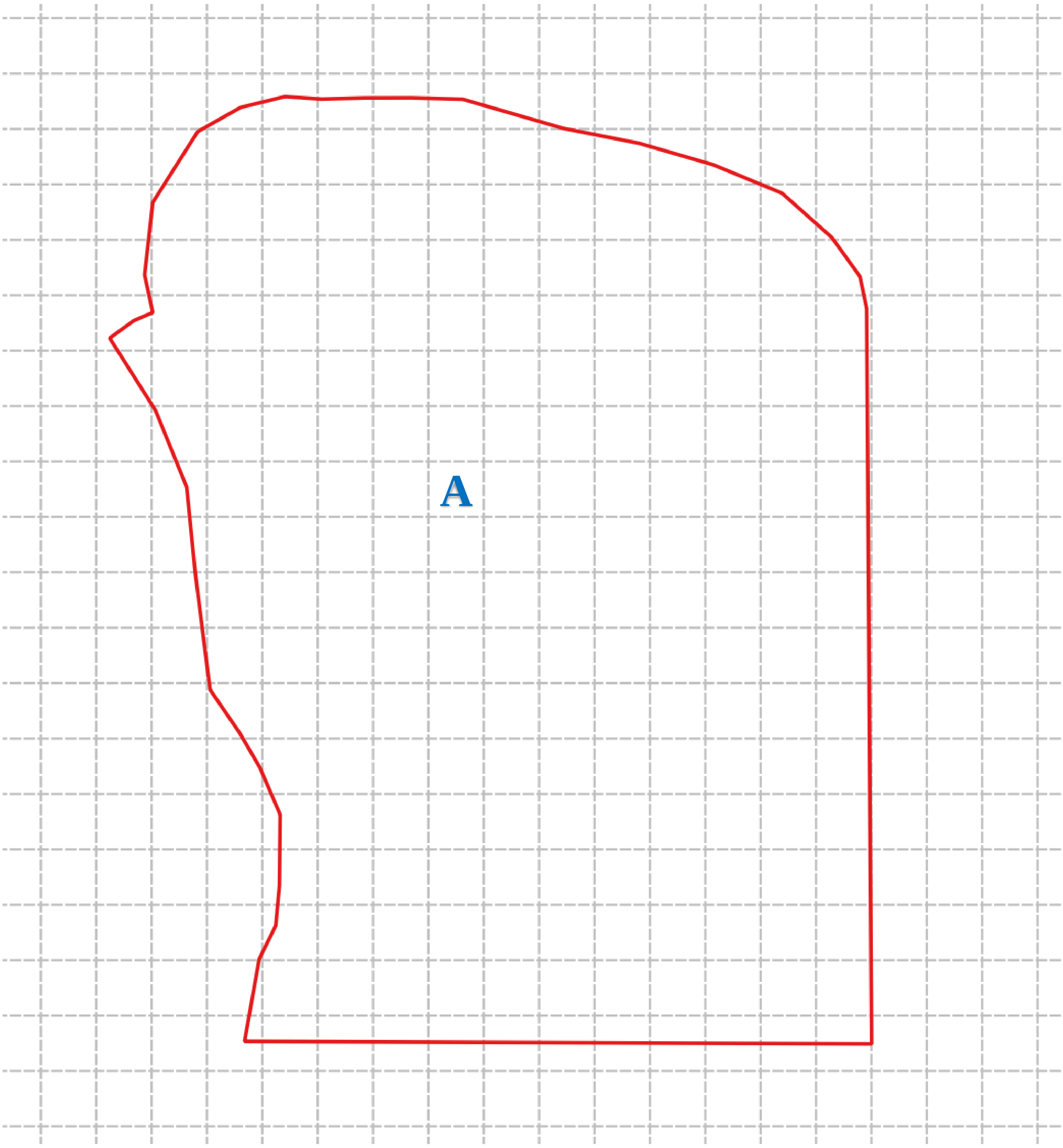


Figure 8. Graphical User Interface of the "Tile Layout Grids" Routine


A

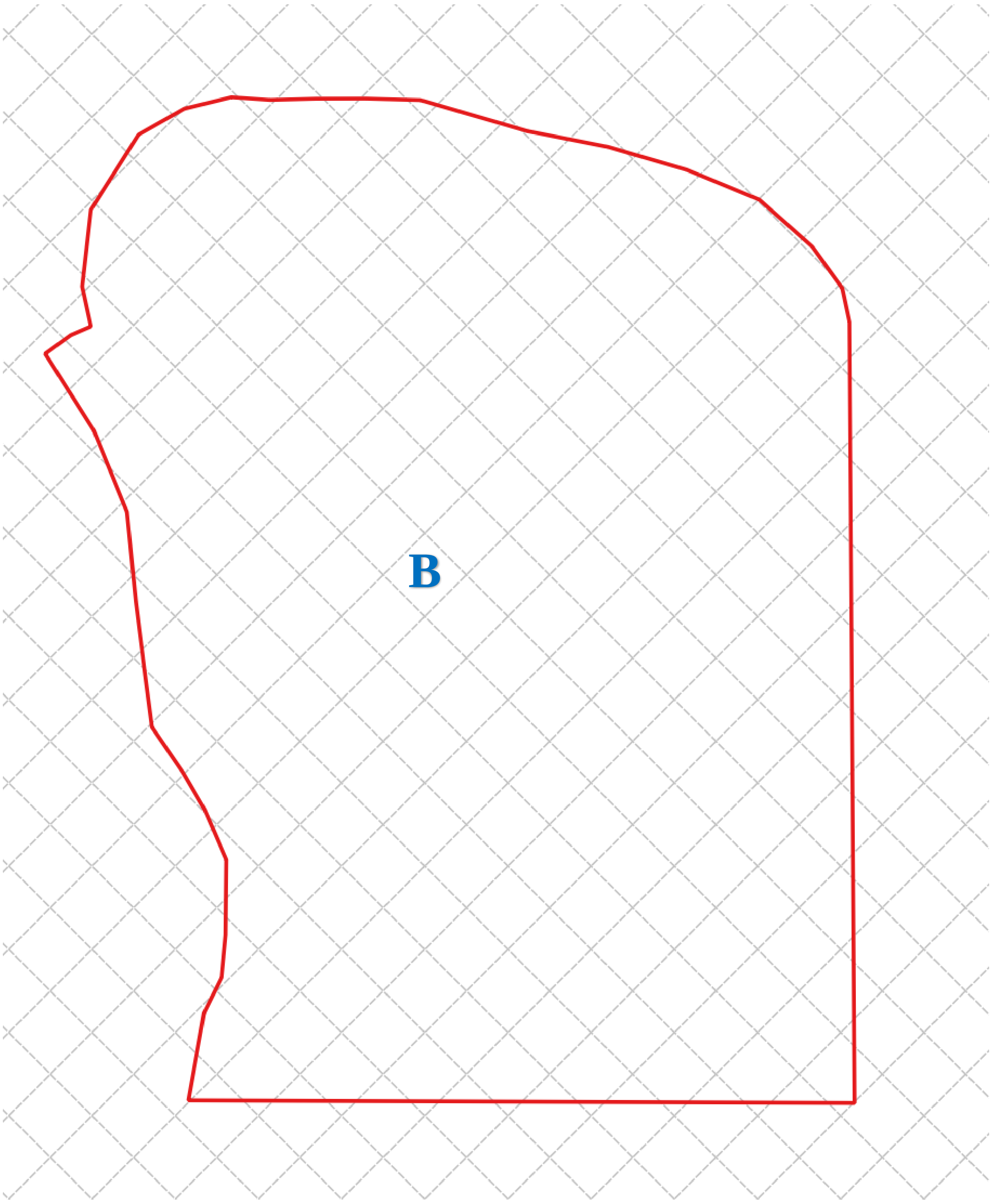


Figure 9. Overlay-Grid Lines: Linear (A) and Perpendicular (B)

e. Tile Node Generator:

This routine is the first stage of the process to produce a topologically sound network from a digitized tile layout. In practice, these tile lines are often not laid out as topologically sound networks. The tile lines may not be all connected and may not be consistently drawn from upstream to downstream or vice versa. No matter the design complexity, the **Tile Node Generator** routine generates geometrically aligned nodes when applied. The interface is shown in Figures 10.

Depending on the layout of the system, the routines perform the following sequence of tasks:

a. Extends the endpoint of each line segment to connect with another line, thus forming a node from fractured lines.
b. Dissolves attributes to aggregate all fracture lines features into a single feature line layer.
c. Extracts nodes at the endpoints and intersections, if any) of each line segment
d. Generates location coordinates for these newly generated points.
e. Snaps the endpoint nodes of a line segment to another node within a specified tolerance.

Figure 11 shows a drainage system layout, discontinuities in the system, and the nodes generated by the node generator.

Input Data Requirements:

a. Select a Line Vector Shapefile Layer (e.g., Hydraulic Layout data)
b. Specify the Extended Distances from both Starting and Ending Points (Ft)
c. Select Targeted CRS (Coordinate Reference System)

Output Datafiles (Optional):

a. New Node Vector Shapefile Layer (e.g., Point data)

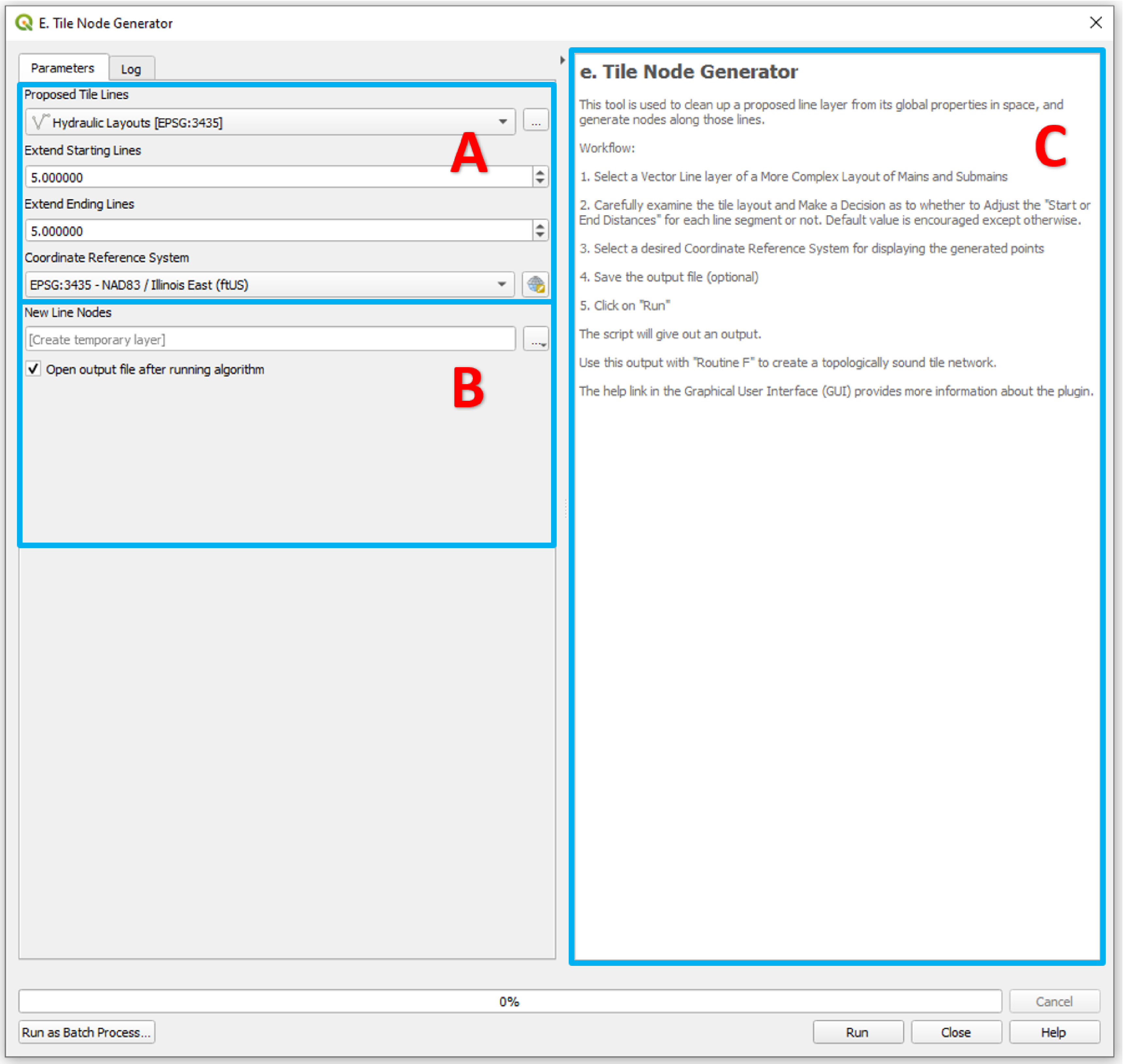


Figure 10. Graphical User Interface of the "Tile Node Generator" Routine

Starting from Routines F – P, their respective input follows the output from the preceding Routine. For example, the input file for Routine F is the output from Routine E, and so on until Routine P.

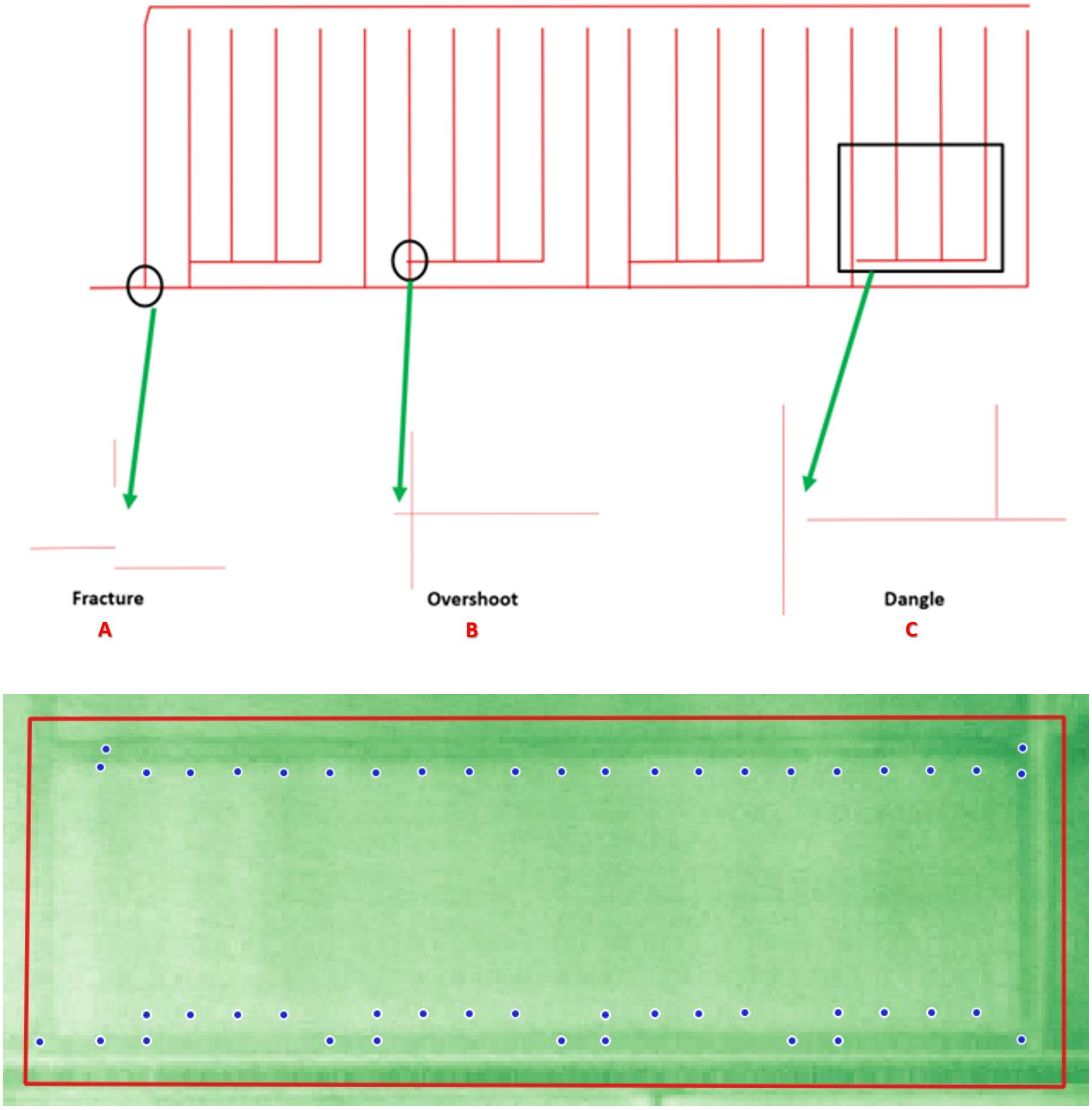


Figure 11. Drainage system with discontinuities and the nodes generated to correct them

f. Tile Network Connectivity:

This routine, **Tile Network Connectivity**, is the final stage of the process involved in creating a topologically sound tile network. It uses the output from either node generator to perform the following tasks:

I. Creates a new line layer by connecting the features from the nodes together.

II. Fix issues related to line geometry, such as adding geometry attributes and removing line features with null entries in the attributes.

III. Explodes the lines into line segments like in the original proposed tiles line.

The interface for the routine, and the results of two network generation steps at one discontinuity, are shown in Figures 12 and 13, respectively.

Input Data Requirements:

a. Select a Node Vector Shapefile Layer (e.g., Point data)
b. Select the named Fields (“Vertex Part Index” & “Group Vertex Part”)

Output Datafiles (Optional):

a. New Line Vector Shapefile Layer (e.g., Line data)

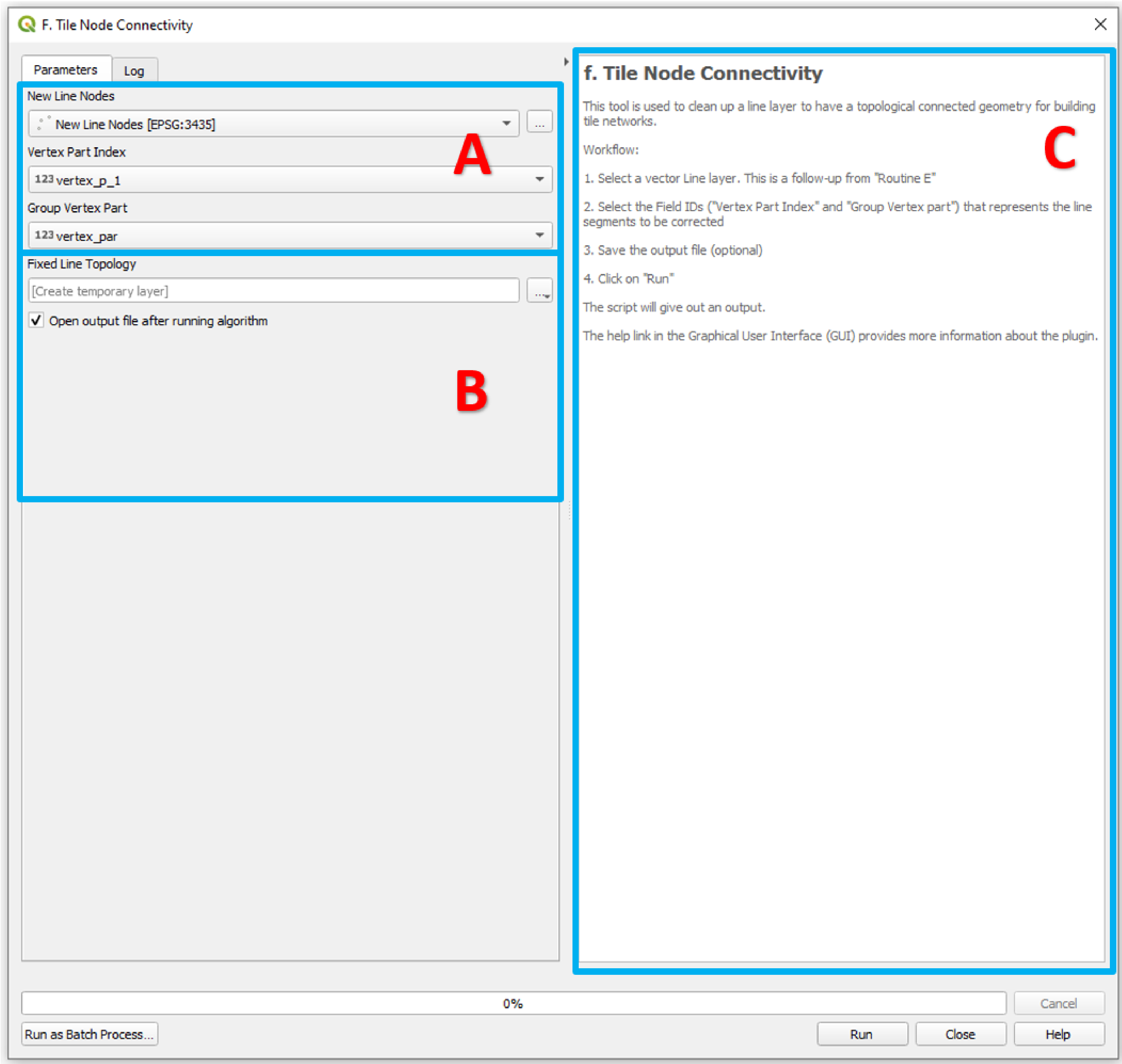


Figure 12. Graphical User Interface of the "Tile Network Connectivity" Routine

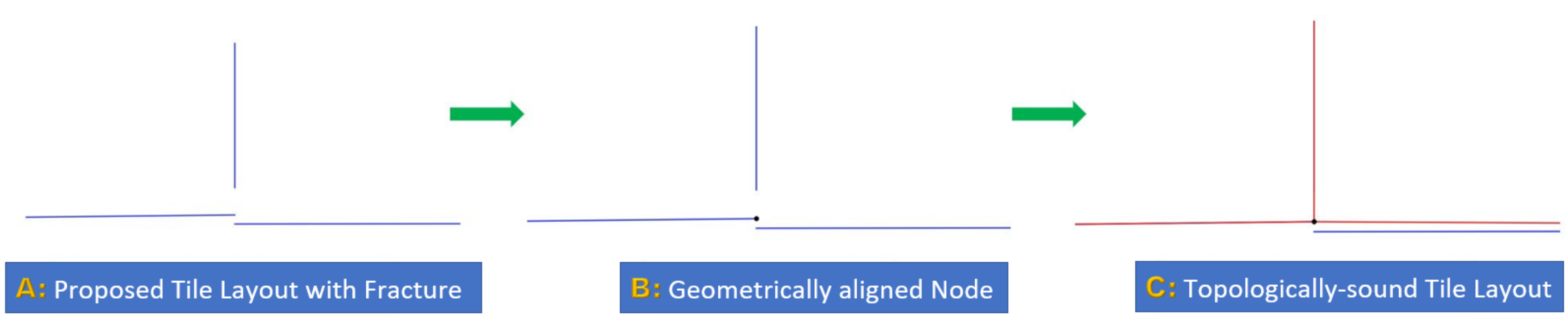


Figure 13. Fixing Flow Process: Topologically Sound Tile Line

g. Tile Network Generator:

The **Tile Network Generator** routine, with interface shown in Figure 14, uses the output generated from the **Tile Network Connectivity** routine to reorient line segments so that the beginning and end nodes of each is consistently upstream and downstream, respectively, and identifies line segments immediately upstream and downstream of each line segment. This routine requires the specification of the outlet line segment (Figure 15). The outlet line segment is easily selected on the map canvas from the corrected network layer using the "Select Feature by Area or Single Click" tool in QGIS. Figure 16 shows the log from the routine with the number of unconnected segments highlighted (zero after this correction). Figure 17 shows a side-by-side comparison of the original digitized tile layout, and the corrected network.

Input Data Requirements:

a. Select a Line Vector Shapefile Layer (e.g., Topologically-sound Line data)

Output Datafiles (Optional):

a. New Line Vector Shapefile Layer (e.g., Line data)

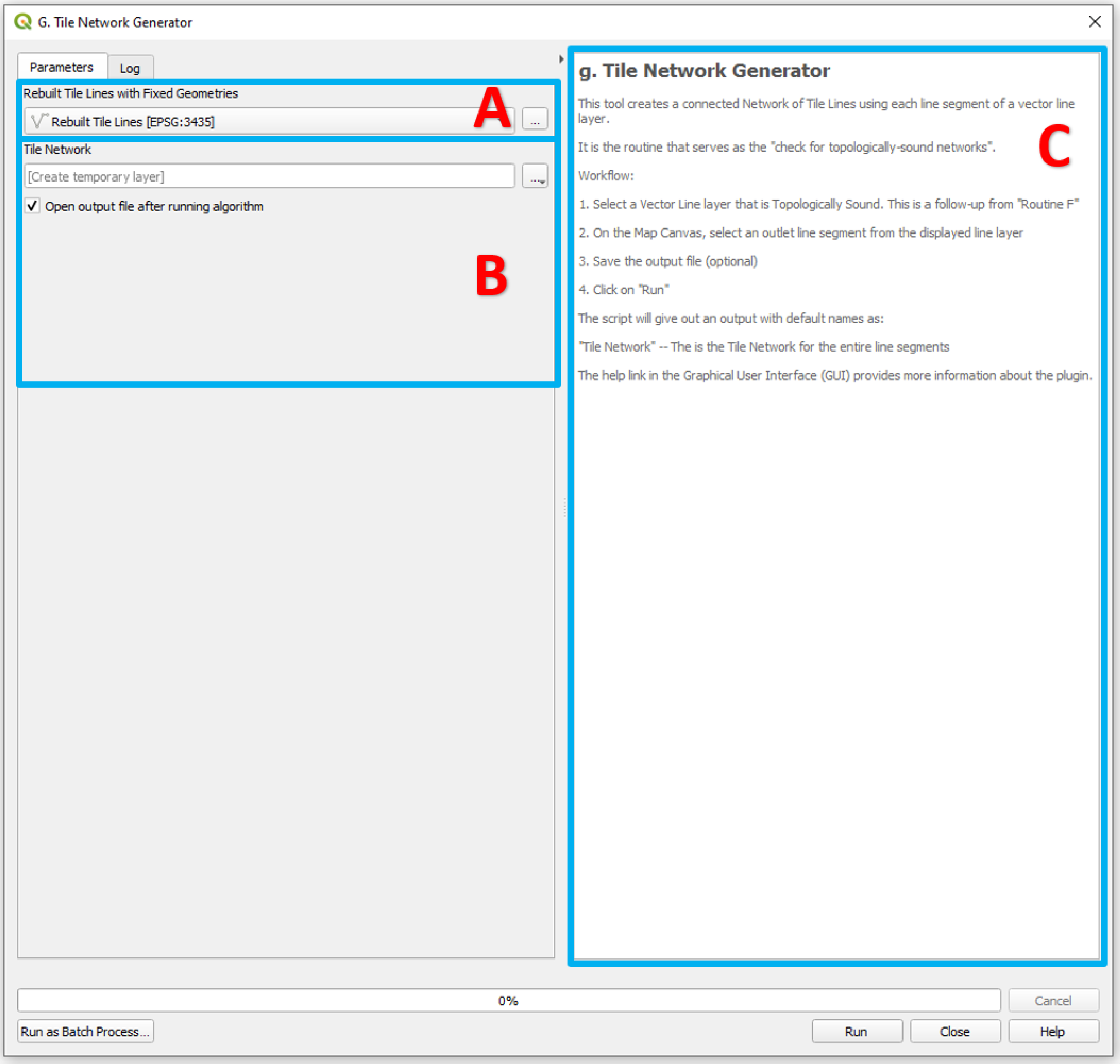


Figure 14. Graphical User Interface of the "Tile Network Generator" Routine

Figure 15. Selected Downstream Outlet Point in the Tile Layout

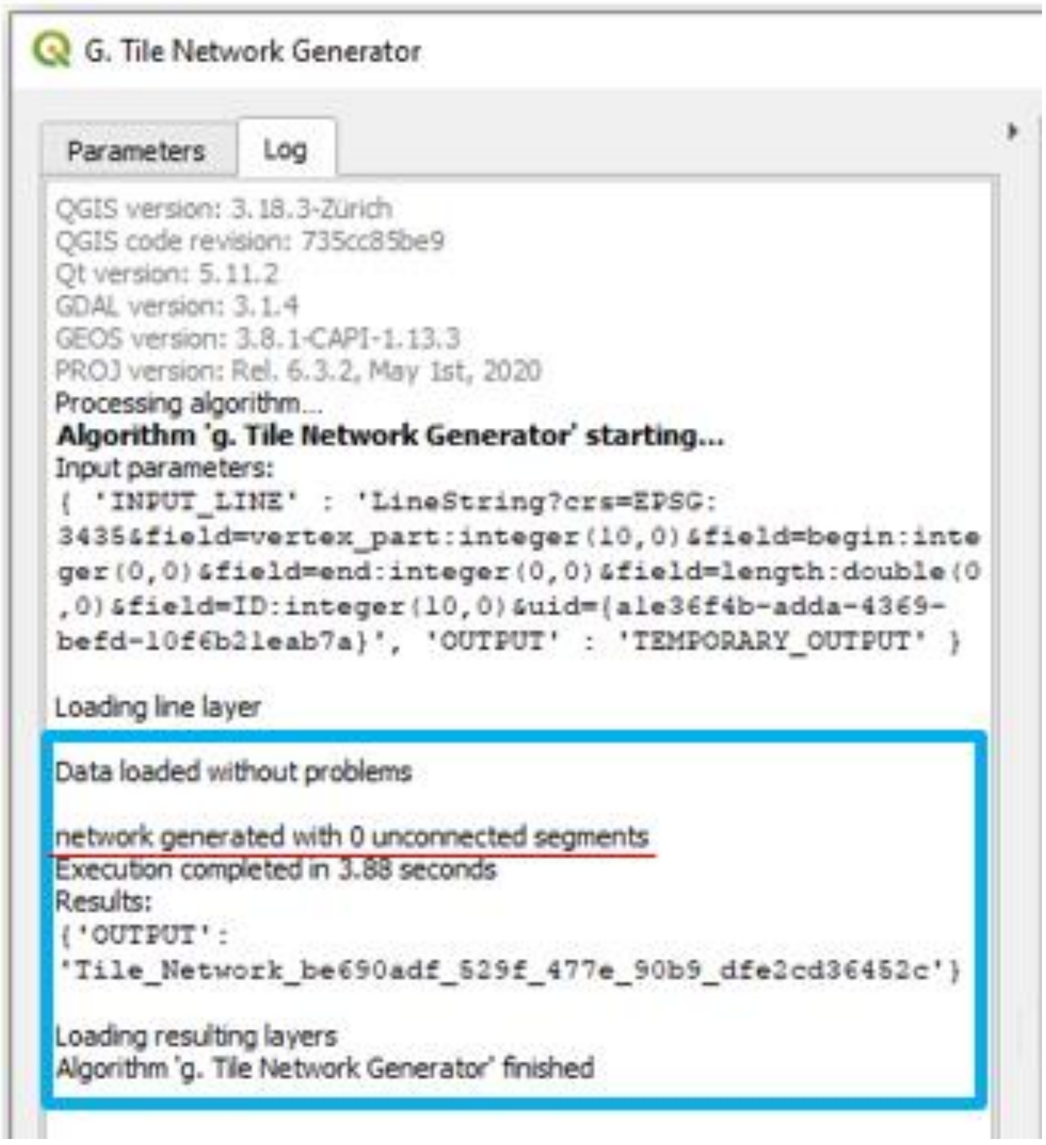


Figure 16. Tile Network Generator Routine Result

Tile_ID	Tile_TO	Tile_FROM
1	unconnected	unconnected
2	unconnected	unconnected
3	unconnected	unconnected
4	unconnected	unconnected
5	unconnected	unconnected
6	unconnected	unconnected
7	unconnected	unconnected
8	unconnected	unconnected
9	unconnected	unconnected
10	unconnected	unconnected
11	unconnected	unconnected
12	unconnected	unconnected
13	unconnected	unconnected
14	unconnected	unconnected
15	unconnected	unconnected
16	unconnected	unconnected
17	unconnected	unconnected
18	unconnected	unconnected
19	Out	19
20	unconnected	unconnected

A

Tile_ID	Tile_TO	Tile_FROM
1	2	1
2	4	2
3	4	3
4	15	4
5	15	5
6	2	6
7	8	7
8	11	8
9	11	9
10	13	10
11	13	11
12	14	12
13	14	13
14	20	14
15	20	15
16	17	16
17	18	17
18	19	18
19	Out	19
20	19	20

B

Figure 17. Attribute Table (A) Unsound Network (B) Sound Network

h. Network Flow Lines:

The routine, **Network Flow Lines**, with interface shown in Figure 18, was developed to determine the flow line path in the tile layout. Flow lines are useful for visualizing flow patterns, wake formation and circulation in layout designs. The results from this routine indicate the direction of flow from the downstream outlet to the upstream inlet of the line segments (Figure 19).

Input Data Requirements:

a. Select a Line Vector Shapefile Layer (e.g., Topologically-sound Tile Network Line data)
b. Select the named Fields (“TILE_FROM” & “TILE_TO”)

Output Datafiles (Optional):

a. New Line Vector Shapefile Layer (e.g., Line data)

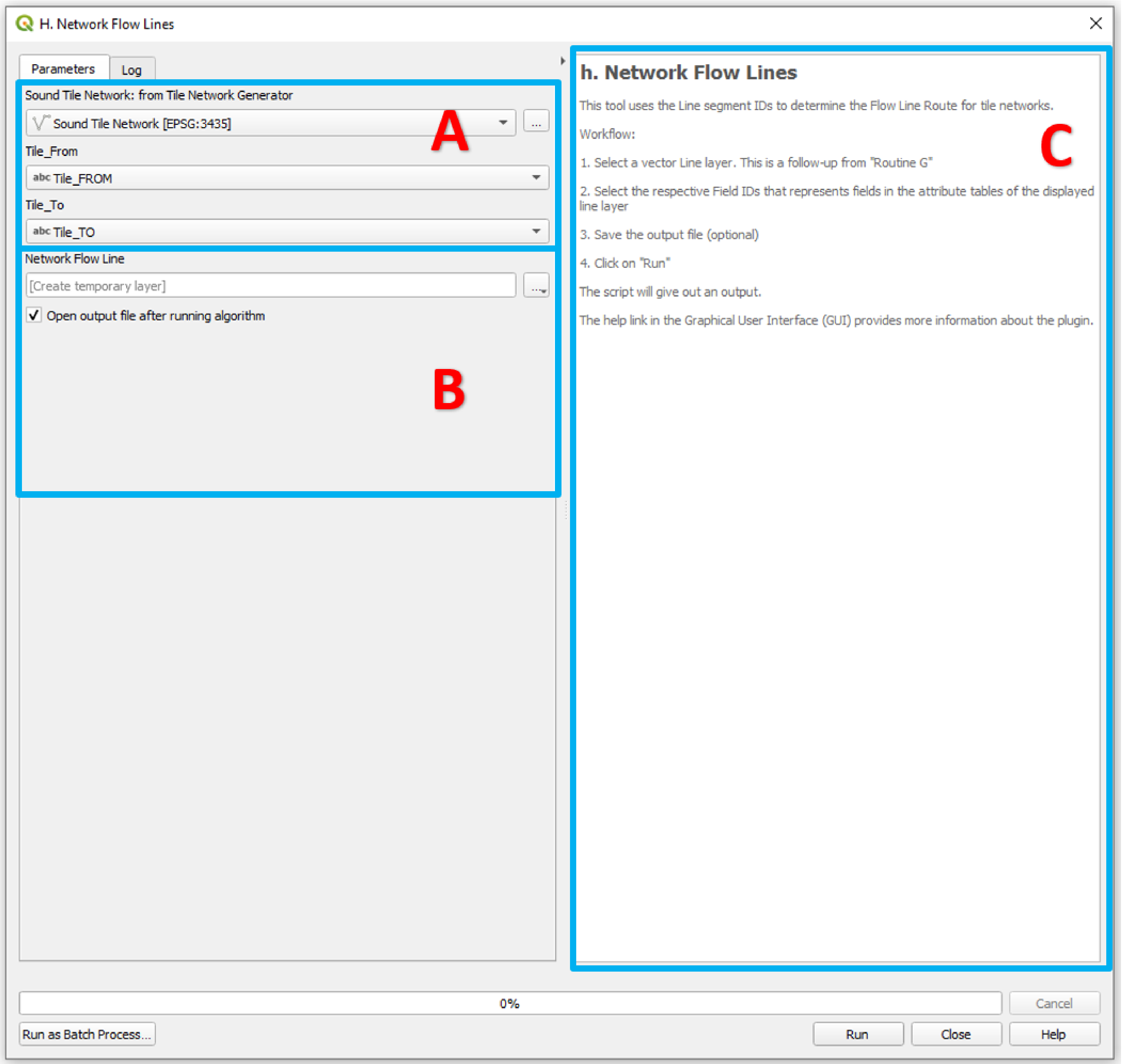


Figure 18. Graphical User Interface of the "Network Flow Lines" Routine

TILE_ID	TILE_TO	TILE_FROM	FLOW_LINE	TILE_FLOW
8	6	8	3	1
7	4	7	2	2
6	4	6	13	3
5	2	5	1	4
4	2	4	12	5
3	13	3	9	6
2	13	2	11	7
13	12	13	8	8
1	12	1	10	9
12	9	12	7	10
9	11	9	4	11
11	10	11	6	12
10	Out	10	5	13

Upstream Inlet Point

Downstream Outlet Point

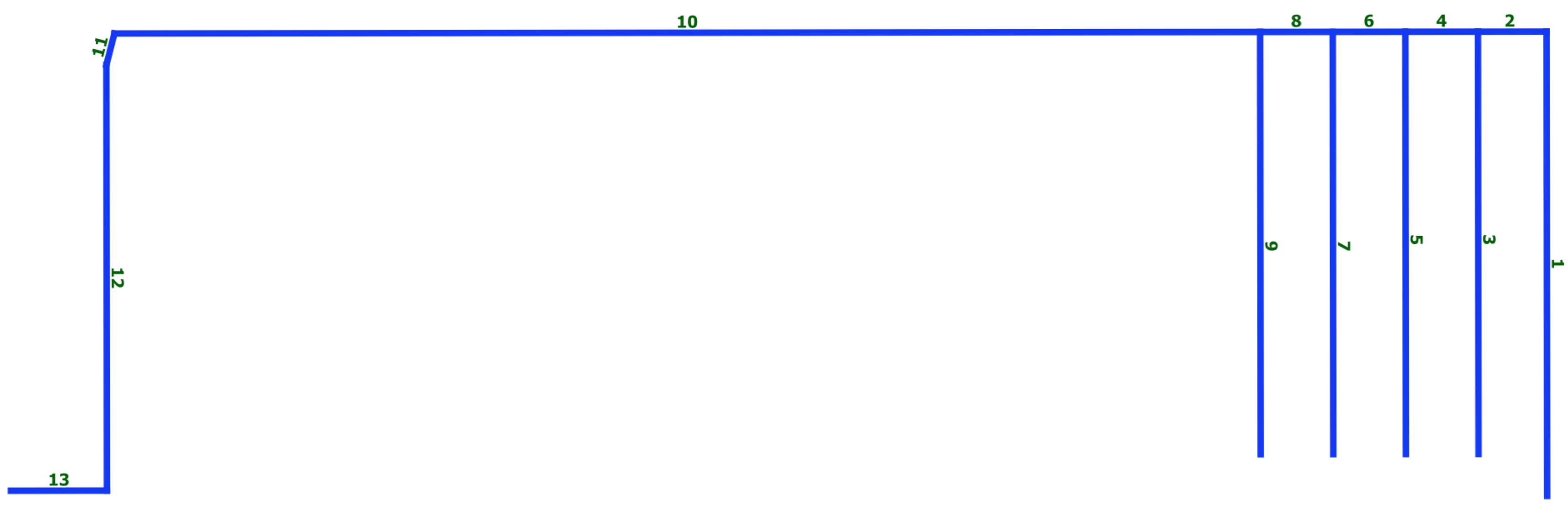


Figure 19. Layout Flow Line: Upstream Inlet to Downstream Outlet Points

i. Tile Network Orders:

The routine, **Tile Network Orders**, with interface shown in Figure 21, was developed by applying the "Top Down" principle of Strahler Stream Order (Figure 20) to determine the Flow Order for each line segment in the tile network. The routine determines two Stream Orders: (a) "Flow_Order" with respect to the Flow_Line field in the attribute table (b) "Tile_Order" with respect to the Tile_ID field in the attribute table (Figure 22a). This provides a hierarchical system within the tile network layout. This ordering of the line segments in tile network layout reflects the flow strength in the drainage system and forms the basis of important hydrographical indicators of its structure, such as its drainage density and frequency.

Input Data Requirements:

a. Select a Line Vector Shapefile Layer (e.g., Topologically-sound Network Flow Line data)
b. Select the named Fields ("TILE_FROM", "TILE_TO" & "FLOW_LINE")

Output Datafiles (Optional):

a. New Line Vector Shapefile Layer (e.g., Line data)

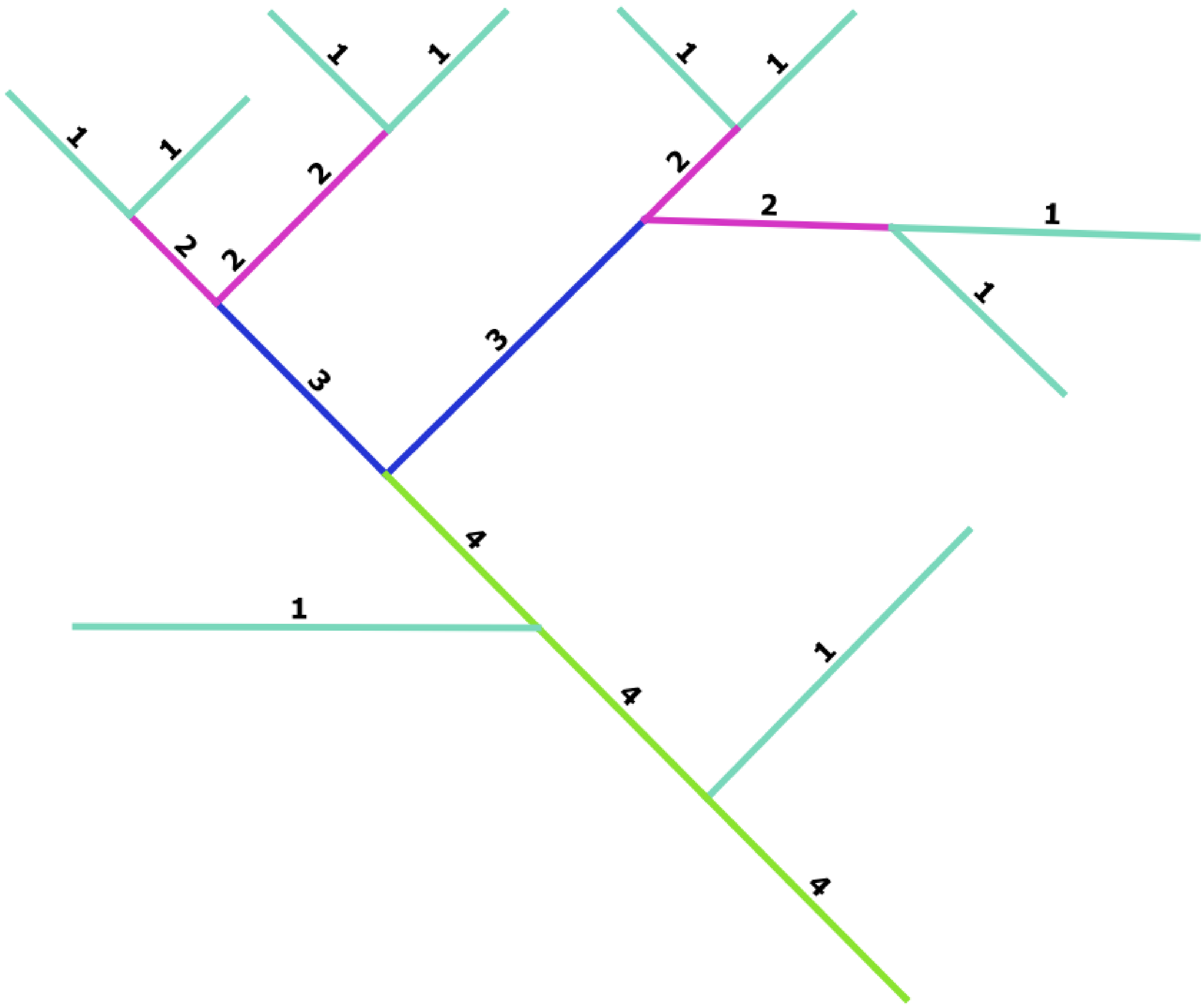


Figure 20. Strahler Stream Ordering

In Figure 20, the number 1 stands for the First-order, which represents the smallest and most numerous streams in the river network, in this case the lateral lines in the tile network. When two first-order streams merge, they form a Second-order, which is represented by the number 2. Order 2 and above refers to the sub-mains in the tile network layout. As a principle, when two streams of the same order converge, they create a higher stream order. However, when two streams of different orders converge, the stream order remains the same as the higher stream order. This same pattern continues until the last order (e.g., Fourth-Order) for the Main is determined in the network. This Strahler Stream Order is exemplified in Figure 22b.

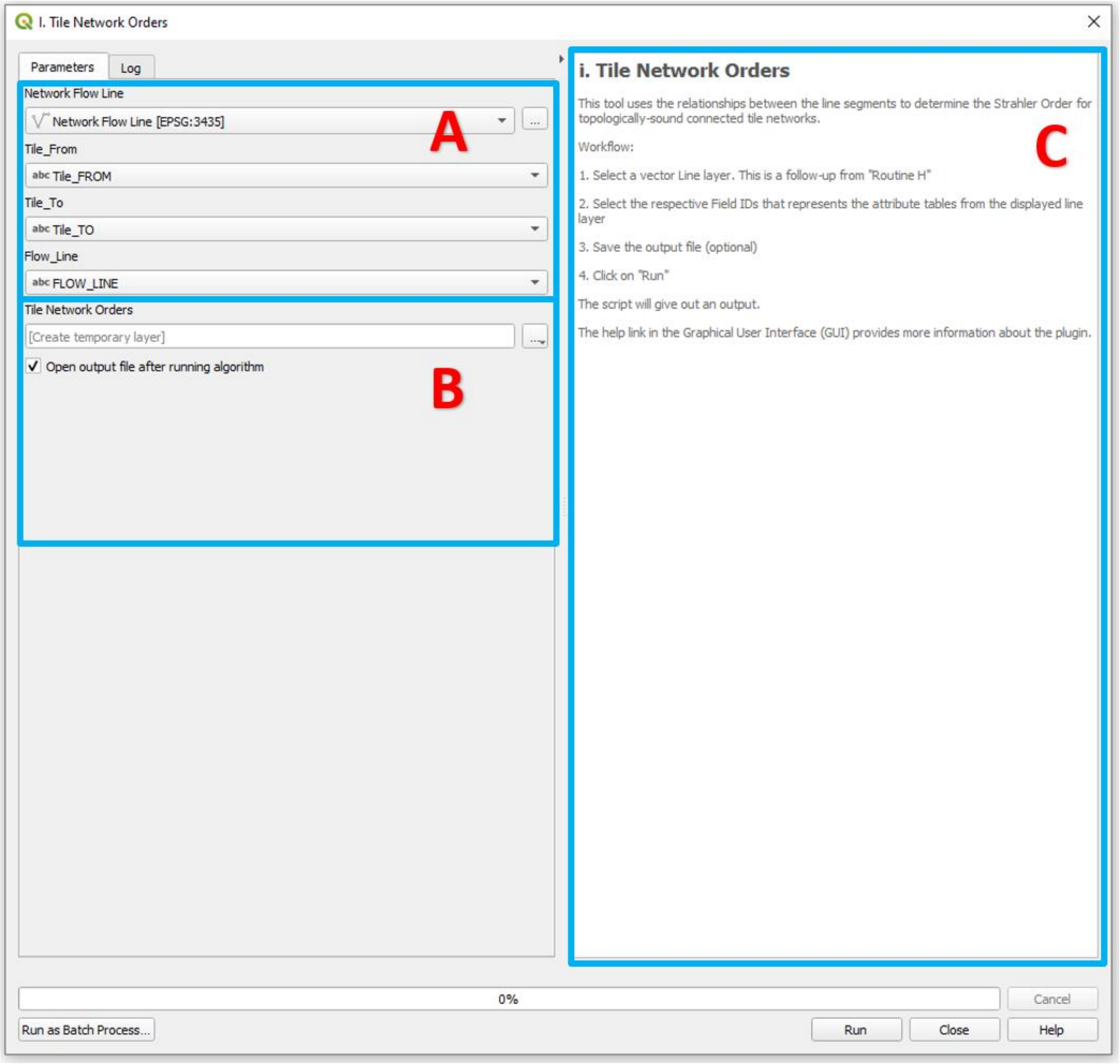
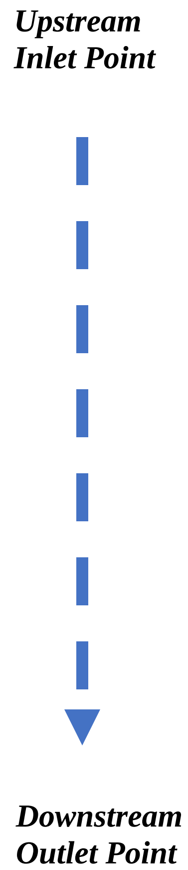
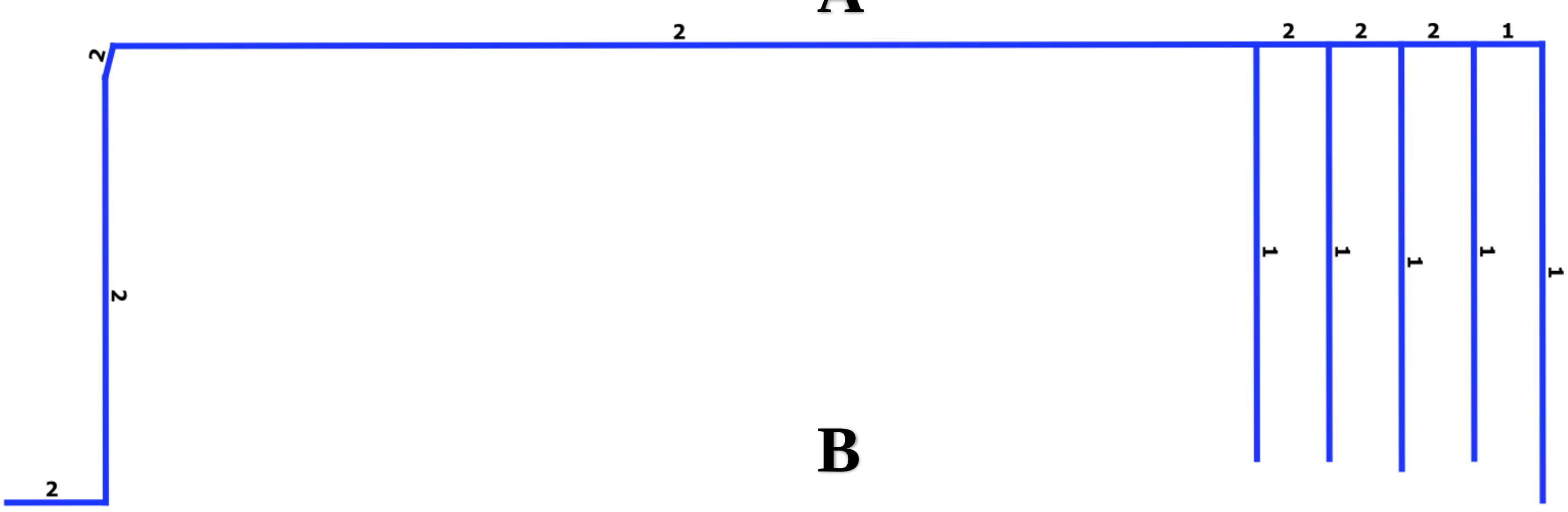


Figure 21. Graphical User Interface of the "Tile Network Orders" Routine

TILE_ID	TILE_TO	TILE_FROM	FLOW_LINE	TILE_FLOW	FLOW_ORDER	TILE_ORDER
8	6	8	3	1	1	1
7	4	7	2	2	2	1
6	4	6	13	3	2	1
5	2	5	1	4	1	1
4	2	4	12	5	2	2
3	13	3	9	6	2	1
2	13	2	11	7	2	2
13	12	13	8	8	1	2
1	12	1	10	9	2	1
12	9	12	7	10	1	2
9	11	9	4	11	2	2
11	10	11	6	12	1	2
10	Out	10	5	13	1	2



A



B

Figure 22. Flow according to the layout Tile Order: Attribute table (A) and Screen Display (B)

j. End Point Elevations:

The **End Point Elevations** routine, with interface shown in Figure 23 drapes a DEM over the tile network, to add four additional fields in the attribute table for the tile network. The four fields are the starting and ending endpoint elevations, the true length, and the slope of each line segment (Figure 24).

Input Data Requirements:

a. Select the Original Raster DEM (LiDAR) Layer (e.g., 4 x 4-pixel size)
b. Select a Line Vector Shapefile Layer (e.g., Topologically-sound Tile Network Orders Line data)
c. Specify the Multiplying Factor Value for the Line Segments (Note: Default value can be left)

Output Datafiles (Optional):

a. New Line Vector Shapefile Layer (e.g., Line data)

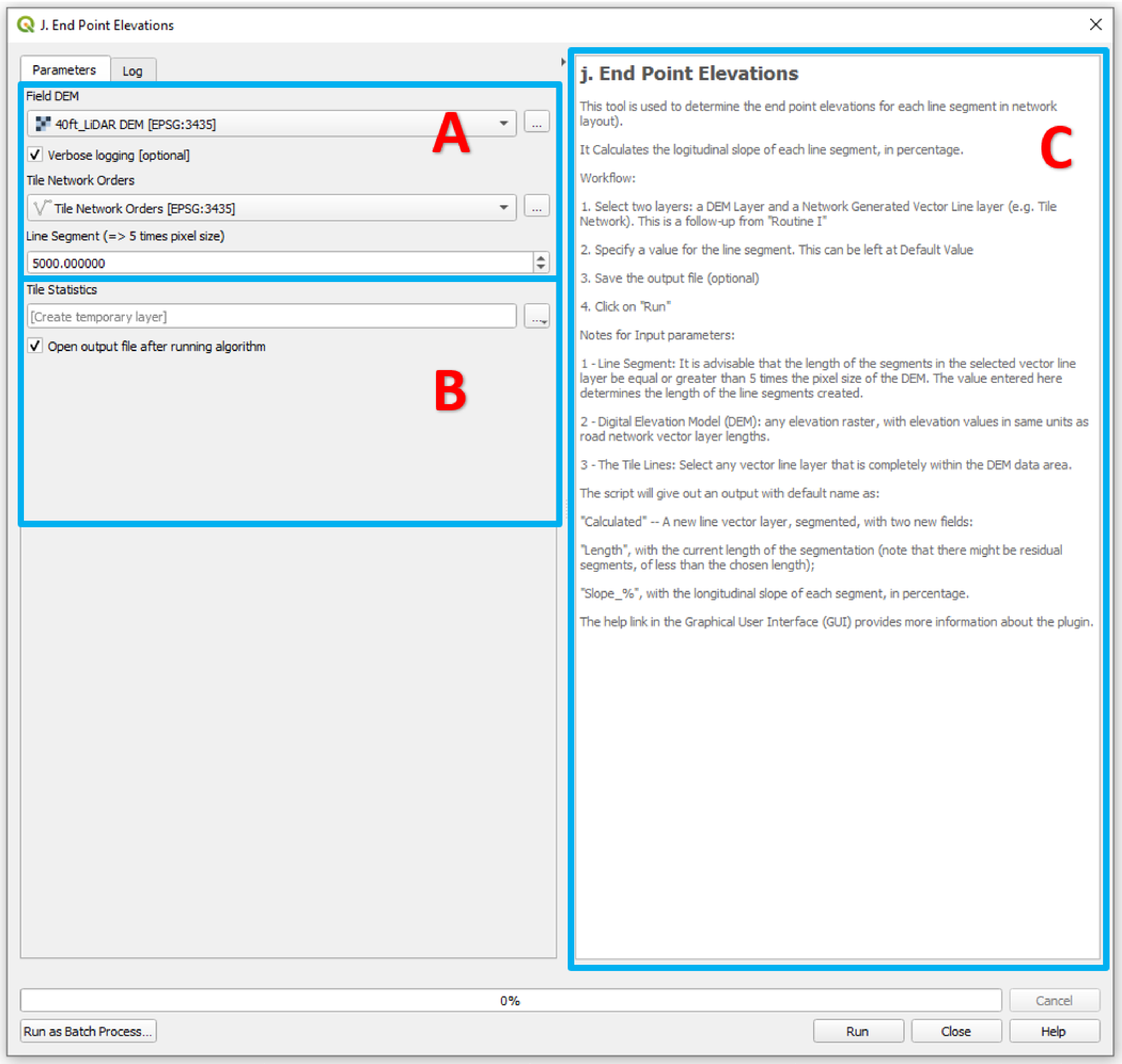


Figure 23. Graphical User Interface of the “End Point Elevations” Routine

Elev_first	Elev_last	LENGTH	Seg_Slope
692.0083618200	694.0092163100	142.8766218800	0.014
694.0092163100	696.9258422900	138.5440168200	0.0211
694.0092163100	705.2492065400	742.4822643700	0.0151
696.9258422900	706.1771850600	730.4726272100	0.0127
696.9258422900	700.4616088900	142.8773866900	0.0247
696.1458740200	699.2117309600	143.0582213900	0.0214
696.1458740200	707.2774658200	503.1237499400	0.0221
700.4616088900	702.6737060500	142.8758656900	0.0155
700.4616088900	707.2675170900	651.0281864700	0.0105
699.2117309600	707.9921875000	374.3810990300	0.0235
699.2117309600	701.2834472700	138.7231237700	0.0149
701.2834472700	702.4991455100	140.8906725800	0.00863
702.4991455100	705.7767944300	106.1574384500	0.0309
701.2834472700	707.4672241200	250.2349434200	0.0247
702.6737060500	704.0334472700	140.7098671500	0.00966
702.6737060500	707.0338745100	557.7922450100	0.00782
689.6454467800	690.8399047900	103.0920615300	0.0116
704.0334472700	707.1461181600	456.8924040600	0.00681
690.8399047900	692.0083618200	101.1574384500	0.0116
704.0334472700	704.4528198200	140.7122925500	0.00298

Figure 24. Attribute Table from after running the End Point Elevation Routine

k. Network Flow Lengths:

The routine, **Network Flow Lengths,** with interface shown in Figure 25, was developed to determine the cumulative flow lengths for all connected adjoining line segments, upstream to downstream, of the network in the tile layout. It adds an additional field called FLOW_LENGTH, in the attribute table for the tile network (Figure 26).

Input Data Requirements:

a. Select a Line Vector Shapefile Layer (e.g., Topologically-sound Tile Network Statistics Line data)
b. Select the named Fields (“LENGTH”, “TILE_ID”, “TILE_TO”, & “TILE_FROM”)

Output Datafiles (Optional):

a. New Line Vector Shapefile Layer (e.g., Line data)

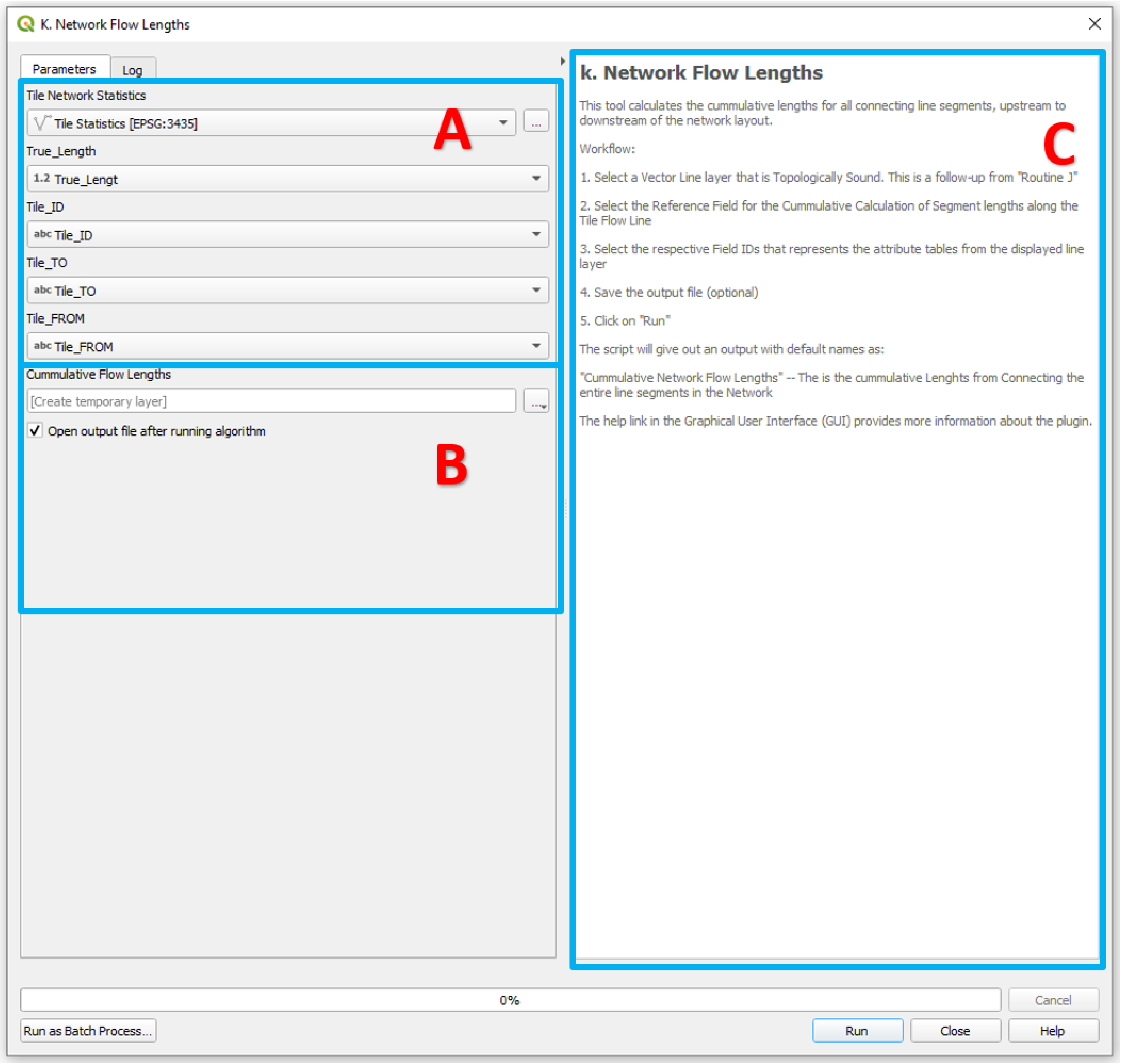


Figure 25. Graphical User Interface of the "Network Flow Lengths" Routine

Elev_first	Elev_last	LENGTH	Seg_Slope	FLOW_LENGTH
692.00836182	694.00921631	142.87662188	0.014004071930...	4349.3801894
694.00921631	696.92584229	138.54401682	0.021051980785...	3464.02130315
694.00921631	705.24920654	742.48226437	0.015138395581...	742.48226437
696.92584229	706.17718506	730.47262721	0.012664872611...	730.47262721
696.92584229	700.46160889	142.87738669	0.024746859401...	2595.00465912
696.14587402	699.21173096	143.05822139	0.021430833615...	1153.445498639...
696.14587402	707.27746582	503.12374994	0.022124957927...	503.12374994
700.46160889	702.67370605	142.87586569	0.015482650966...	1801.099085960...
700.46160889	707.26751709	651.02818647	0.010454091453...	651.02818647
699.21173096	707.9921875	374.38109903	0.023453258091...	374.38109903
699.21173096	701.28344727	138.72312377	0.014934181509...	636.00617822
701.28344727	702.49914551	140.89067258	0.008628663755...	247.04811103
702.49914551	705.77679443	106.15743845	0.030875358032...	106.15743845
701.28344727	707.46722412	250.23494342	0.024711883822...	250.23494342
702.67370605	704.03344727	140.70986715	0.009663439014...	1100.430975260...
702.67370605	707.03387451	557.79224501	0.007816832340...	557.79224501
689.64544678	690.83990479	103.09206153	0.011586323837...	13392.15757497...
704.03344727	707.14611816	456.89240406	0.006812700019...	456.89240406
690.83990479	692.00836182	101.15743845	0.011550876019...	6307.889064869...
704.03344727	704.45281982	140.71229255	0.002980354753...	502.8287040500...

Figure 26. Attribute Table from after running the Network Flow Lengths Routine

I. Network Elevation Exports:

The routine, **Network Elevation Points,** with interface shown in Figure 27, was developed to generate elevation points for each line segment of the tile network. The outputs from this routine as shown in Figure 28 are used by the **Tile Burying System** and the **Network Pipe Sizing** routines.

Input Data Requirements:

a. Select the Original Raster DEM (LiDAR) Layer (e.g., 4 x 4-pixel size)
b. Select a Line Vector Shapefile Layer (e.g., Topologically-sound Tile Cumulative flow Lengths Line data)
c. Select the named Field: “TILE_ID.”
d. Select Targeted CRS (Coordinate Reference System)

Output Datafiles (Optional):

a. New Line Vector Shapefile Layer (e.g., Line data)
b. Two New Node Vector Shapefile Layers (e.g., Point datasets)
c. New CSV Spreadsheet Files into a Folder

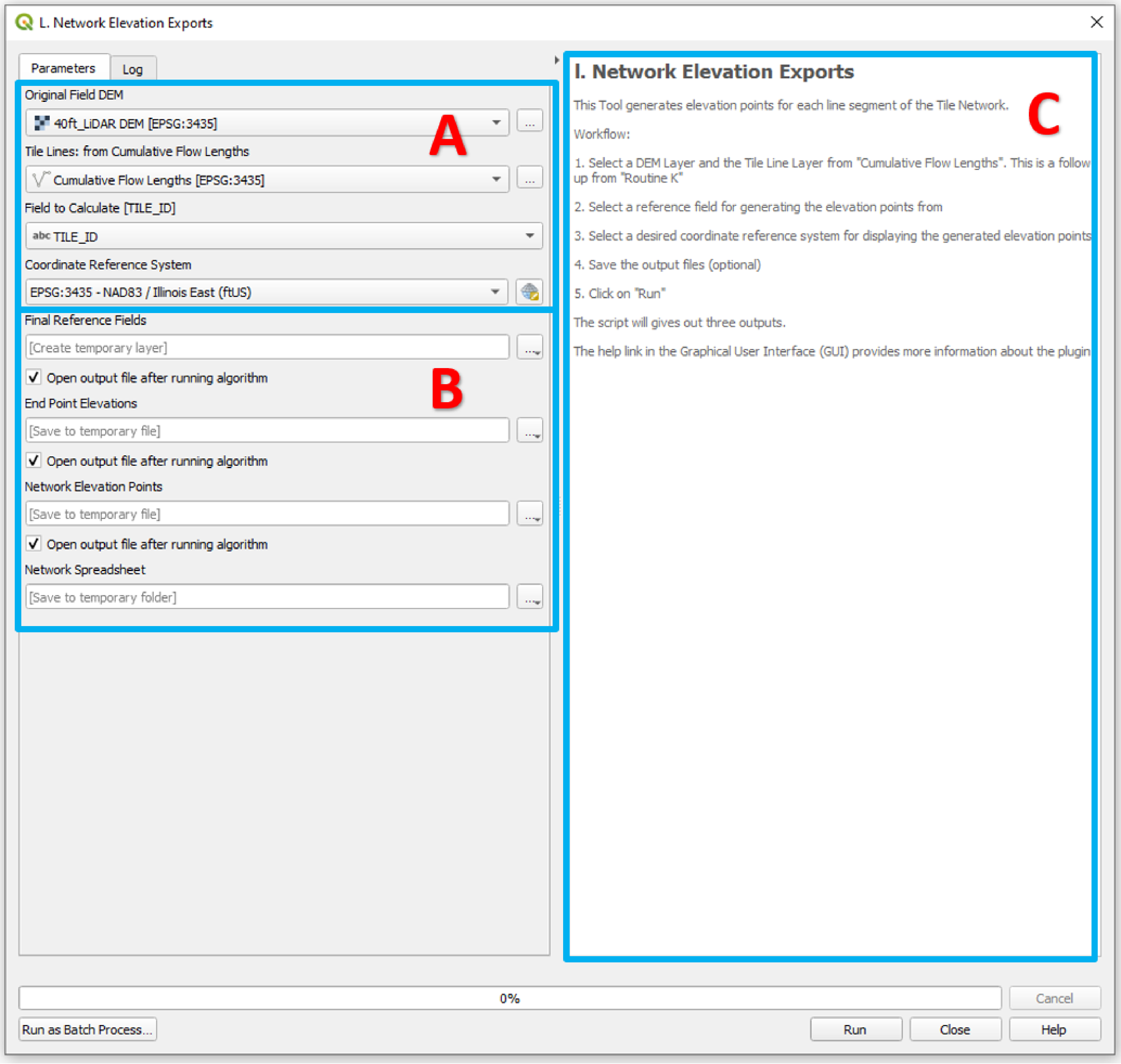


Figure 27. Graphical User Interface of the "Network Elevation Exports" Routine

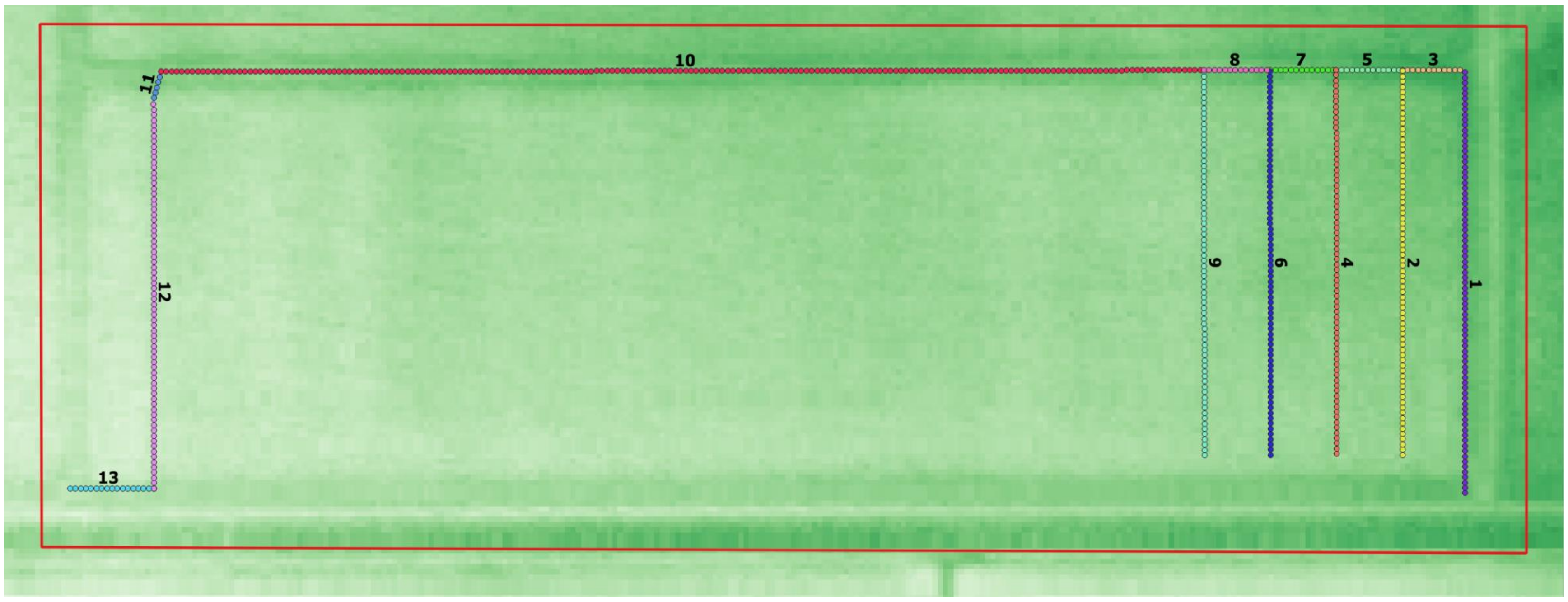


Figure 28. Results from after running the Network Elevation Exports Routine

m. Tile Burying System:

A new routine, **Tile Burying System [TBS]**, was developed for subsurface drainage systems to bury a distribution of tile networks. The routine has minimal input requirements; a line layer of tile network with its routing fields, and the specification of maximum and minimum required buried depths and slopes (Figure 29). The output includes fields for the buried elevations, slope points, and buried depths of points along the main(s) and laterals, in the attribute table for the tile network (Figure 30). Also, a significant part of the tool is highlighted in B, an optional input parameter section for the field terrain. The default option is left unchecked as most fields have some measure of steepness. When checked, the tool determines the tile elevation buried depth for fields with flat terrains. The routine is intended for use for both simple and complex systems by inexperienced designers or do-it-yourself producers.

Input Data Requirements:

a. Select a Line Vector Shapefile Layer (e.g., Topologically-sound Tile Network with Referenced Fields Line data)
b. Select the named Fields (“BURY_ORDER”, “LENGTH”, “Elev_first”, & “Elev_last”)
c. Specify the Burying Parameters (Note: Default value can be left)
d. Decide on Constant Slope based on Field Topography (Optional)

Output Datafiles (Optional):

a. New Line Vector Shapefile Layer (e.g., Line data)

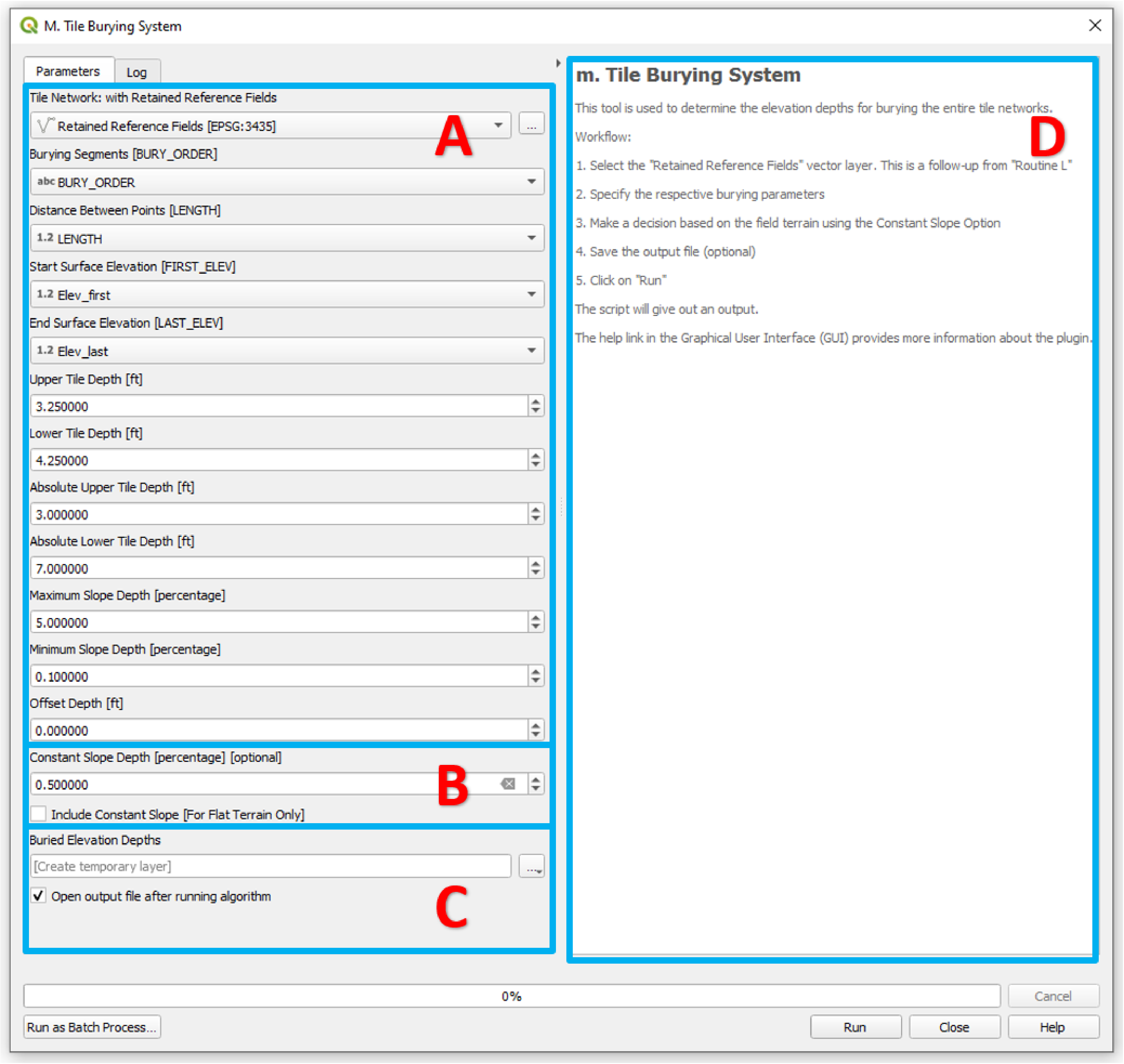


Figure 29. Graphical User Interface of the “Tile Burying System” Routine

Figures 30 and 31 show the attribute tables and the corresponding screen display illustrating the different outputs after running the *Tile Burying System* [TBS] tool. The two Figures (30 and 31) compare the values of the elevation depths, for different field terrain as indicated with whether a constant slope is applied when burying or not. When buried with a constant slope, the tile layout follows a relatively straight line as shown in Figure 30 but follows the shape of the terrain when applied without a constant slope as shown in Figure 31.

Elev_first	Elev_last	ElevDepth1	BuryDepth1	ElevDepth2	BuryDepth2	InSlope
689.6454	690.84	685.89545	3.75	687.0899	3.75	0.0116
690.8399	692.008	687.0899	3.75	692.51415	0.50578719	0.005
690.8399	690.975	687.0899	3.75	691.4787	0.50323945	0.005
691.0134	690.84	691.51212	0.49875071	687.0899	3.75	0.005
692.0084	694.009	692.51415	0.50578719	694.7236	0.71438311	0.005
692.0084	696.146	692.51415	0.50578719	697.14978	1.00391094	0.005
690.9755	691.005	691.4787	0.50323945	691.51652	0.51108683	0.005
690.9755	693.278	691.4787	0.50323945	694.00513	0.72711843	0.005
691.3951	691.013	691.90104	0.50589732	691.51212	0.49875071	0.005
691.0134	696.28	691.51212	0.49875071	697.63288	1.35278519	0.005
694.0092	696.926	694.7236	0.71438311	697.61856	0.69272008	0.005
694.0092	705.249	694.7236	0.71438311	708.96162	3.71241132	0.005
696.1459	699.212	697.14978	1.00391094	699.92702	0.71529111	0.005
696.1459	707.277	697.14978	1.00391094	709.79308	2.51561875	0.005
691.0054	692.152	691.51652	0.51108683	692.65503	0.50329167	0.005
691.0054	696.175	691.51652	0.51108683	697.30427	1.12915615	0.005
691.3951	699.642	691.90104	0.50589732	701.43177	1.78961828	0.005
691.9793	691.395	692.47747	0.49815789	691.90104	0.50589732	0.005
696.9258	706.177	697.61856	0.69272008	709.82955	3.65236314	0.005
696.9258	700.462	697.61856	0.69272008	701.176	0.71438693	0.005
699.2117	707.992	699.92702	0.71529111	709.86409	1.8719055	0.005
699.2117	701.283	699.92702	0.71529111	701.97706	0.69361562	0.005
692.1517	700.424	692.65503	0.50329167	702.02491	1.60132145	0.005
692.1517	693.438	692.65503	0.50329167	693.94951	0.51103462	0.005
691.9793	700.239	692.47747	0.49815789	702.53411	2.29540167	0.005

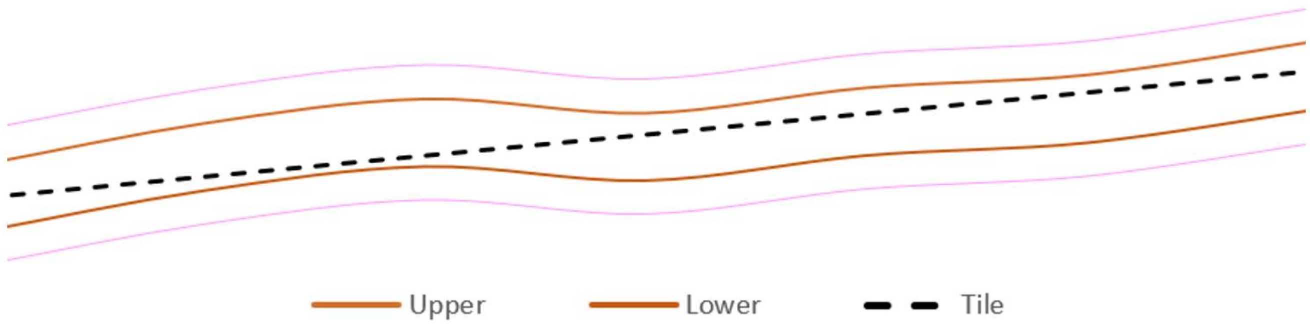


Figure 30. Attribute Table showing the Elevation Depths buried at Constant Slope

Elev_first	Elev_last	ElevDepth1	BuryDepth1	ElevDepth2	BuryDepth2	InSlope
689.645	690.84	685.89545	3.75	687.0899	3.75	0.01159
690.84	692.008	687.0899	3.75	688.25836	3.75	0.01155
690.84	690.975	687.0899	3.75	687.22546	3.75	0.00135
691.013	690.84	687.26337	3.75	687.0899	3.75	0.00174
692.008	694.009	688.25836	3.75	690.25922	3.75	0.014
692.008	696.146	688.25836	3.75	692.39587	3.75	0.02061
690.975	691.005	687.22546	3.75	691.10765	0.1022174	0.001
690.975	693.278	687.22546	3.75	689.52802	3.75	0.01583
691.395	691.013	687.64514	3.75	687.26337	3.75	0.00377
691.013	696.28	687.26337	3.75	692.53009	3.75	0.01947
694.009	696.926	690.25922	3.75	693.17584	3.75	0.02105
694.009	705.249	690.25922	3.75	701.49921	3.75	0.01514
696.146	699.212	692.39587	3.75	695.46173	3.75	0.02143
696.146	707.277	692.39587	3.75	703.52747	3.75	0.02212
691.005	692.152	691.10765	0.1022174	692.25239	0.1006583	0.001
691.005	696.175	691.10765	0.1022174	692.42511	3.75	0.00583
691.395	699.642	687.64514	3.75	695.89215	3.75	0.02304
691.979	691.395	688.22931	3.75	687.64514	3.75	0.00586
696.926	706.177	693.17584	3.75	702.42719	3.75	0.01266
696.926	700.462	693.17584	3.75	696.71161	3.75	0.02475
699.212	707.992	695.46173	3.75	704.24219	3.75	0.02345
699.212	701.283	695.46173	3.75	697.53345	3.75	0.01493
692.152	700.424	692.25239	0.1006583	696.67358	3.75	0.0138
692.152	693.438	692.25239	0.1006583	693.54068	0.1022069	0.001
691.979	700.239	688.22931	3.75	696.48871	3.75	0.01799

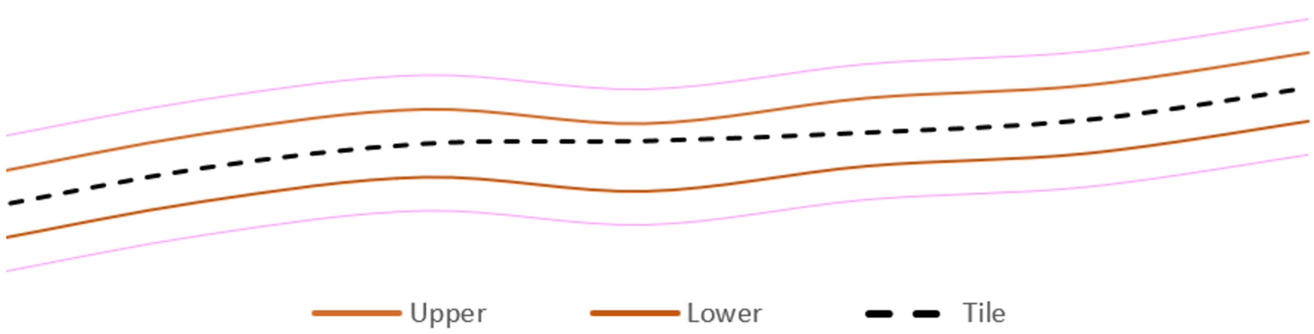


Figure 31. Attribute Table showing the Elevation Depths buried without Constant Slope

n. Network Pipe Sizing:

The **Network Pipe Sizing** routine, with interface shown in Figure 32 was developed for estimating the pipe sizes for a tile network layout. The routine relies on the Tile Order, Cumulative Flow Length, and the Burying Slope (Inslope) for each line segment, for determining the pipe size. The output includes fields for the actual and nominal pipe sizes for each line segment in the attribute table of the tile network layout (Figure 34).

Input Data Requirements:

a. Select a Line Vector Shapefile Layer (e.g., Topologically-sound Buried Elevation Depths Line data)
b. Select the named Fields (“Tile_ID”, “TILE_TO”, “TILE_ORDER”, “FLOW_LENGTHS”, & “InSlope”)
c. Specify the Drain Spacing and Type of Pipe Material
d. Specify the Drainage Intensity
e. Decide on How to Assign Value for the Drainage Coefficient: By System Assigned (A) By Line Segments, or (C) By Orders)

Output Datafiles (Optional):

a. New Line Vector Shapefile Layer (e.g., Line data)

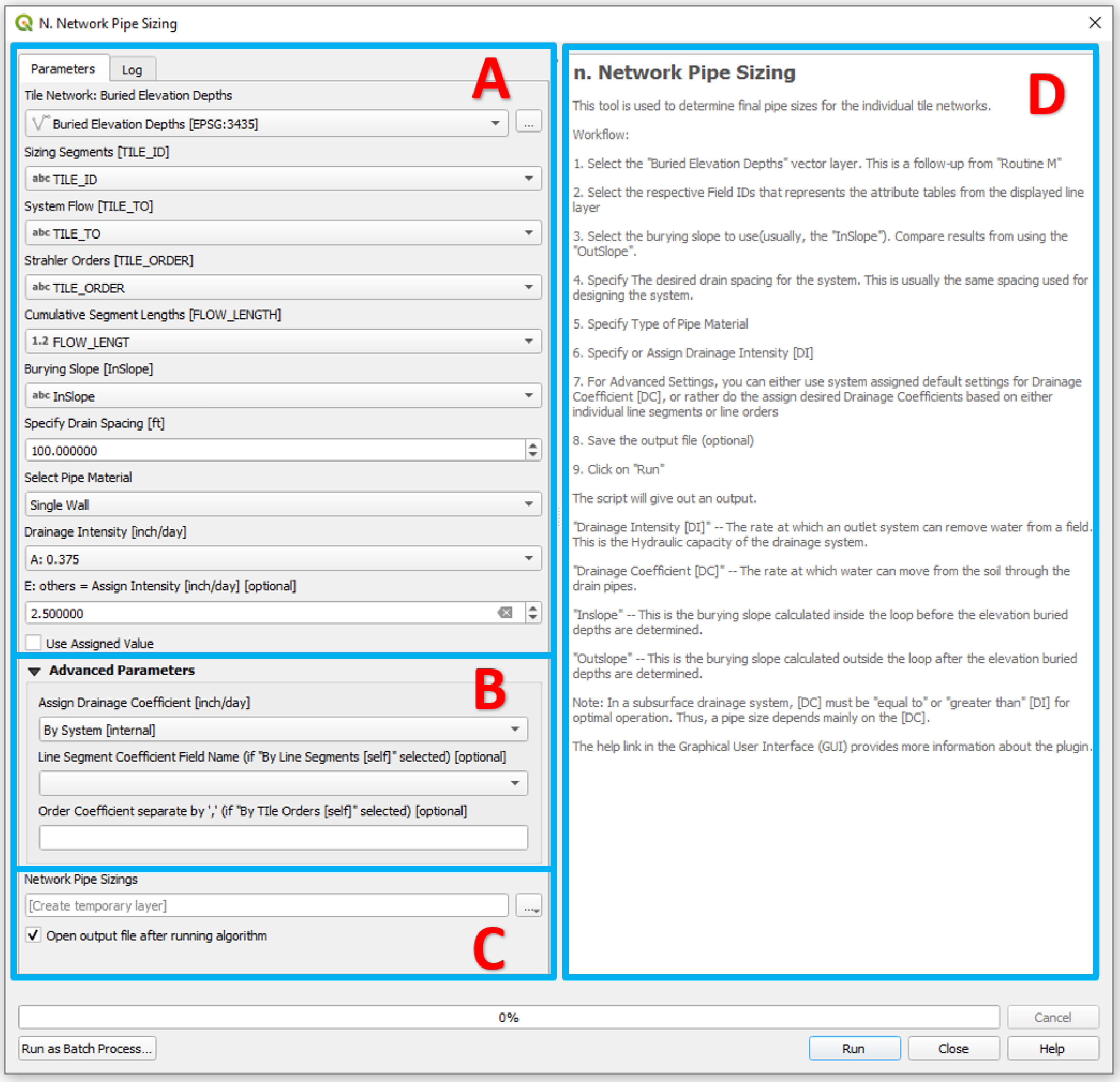


Figure 32. Graphical User Interface of the "Network Pipe Sizing" Routine

Figure 33 shows the other two options by which the Drainage Coefficient (DC) value can be determined and assigned. These two options require more painstaking efforts to assign the values by self. These advanced options by Routine P are for experienced designers and contractors.

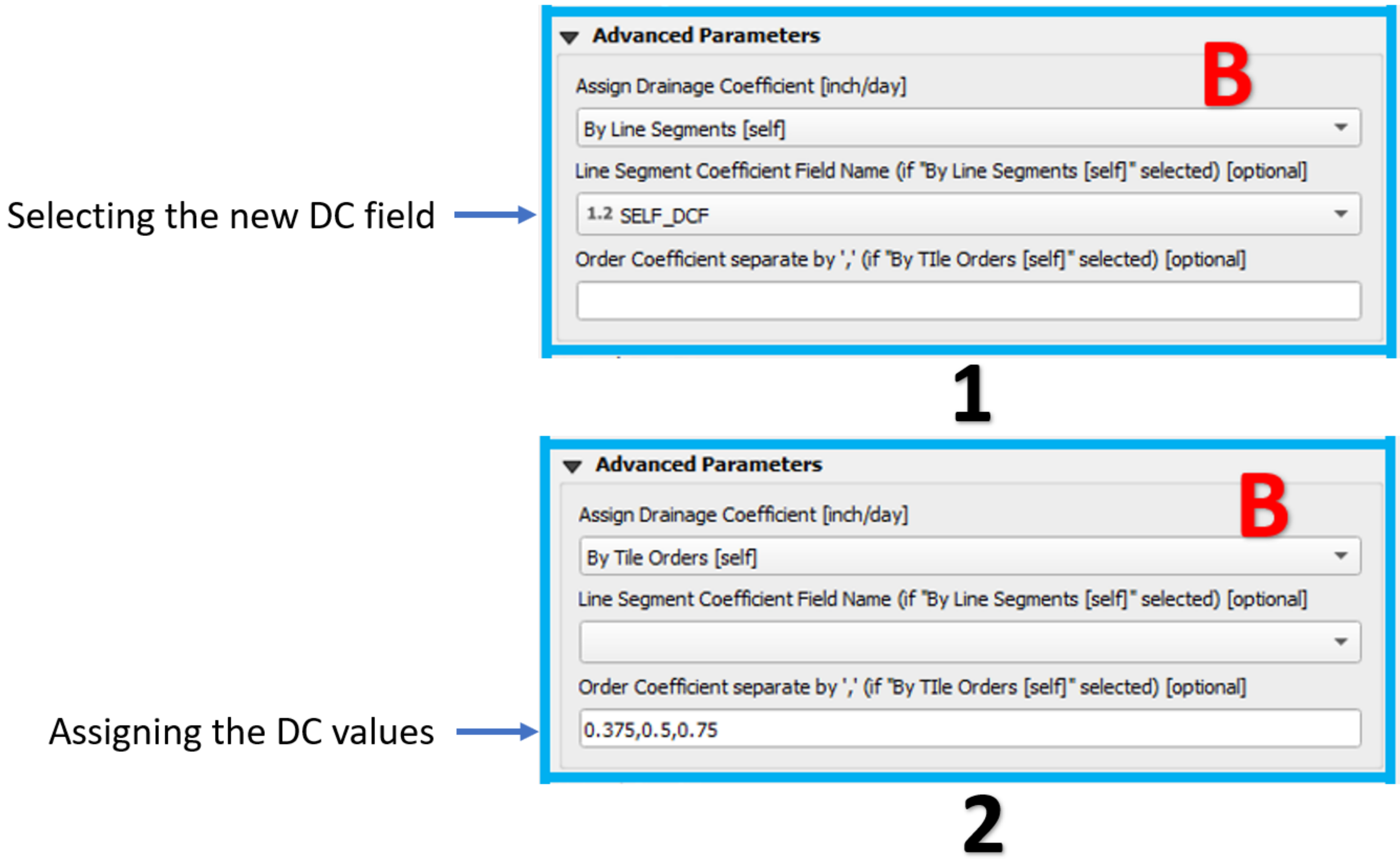
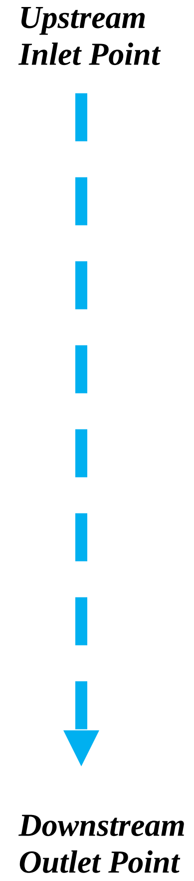


Figure 33. Advanced options for self-assigned DC values: (1) By Line Segments (2) By Tile Segment Orders

InSlope	OutSlope	D_COEFF	SYSTEM_FLOW	ACTUAL_SIZE	NOMINAL
0.004686798633...	0.001	0.46875	0.693023487271...	7.890362783700...	8
0.005	0.001	0.46875	0.563228996650...	7.212001287510...	8
0.005	0.001	0.46875	0.436444328674...	6.554238473428...	8
0.005	0.001	0.46875	0.323000114616...	5.854636314496...	6
0.005	0.001	0.375	0.010589808025...	1.625106963490...	4
0.005	0.010589040562...	0.46875	0.199986164567...	4.891295493973...	5
0.005	0.001	0.375	0.010589784386...	1.625105603150...	4
0.005	0.001	0.46875	0.126145893608...	4.115061570855...	5
0.005	0.001	0.375	0.010589757073...	1.625104031357...	4
0.005	0.001	0.46875	0.067820146153...	3.26068194754029	4
0.005	0.001	0.375	0.010589726077...	1.625102247587...	4
0.005	0.001	0.375	0.025009102688...	2.243033240905...	4
0.005	0.003082398511...	0.375	0.011643753981...	1.683967871489...	4



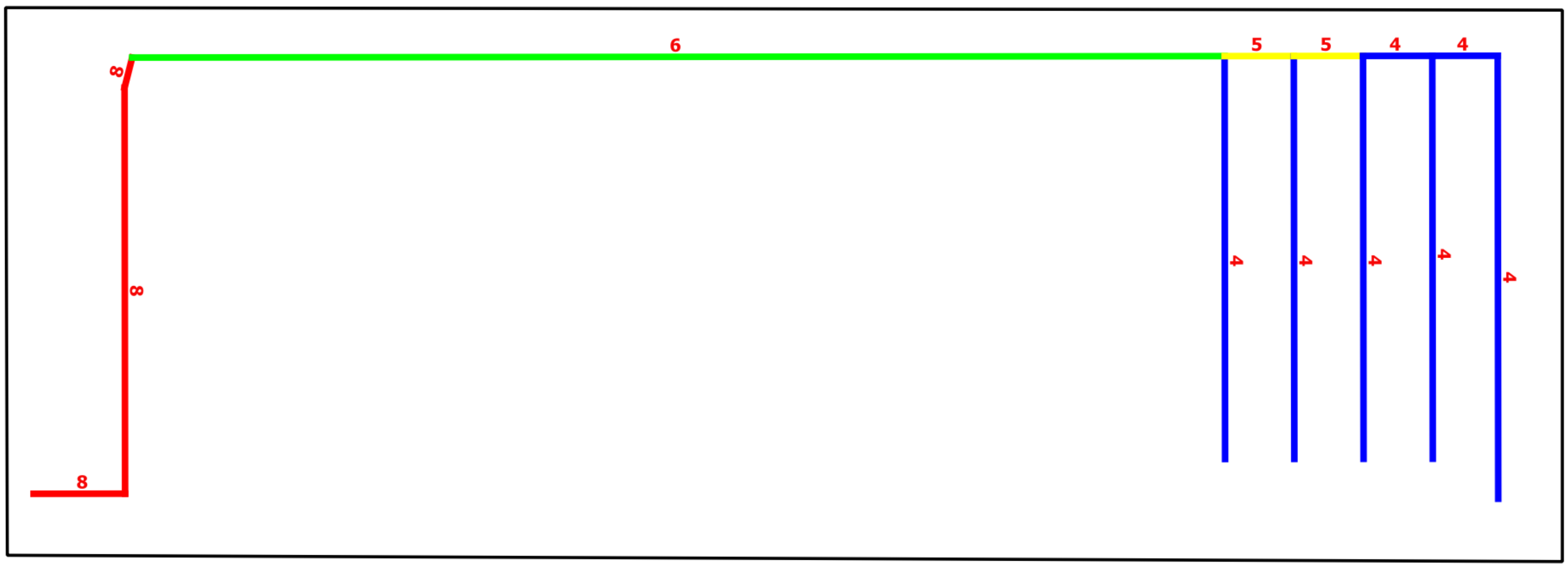


Figure 34. Layout pipe sizes from after running the Network Pipe Sizing

o. Sized Pipe Estimations:

This new routine, **Sized Pipe Estimations**, with interface shown in Figure 35 was developed as a tool for generating possible pipe prices for the different sizes determined using their frequencies and total lengths. The tool also renders the vector line layer into different sized pipes and then estimates the cost based on the values in Figure 36. The estimations are done simultaneously across the entire drainage network for all four (4) types of pipe materials featured in the **Network Pipe Sizing** tool, namely: Single-Wall, Smooth-Wall, Clay-Wall, and Concrete-Wall. Figure 37 shows the attribute table after running the *Sized Pipe Estimations* tool. These estimations give insight on the possible economic implications of using different pipe material types. This tool is sequel to the **Network Pipe Sizing** tool since it uses its output as input layer.

Input Data Requirements:

a. Select a Line Vector Shapefile Layer (e.g., Topologically-sound Buried Elevation Depths Line data)
b. Select the named Fields (“NOMINAL_SIZE” & “LENGTH”)

Output Datafiles (Optional):

b. New Line Vector Shapefile Layer (e.g., Line data)

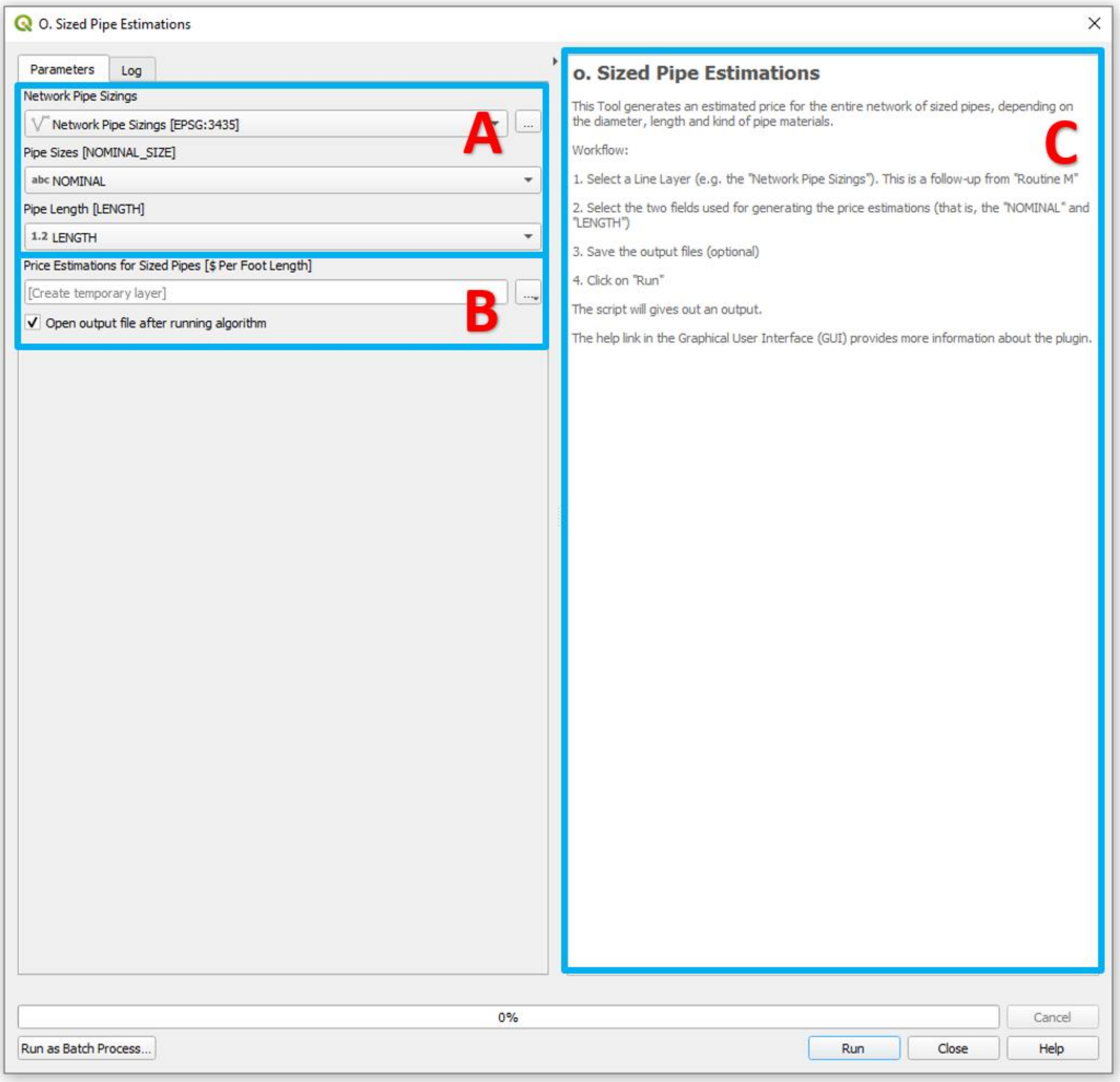


Figure 35. Graphical User Interface of the "Sized Pipe Estimations" Routine

Nominal Pipe Sizes	Pipe Types with Prices per Linear Foot [$]			
	Single-Wall	Smooth-Wall	Clay-Wall	Concrete-Wall
4	2	3	12	15
5	3	4	15	20
6	4	5	18	25
8	5	7	25	40
10	8	10	30	50
12	10	13	40	70
15	20	20	55	100
18	30	30	80	150
21	40	45	110	200
24	50	60	140	250
30	80	90	250	400
36	100	150	450	600
42	150	250	600	800

Figure 36. Estimated pipe prices Per Linear Foot

N_SIZES	FREQUENCY	TOTAL_FEET	SING_EST	SING_POSB	SMOT_EST	SMOT_POSB	CLAY_EST	CLAY_POSB	CONC_EST	CONC_POSB
8	3	384.20432	1921.02	1728.9194	2689.43	2420.48721	9605.11	8644.5972	15368.17	13831.355
6	1	794.85557	3179.42	2861.48	3974.278	3576.85006	14307.4	12876.66	19871.39	17884.25
5	2	100.74361	302.231	272.00776	402.9745	362.677008	1511.15	1360.0388	2014.872	1813.385
4	7	1591.043	3182.09	2863.8773	4773.129	4295.81599	19092.5	17183.264	23865.64	21479.08

Figure 37. Attribute table of result showing the possible estimated cost for all sized pipes distributed across the drainage network.

p. Tile Spreadsheet ReadOut:

This new routine, **Tile Spreadsheet ReadOut**, with interface shown in Figure 38 was developed as a tool for splitting a vector layer according to its unique ID and likewise exporting them to separate spreadsheet files (Figure 39). This routine is sequel to the **Tile Burying System** routine since it uses its output as input layer. The output from the **Tile Spreadsheet ReadOut** routine in the excel format can be transferred to a drain installation machine.

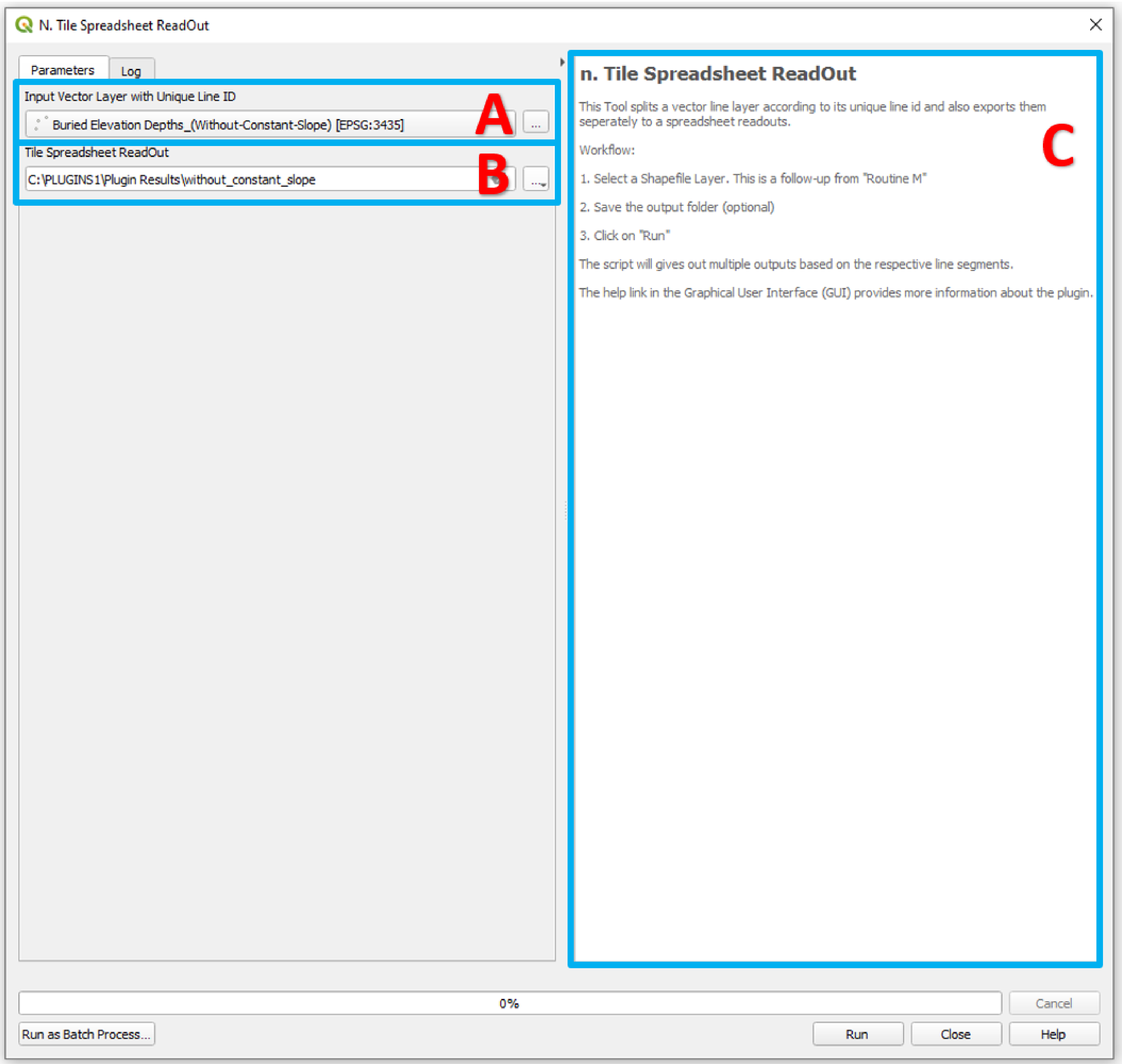


Figure 38. Graphical User Interface of the "Tile Spreadsheet ReadOut" Routine

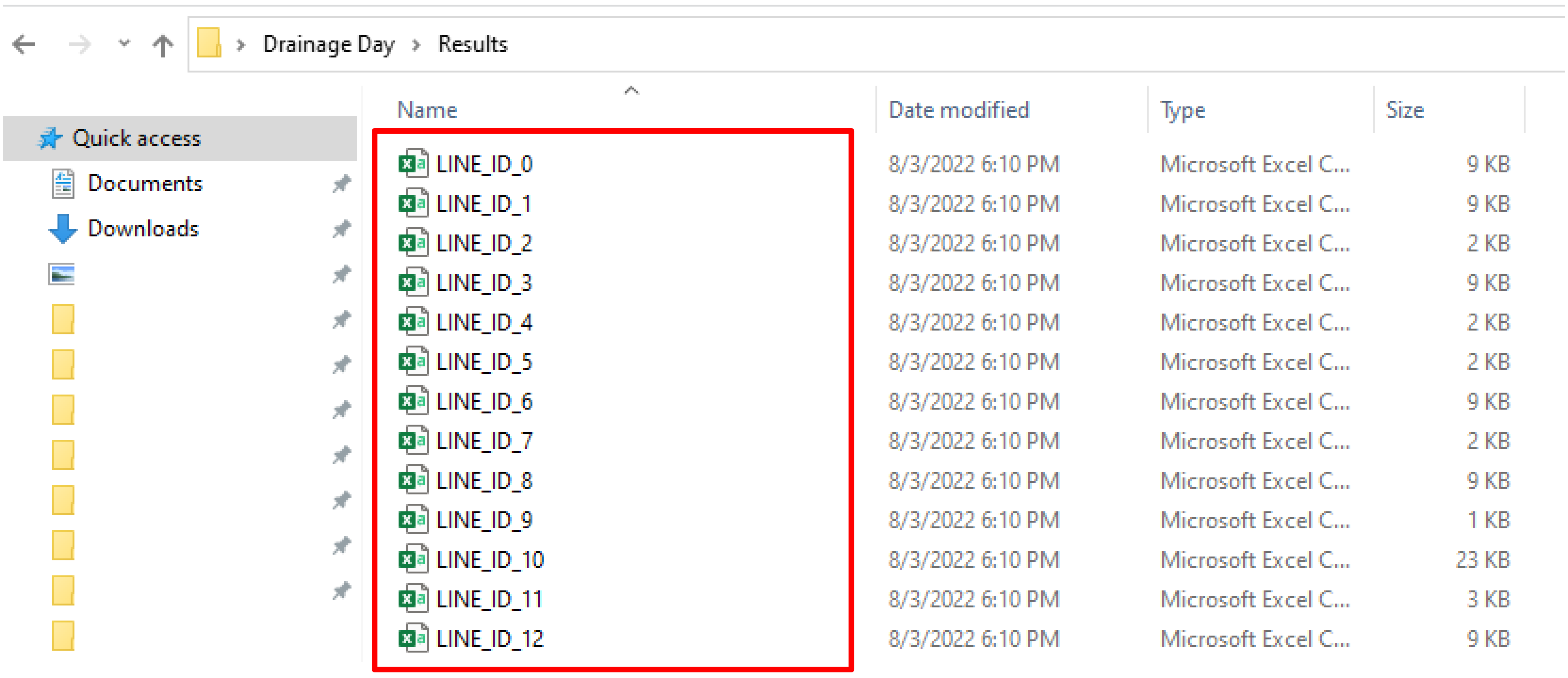


Figure 39. Folder Results from after running the Tile Spreadsheet ReadOut Routine