Hochschule für Technik Stuttgart
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Hochschule für Technik Stuttgart
University of Applied Sciences
Photogrammetry and Geoinformatics

Geographic Information System – GIS
GIS Practice
Hydrological Analysis for a Dam Construction Project
Pro. Dr. Dietrich Schröder

Presented by:
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1. Generation of DEM

For the generation and improvement of the DEM the following inputs from Topographic map 1:25000 from Linach Valley are used:

- Digitalized river
- Digitalized Height Points
- Contour lines

The resolution for the DEM is one of the main aspects to define. To establish the pixel, size the steepest part of the contour lines is cheeked, and the distance between two contour lines is measured. To guarantee that only one contour line is located in one pixel the resolution is selected of 5 meters.

The tool used to process all the inputs is Topo to Raster. The result is shown in Figure 1.

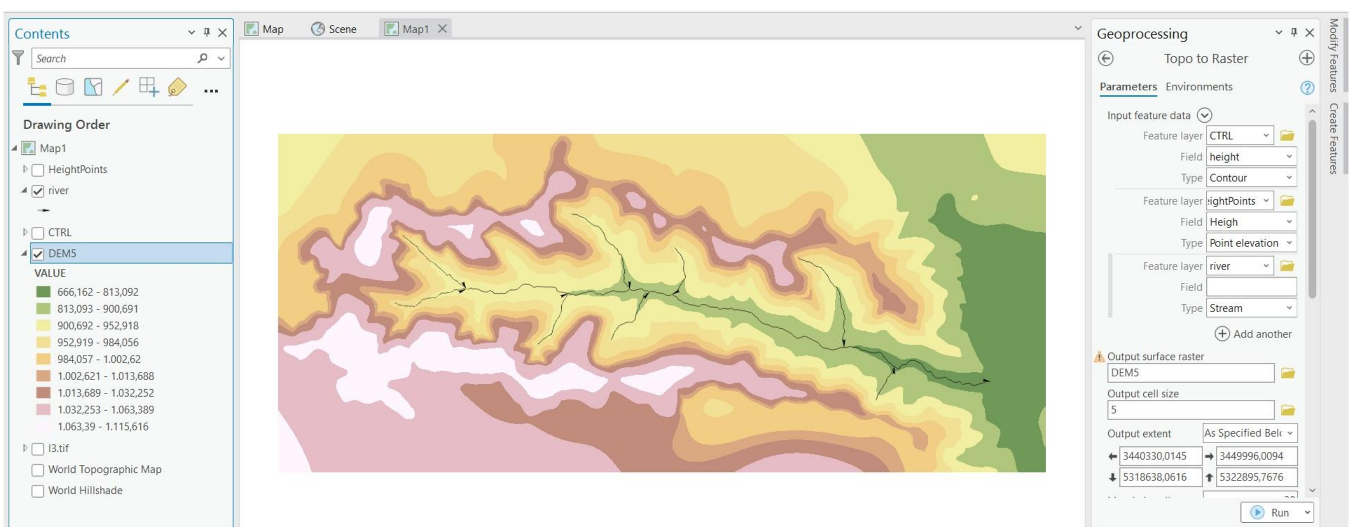

Figure 1. Creation of DEM with Topo to Raster tool.

2. Hydrological parameters

2.1. Creation of the watershed upstream from the outlet to the Breg river.

2.1.1. Fill

This tool is used to fill the depressions or artefacts of the DEM Figure 2. This is the input used to generate the next steps.

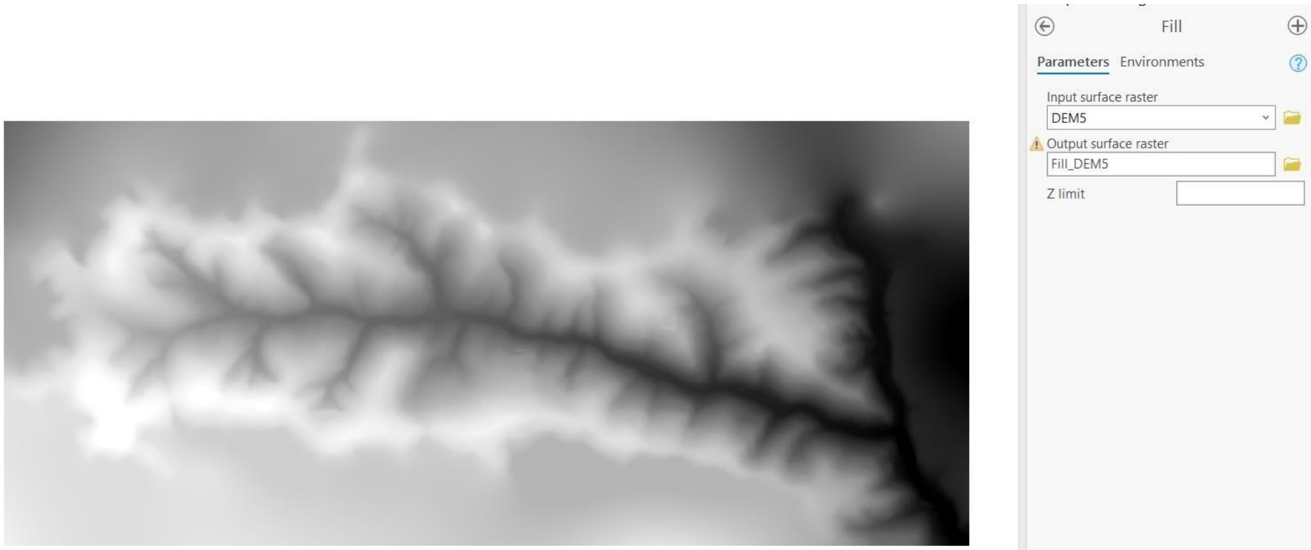

Figure 2. Filled DEM.

2.1.2. Calculate of filled height

With the Raster Calculator tool, the differences of height between the initial DEM and the Filled DEM are calculated. As result the higher difference is of near 98 meters (Figure 3), what according to the image and analysis of this, this corresponds to an artifact.

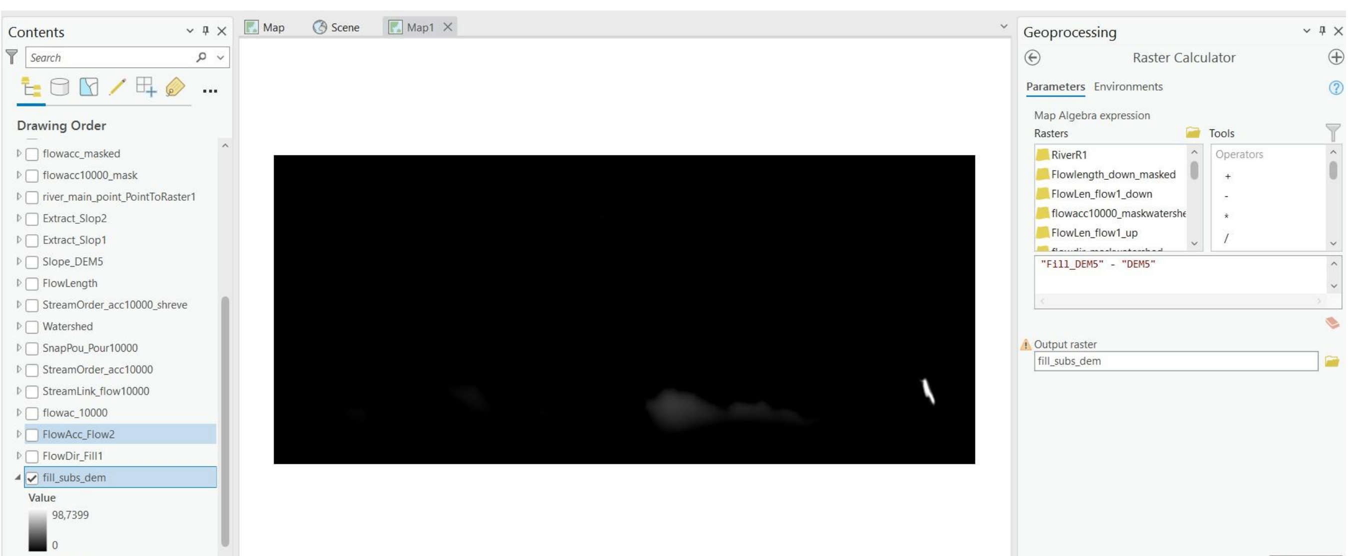

Figure 3. Differences of height between DEMs.

2.1.3. Flow Direction

Creates a raster of flow direction from each cell to its downslope neighbor (Figure 4). The method used is D8, which models the flow from each cell to its steepest downslope neighbor.

Figure 4. Flow Direction

2.1.4. Flow Accumulation

Creates a raster of accumulated flow into each cell. The accumulated flow is based on the number of total of cells flowing into each cell. The highest value is located in the outlet (Figure 5).

Figure 5. Flow Accumulation

2.1.5. Stream Network Extraction

This process is performed to show the set of cells through which surface water flows. According to the resolution and specific area, the value needs to be defined. This process generates a Boolean raster with the elements of the channel. In this case all the values bigger than 10000 were took into account (Figure 6).

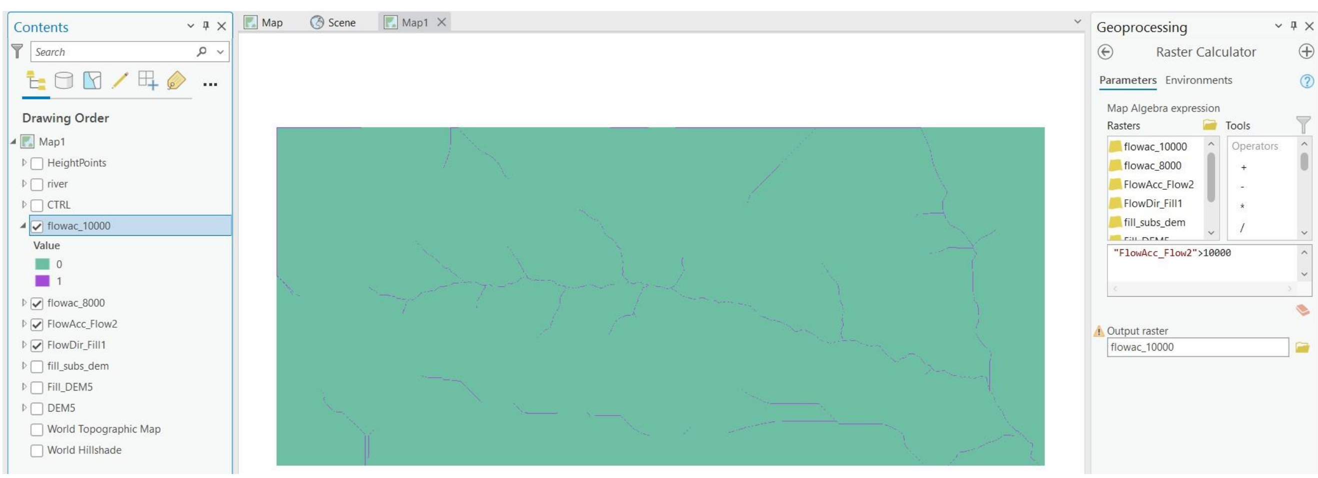

Figure 6. Stream Network Extraction with Raster Calculator.

2.1.6. Stream order

The method used for stream ordering was Strahler (Figure 7). With this option the stream order only increases when streams of the same order intersect.

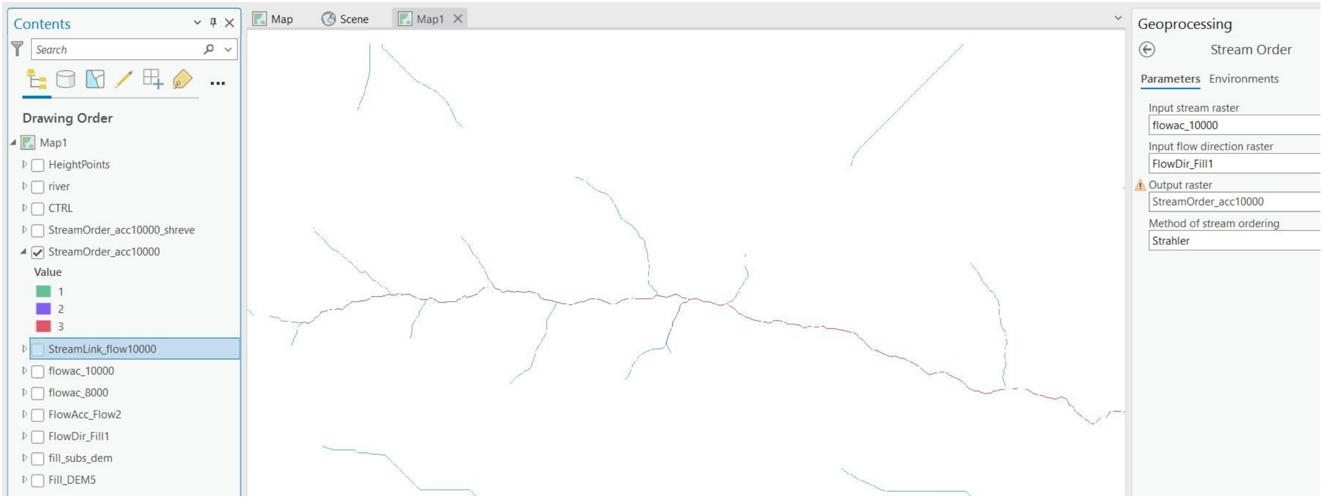

Figure 7. Stream order with Strahler method.

2.1.7. Vectorizing Stream

The product of this steps is the stream order obtained in the previous step in vector format (Figure 8).

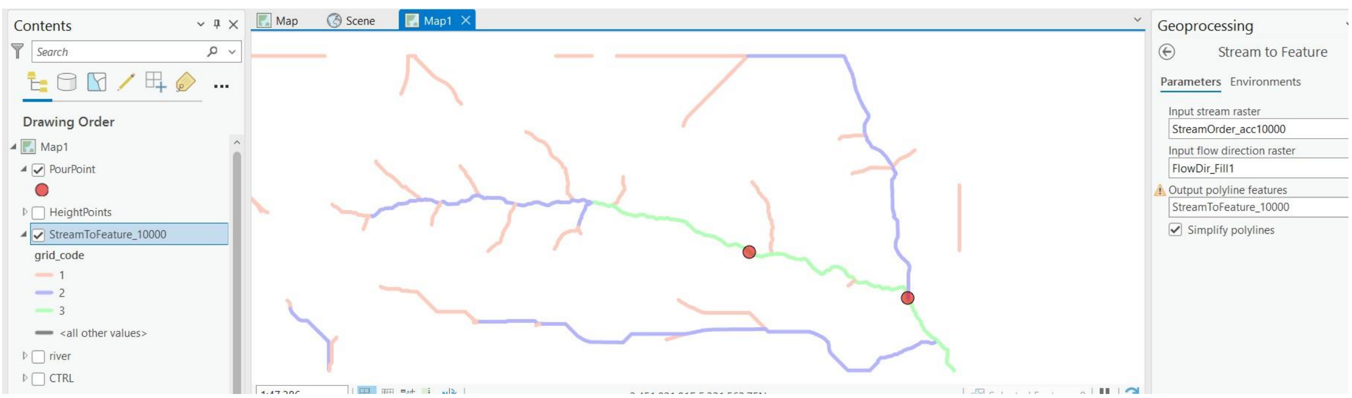

Figure 8. Stream vectorized.

2.1.8. Defining Pour Points

The Pour Points are created to indicate the starting point of the watershed delimitation. These needs to be located exactly on the accumulation raster, in the pixel with the highest value. In Figure 9 there are two Pour Points, one in the intersection with the Breg river, and another one in the free board of the Dam.

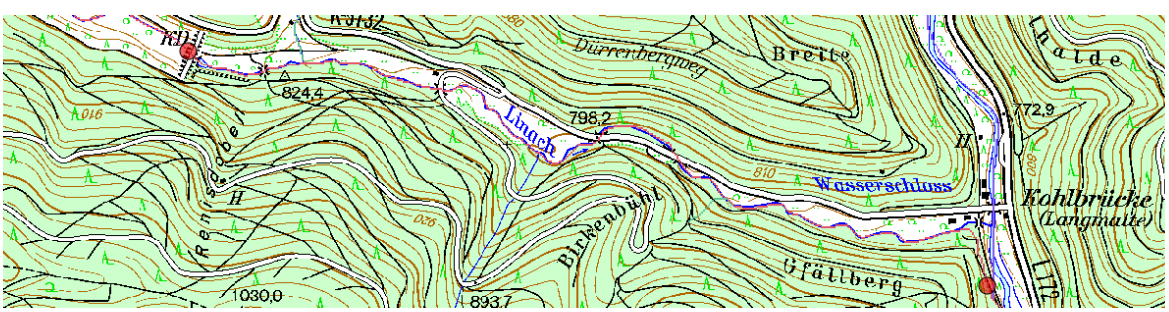

Figure 9. Creation of Pour points.

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2.1.9. Snap pout point

With the tool Snap to pour point, the pour points are transformed in raster (Figure 10), related with the accumulation raster pixels. This is used to ensure the selection of the point of higher accumulated flow.

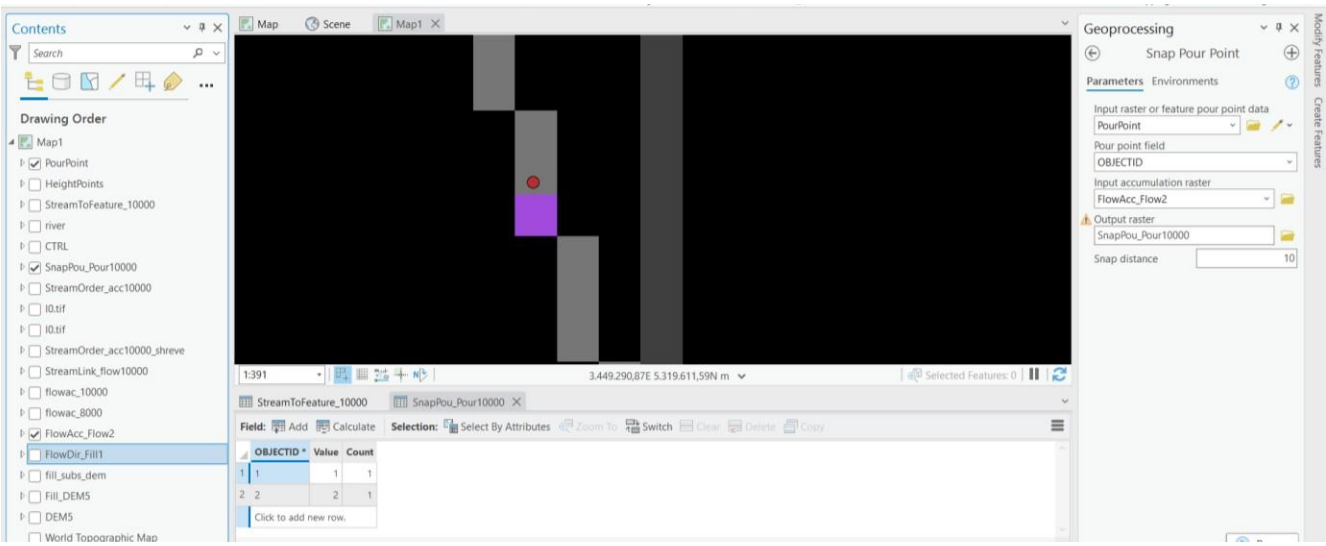


Figure 10. Snap to pout point.

2.1.10. Delimitation of Watershed

The inputs used to the delimitation of the Watershed are the flow direction raster and the pour points, which establish where the watershed needs to be segmented (Figure 11).

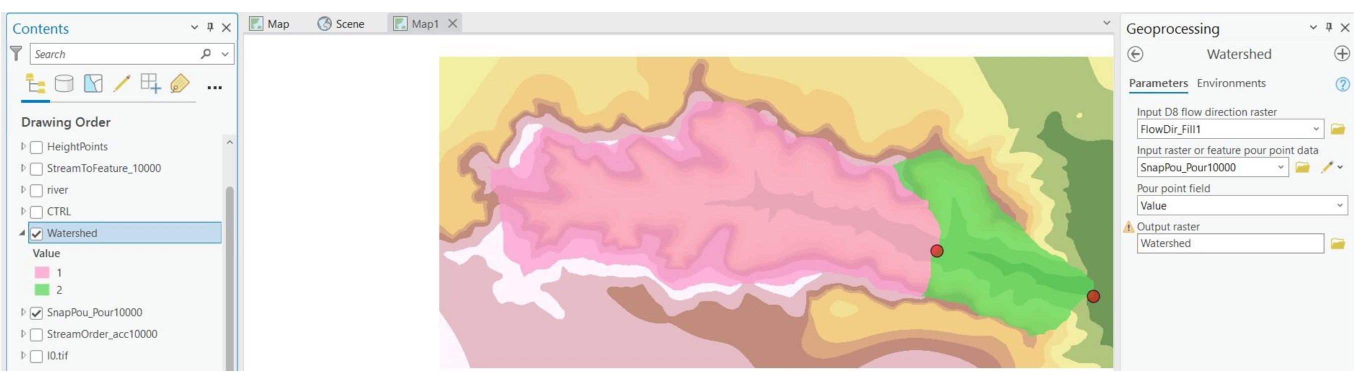


Figure 11. Watershed.

2.2. Maximum flow length

The Flow Length tool is used to calculate the hydrological longest path through the watershed. This measure should be done using the upstream option.

As input the flow direction is required, because of this, is necessary to mask (extract by mask) the direction raster (Figure 12), to calculate the flow length in the correct starting point. The resulting maximum flow length is presented in Figure 13, the maximum value is 9210.57 m.

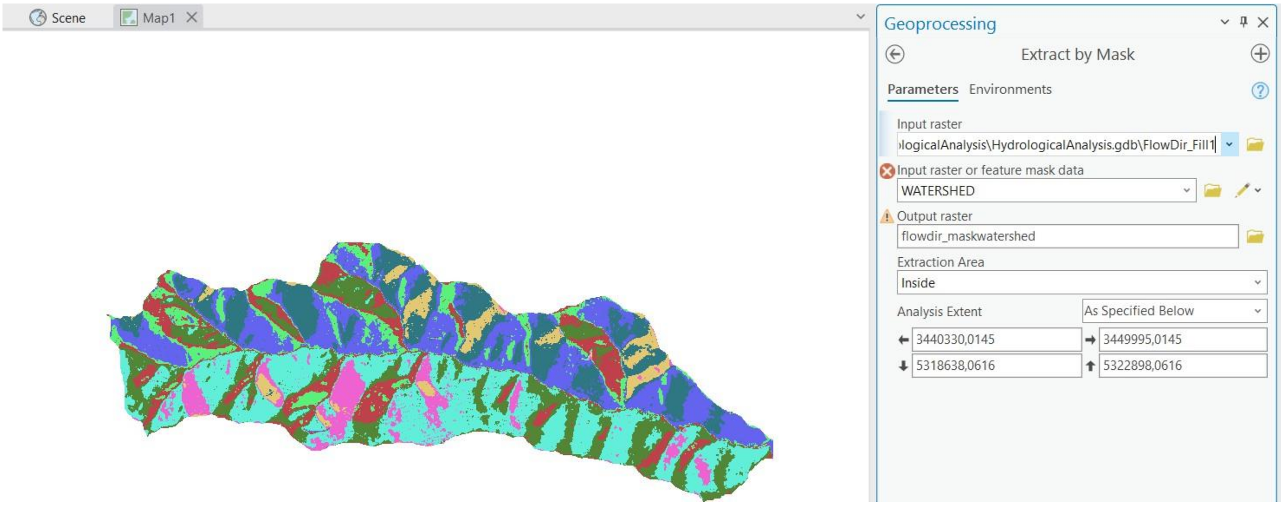


Figure 12. Flow direction masked by the Watershed

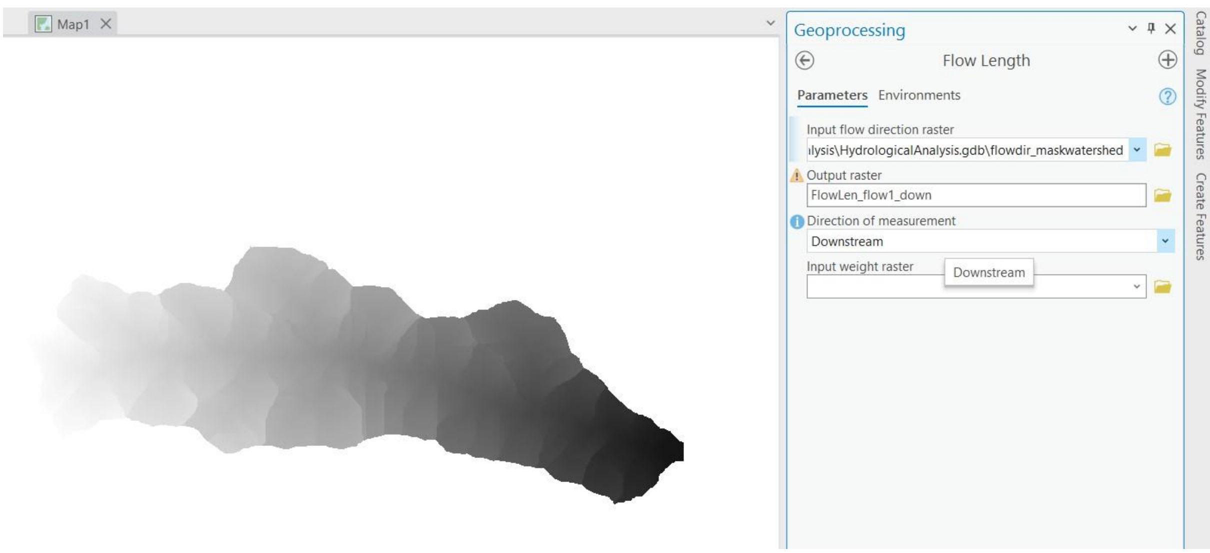


Figure 13. Maximum Flow length for the Watershed area.

For furthest analysis, the flow length is obtained only for the river (Figure 14). This is made by masking the flow length with the extracted river from the raster (in the extracted river, after masking it, the values of 0 are delated).

Figure 14. Flow length for the river.

2.3. Flow time map

The flow time map shows for each pixel its flow time to the outlet point. As it depends also on the roughness of the surface, the distance and the slope, three variables need to be calculated.

2.3.1. Manning value K: This value gives a measure for the roughness of the surface. Each cover land in the study area has a different K value, and also the river stream. In this case the following values were used:

Surface description	K_{st} in $m^{1/3}s^{-1}$
Pastures	5
Wood	17
Channel flow	40

As first step, the k value is assigned to the cover lands in the vector in the area of studio. After, is converted to raster. The flow length extracted is summed with the previous raster. To assign the correct values, a reclassify is performed, as showed in Figure 15.

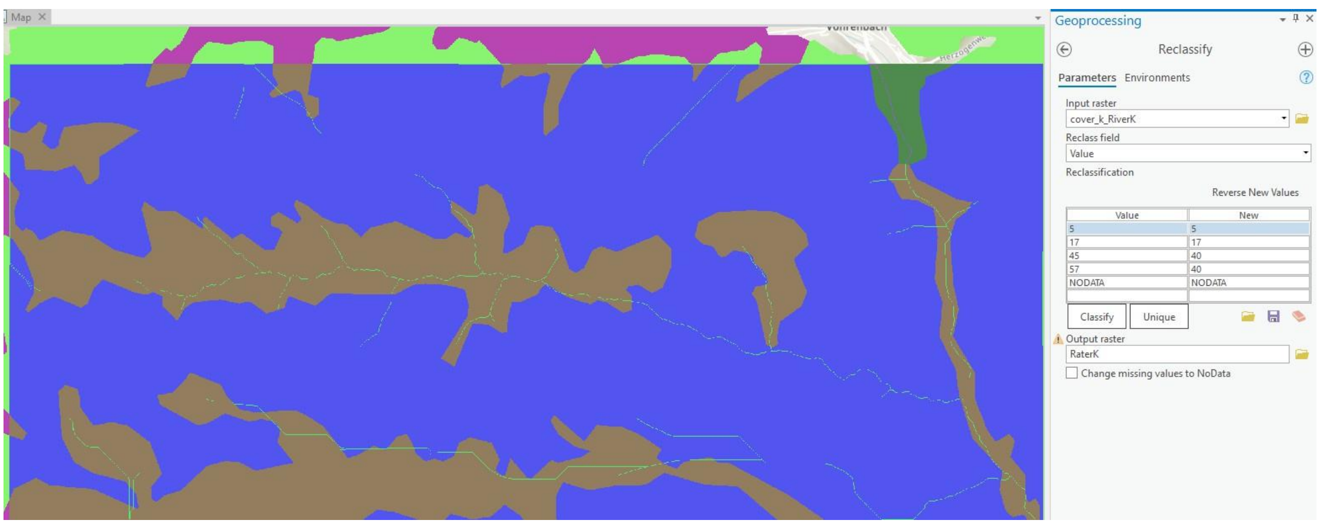


Figure 15. Generation of k raster.

2.3.2. Hydraulic Radius

To calculate hydraulic radius or R, the R in outlet (R2) and in the farthest part of the river (R1) from the outlet is calculated in the beginning. Then, linear interpolation is used for defining the R value on the river between those points using the flow length as the x value. Because the value of the flow length in the outlet is zero and getting bigger as it away from there, the X should be modified:

$$Rint = \frac{R2 - R1}{\Delta X} * (\Delta X - FlowLength) + R1$$

Where R is Area of the water in river cross section divided by the perimeter (wetted area) (Figure 16).

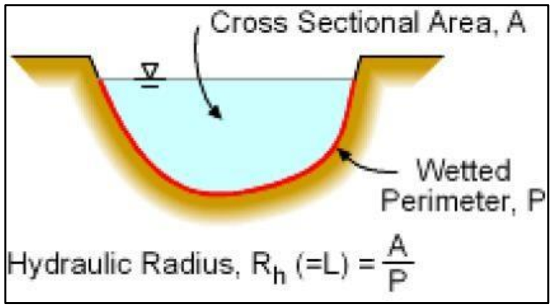


Figure 16 Hydraulic radius of a river

Assumed that the cross sections for the river bed is rectangular with starting point's width of 0.5m and a depth of 0.1 and the outlet has width of 3m and a depth of 0.4m. Here is the formula used in the *raster calculator*:

(((3*0.4/(3+0.4*2))-((0.5*0.1)/(0.5+0.1*2)))/(9210.57))*(9210.57-"Flowlength_down_masked")+((0.5*0.1)/(0.5+0.1*2))

Using this formula, it shows that the result is correct with crosschecking the value in the beginning and the outlet of the river (Figure 17).

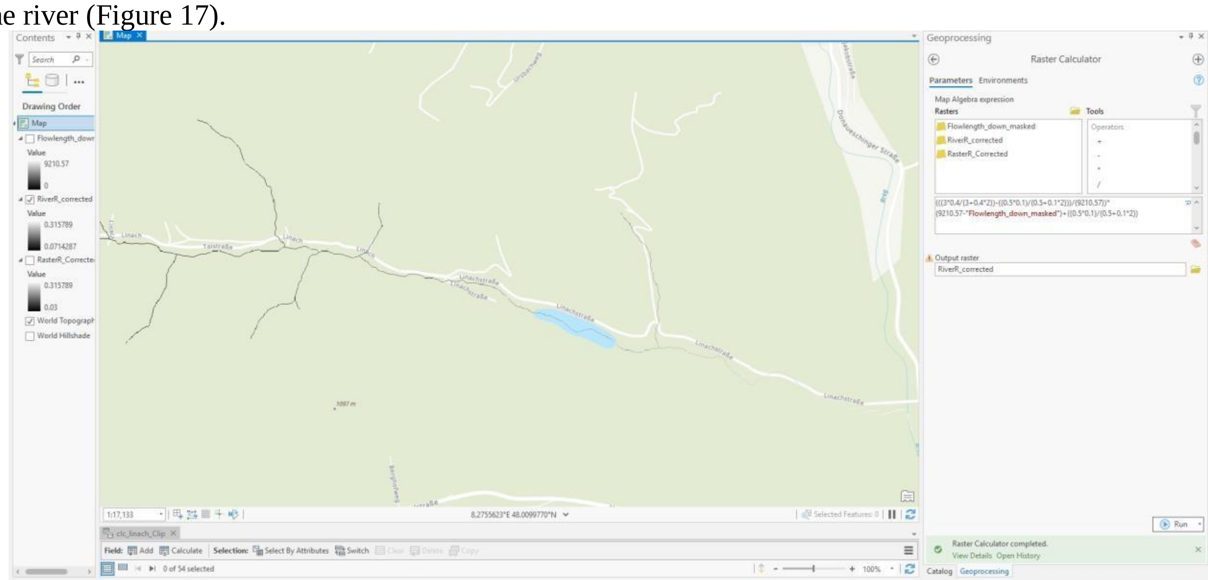


Figure 17 The R value of the river

After R value of the river is calculated, then, The R value of the land should be added by exporting the River R value into tiff, so it has rectangular shape of the study area and adding the 0.03 (assuming from the task) value to the 0 value outside the river using *raster calculator* (Figure 18).

Figure 18 final result of R Raster map

2.3.3. Slope

The input required to generating the slope is the DEM creating in the first step (Figure 19). The method used is percentage.

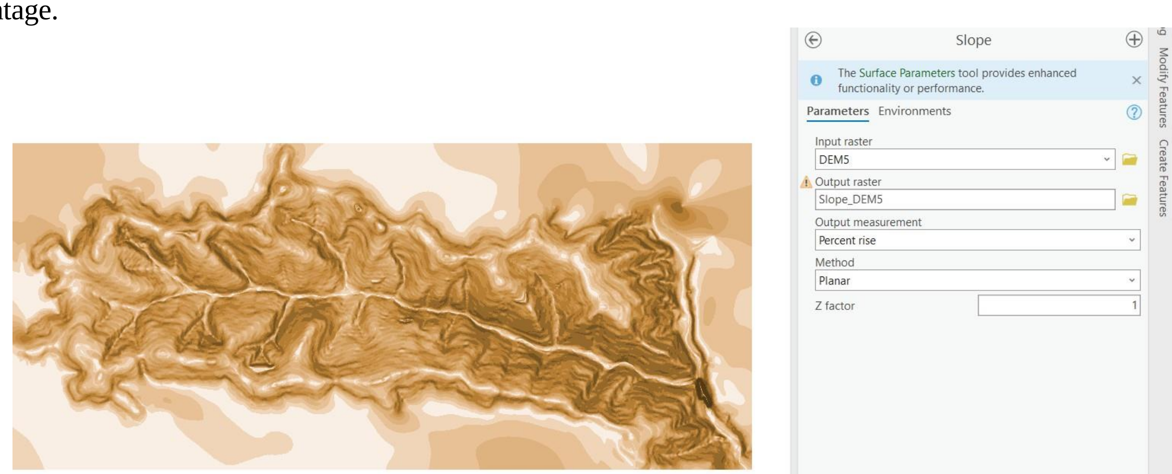


Figure 19. Slope

2.3.4. Flow Velocity

Here, to calculate the flow time map, the flow velocity map is needed. Here is the equation to calculate the flow velocity map:

$$v = K_{st} * R^{\frac{2}{3}} * S^{1/2}$$

In the raster calculator this code "RasterK"*(Power("RasterR_Corrected",2/3))*(Power(("Slope"/100),1/2)) is written to have the result (Figure 20).

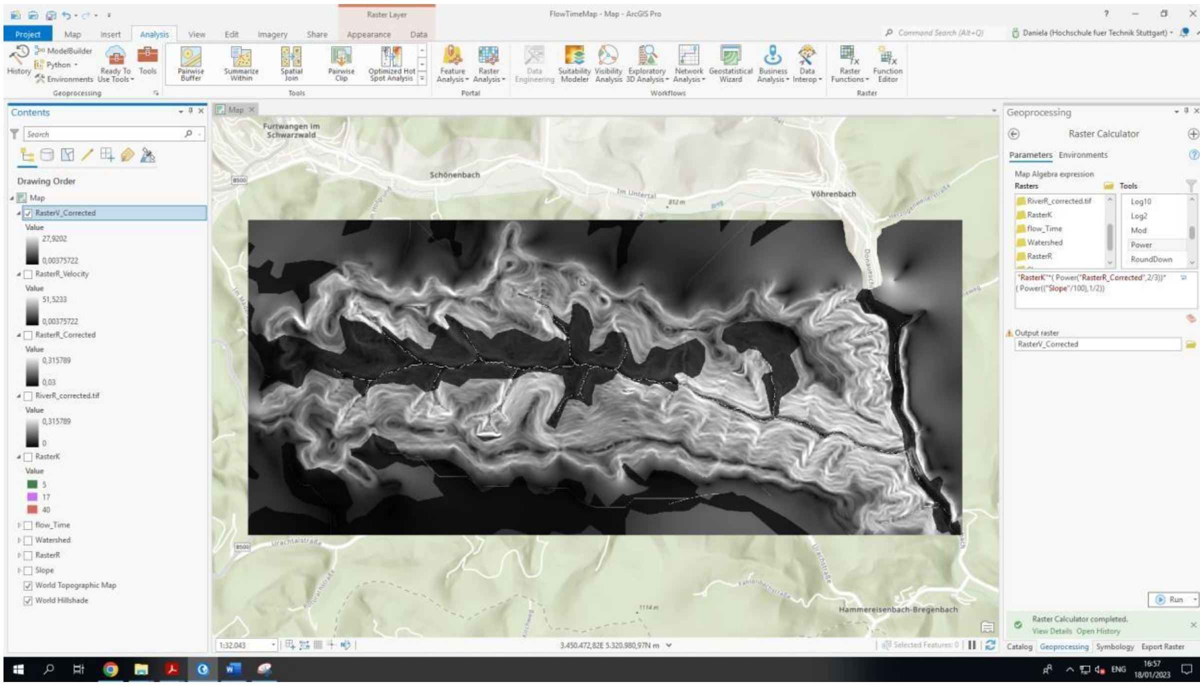


Figure 20 Time velocity map

To have flow time, it is known that to calculate time, velocity and distance are needed. The formula will be:

$$Time = \frac{length}{velocity}$$

Therefore, the inverse of flow velocity map is calculated (Figure 21).

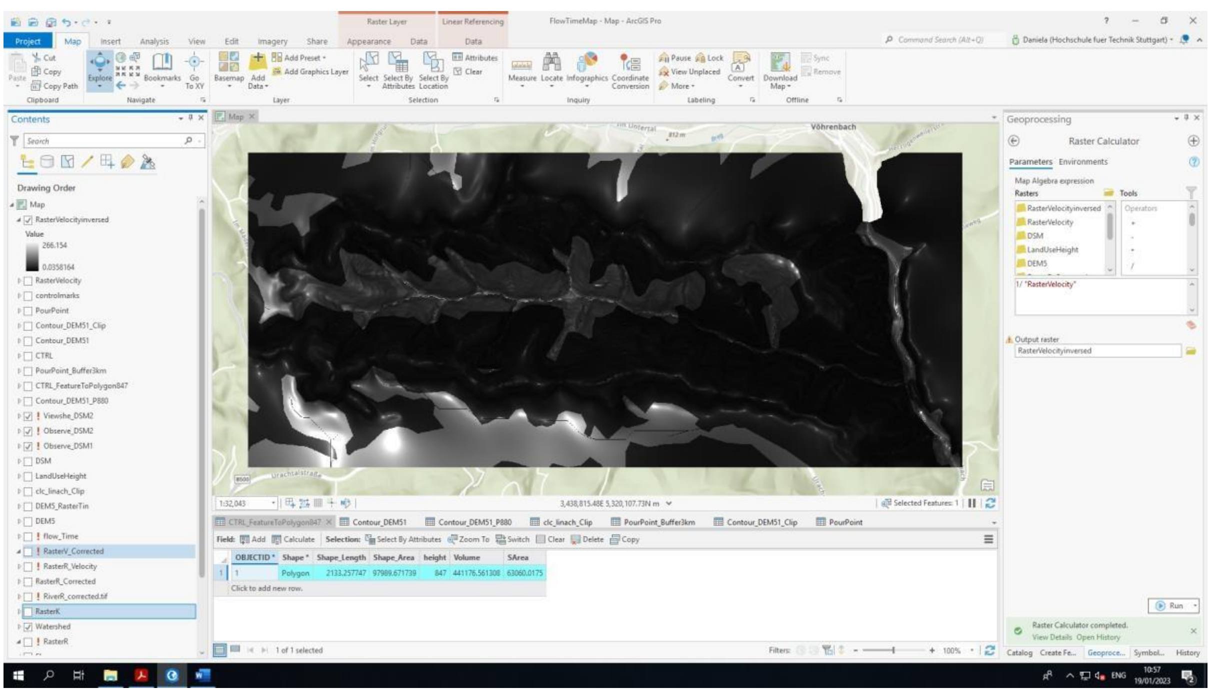


Figure 21 inverse flow velocity map

2.3.5. Flow Time Map

To calculate, the flow velocity map, flow length tools is used with flow direction as an input and inversed of flow velocity as a weight parameter. Here is the result (Figure 22).

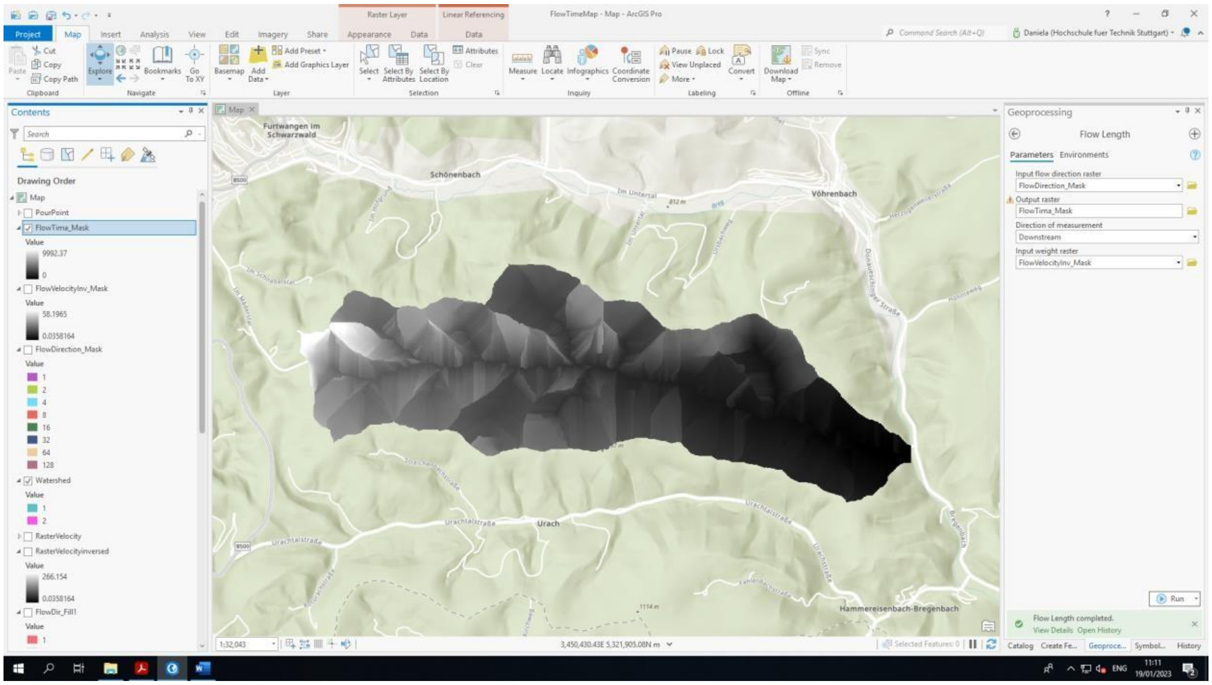


Figure 22 Flow Time Map

3. Time area histogram, time area diagram, unit hydrograph.

3.1. Time Area Diagram and Histogram

To make the Flow Time easier to analyze and present, it could be divided into classes. As Known that the Flow Time map maximum number is 9992 seconds, it can be divided into 11 classes with approximately (Δt) 900 seconds or 15 minutes per class (Figure 23). Then the histogram is generated by inserting histogram in *ArcGIS* (Figure 24).

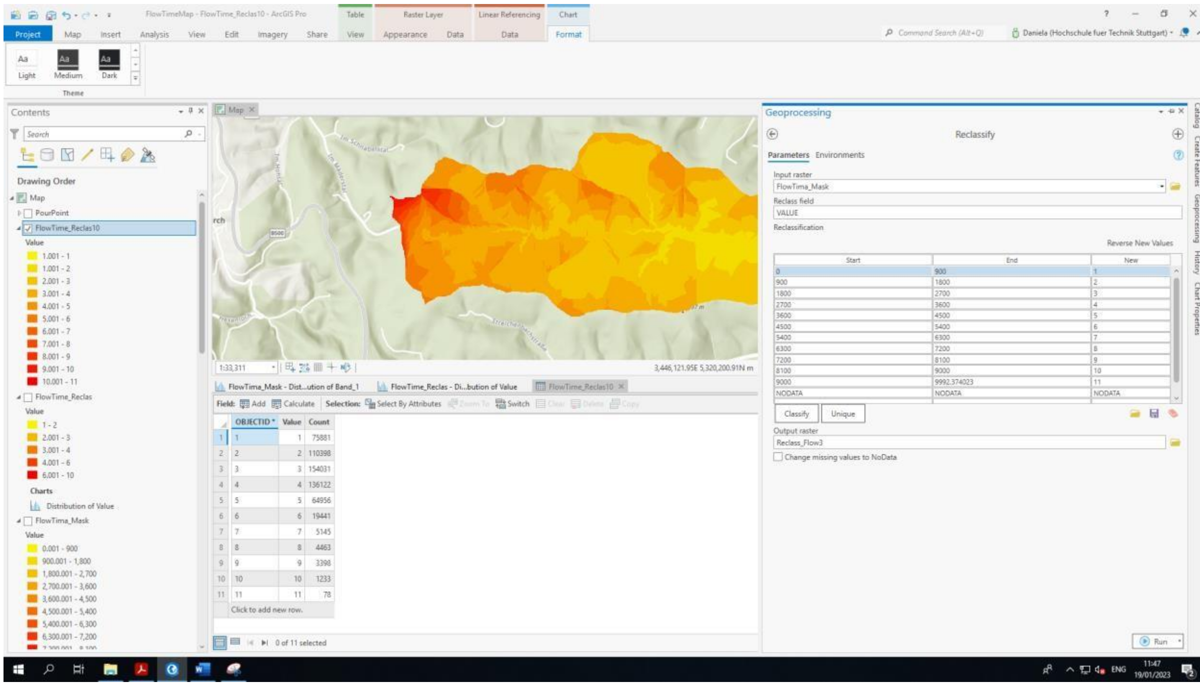


Figure 23 Flow time map divided into 11 classes

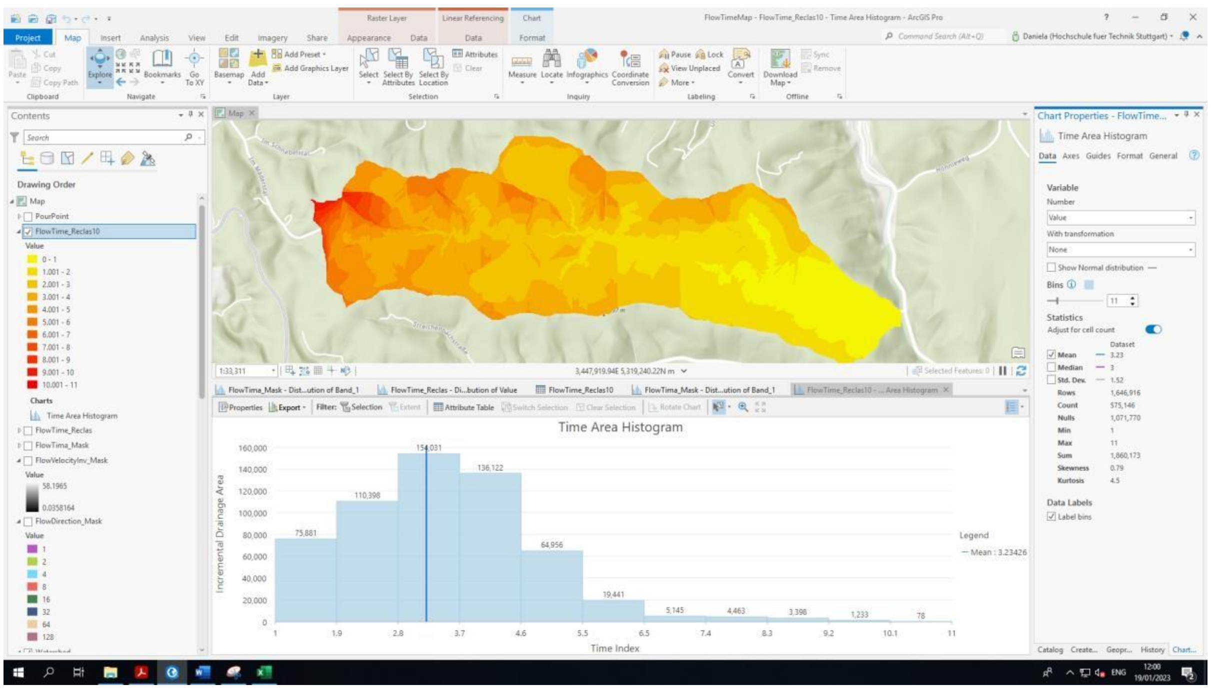
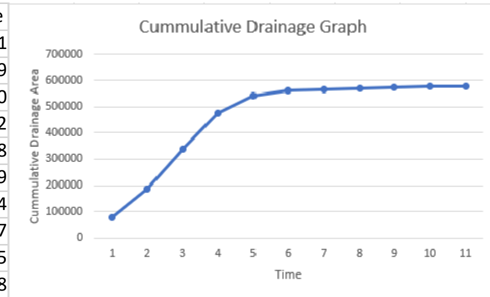


Figure 24 Flow Time Map Histogram and Diagram

The next step is to make the cumulative drainage area graph in Excel. The areas from the histogram are summed cumulatively calculated in excel (Figure 25).

OBJECTID	Value	Count	cummulative
1	900	75881	75881
2	1800	110398	186279
3	2700	154031	340310
4	3600	136122	476432
5	4500	64956	541388
6	5400	19441	560829
7	6300	5145	565974
8	7200	4463	570437
9	8100	3398	573835
10	9000	1233	575068
11	9992	78	575146



X axis 1 = 15 minutes

Figure 25 Cumulative Drainage Graphic

Unit hydrograph is to define the discharge over time. This consider the area and the period time defined, which is 15 minutes.

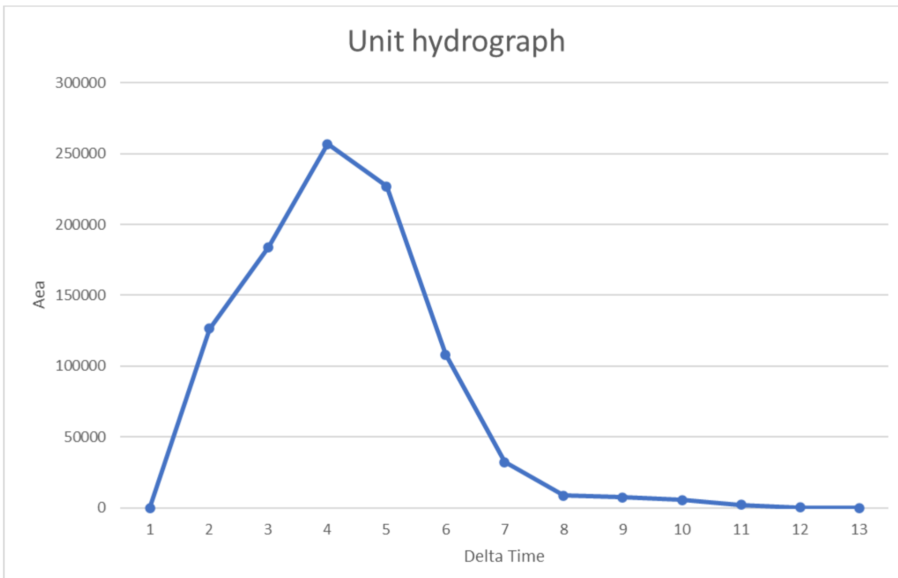


Figure 26 Unit Hydrograph Graphic

3.2. Unit Hydrograph

To model the discharge for storm event in time interval n, the unit hydrograph is used with formula given below:

$$Qn = \sum_{i=1}^{n} \frac{PijAi}{\Delta t}$$

where j = n-i+1 and Pij is the average excess rainfall over all cells in isochrones zone i during time interval j. Qn is the direct runoff at time t = n Δt which is the sum of all runoff contribution from each of the applicable isochrone zones suitably lagged in time. Given that storm event has 60mm in 2 hours. Given in the Table 1 below is the calculation of unit hydrograph. Until 2 hours (7200 minutes) the rain stop, and the calculation of Qn (sigma) will be the cumulative of the Qn per area. After the rain stops, the calculation become sum of Qn with moving window of 8 value of Qn (area). For example, the sigma Qn in minute 9900 is the sum of Qn (area) of 4-11 or 3600 until 9900. Here shown the graph of unit hydrograph (Figure 27). We can see from the graph that the peak of runoff is in the second hour and the total storm until it became normal is 17100 seconds or 4.75 hours.

Table 1 Unit Hydrograph

		Time (min)	AREA (m2)	P (m)	Qn (m3/s)	sigma	Remark
0	0	0	0	0	0	0	
1	900	15	1897025	0.0075	948.5125	948.5125	
2	1800	15	2759950	0.0075	1379.975	2328.488	
3	2700	15	3850775	0.0075	1925.388	4253.875	
4	3600	15	3403050	0.0075	1701.525	5955.4	
5	4500	15	1623900	0.0075	811.95	6767.35	
6	5400	15	486025	0.0075	243.0125	7010.363	
7	6300	15	128625	0.0075	64.3125	7074.675	
8	7200	15	111575	0.0075	55.7875	7130.463	rain stop
9	8100	15	84950	0.0075	42.475	6224.425	
10	9000	15	30825	0.0075	15.4125	4859.863	
11	9900	15	1950	0.0075	0.975	2935.45	
12	10800	15	0	0	0	1233.925	
13	11700	15	0	0	0	421.975	
14	12600	15	0	0	0	178.9625	
15	13500	15	0	0	0	114.65	
16	14400	15	0	0	0	58.8625	
17	15300	15	0	0	0	16.3875	
18	16200	15	0	0	0	0.975	
19	17100	15	0	0	0	0	

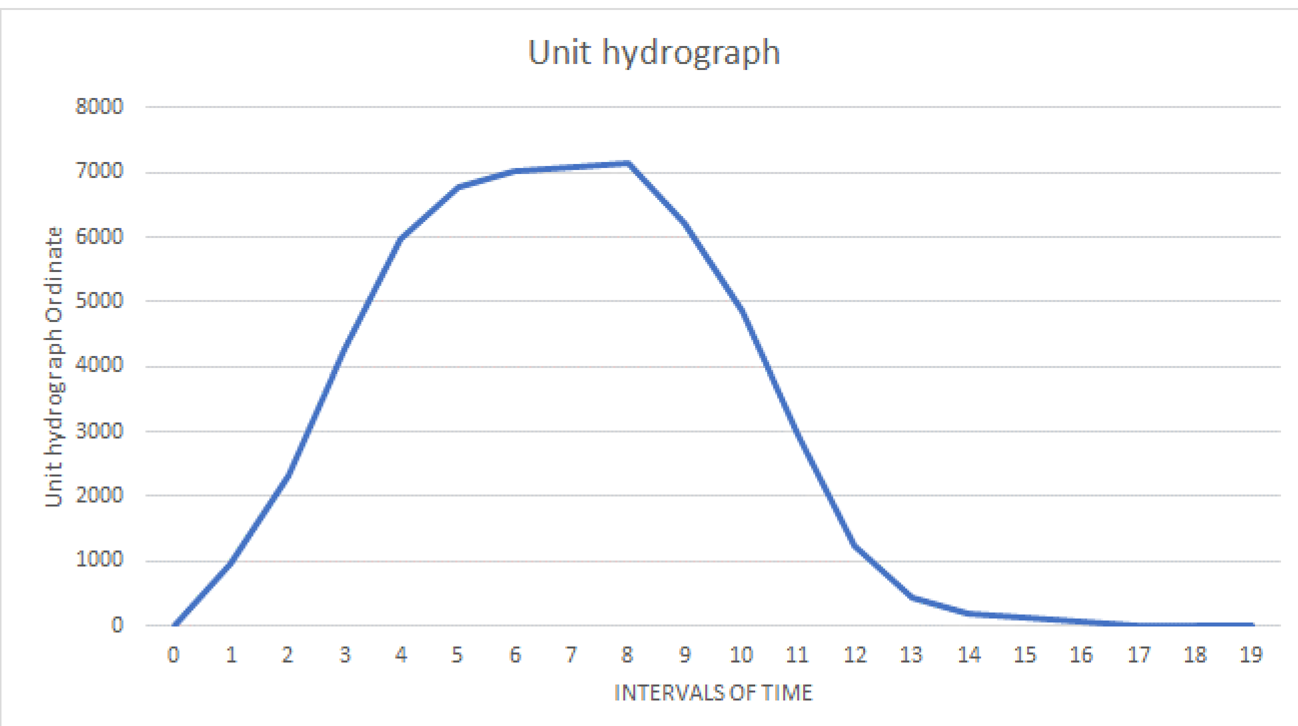


Figure 27 Unit hydrograph calculated from unit hydrograph formula (Qn)

3.3. Time Lag

The lag time can be approximated by the following equation:

$$T_L = \frac{2.587 \times L^{0.8} \left(\frac{1000}{CN} - 9\right)^{0.7}}{1900 \times s^{0.5}}$$

Where:

$T_L = Lag\ time\ in\ hr\ (centroid\ of\ time\ period\ t_r\ to\ time\ of\ Q_P)$
$L = Hydraulic\ watershed\ length\ (m)$
$s = Average\ watershed\ slope\ (dimensionless!\ m/m)$
$CN = Watershed\ area - weighted\ curve\ number$

L comes from the maximum flow length, obtained in previous steps (9210.57 m). CN is calculated from theorical values established for each cover land. In the area of studio there are only two cover lands, therefore the average of these values is used in the following formula (68.25). The average slope is calculated with the height value of the two extremes of the stream (1000.039 and 763.2986) and the distance of the maximum flow length (9210.57m), generating a slope of 0.0257.

$$T_L = \frac{2.587 \times 9210.57^{0.8} \left(\frac{1000}{68.25} - 9\right)^{0.7}}{1900 \times 2.57^{0.5}}$$

$$T_L = 4.24\ hr$$

The Lag Time obtained with the theoretical equation is bigger that the value obtained by the previous calculation where the peak was in 2 hours. This difference can be given by the generality of the factors took into account, as the average of the slope, and the value established for the CN. The theoretical calculation is a general estimation, on the other side, the calculation performed previously is more specific for the study area.

4. Area of the water surface and volume of Dam

4.1. Create TIN Surface

To calculate volume of the DAM, one of the possible ways include the use of a TIN. To have TIN surface, the step is to convert the DEM into TIN using *Raster To TIN* tools with Z tolerance equal to 1.

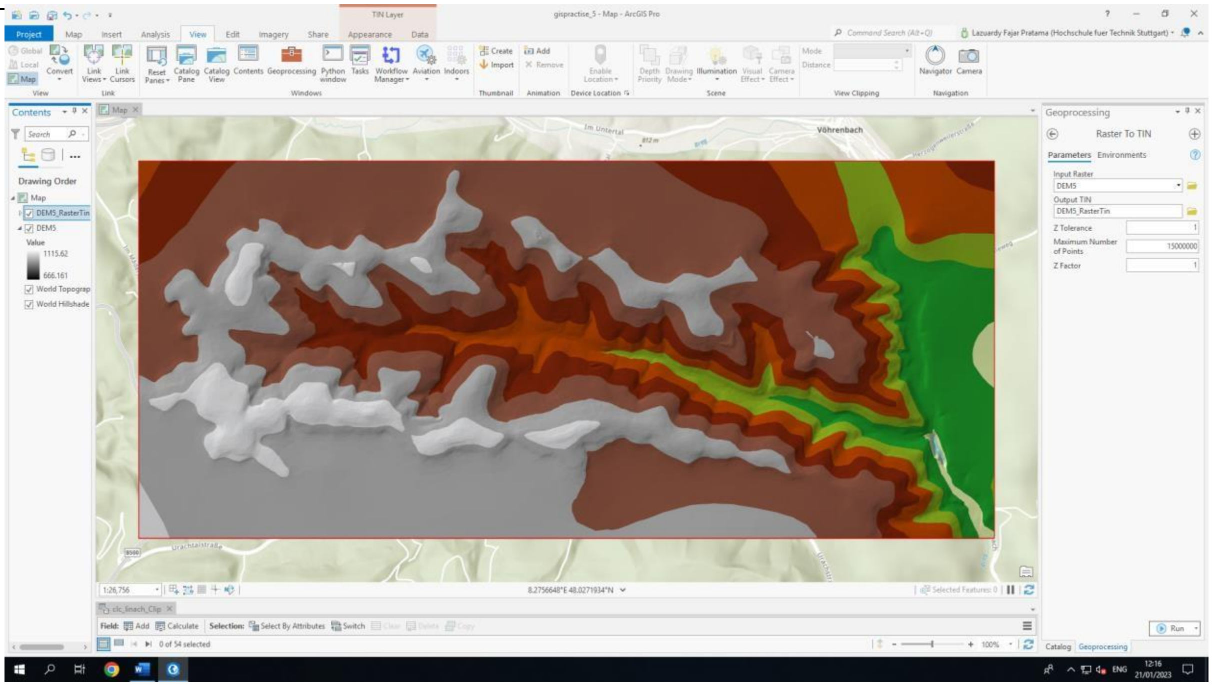


Figure 28 TIN surface generated from DEM

4.2. Calculate Volume

After the Surface created, the next step is to model the water surface on 847- and 880-meter surface height using polygon. To create the polygon, the first step is to generate the contour line using DEM and make a query for the contour line with 847 and 880 height value (Figure 29). After that, we model the dam free board connecting the contour line in two sides located in DAM pour point and make a closed polyline and convert the polyline into polygon.

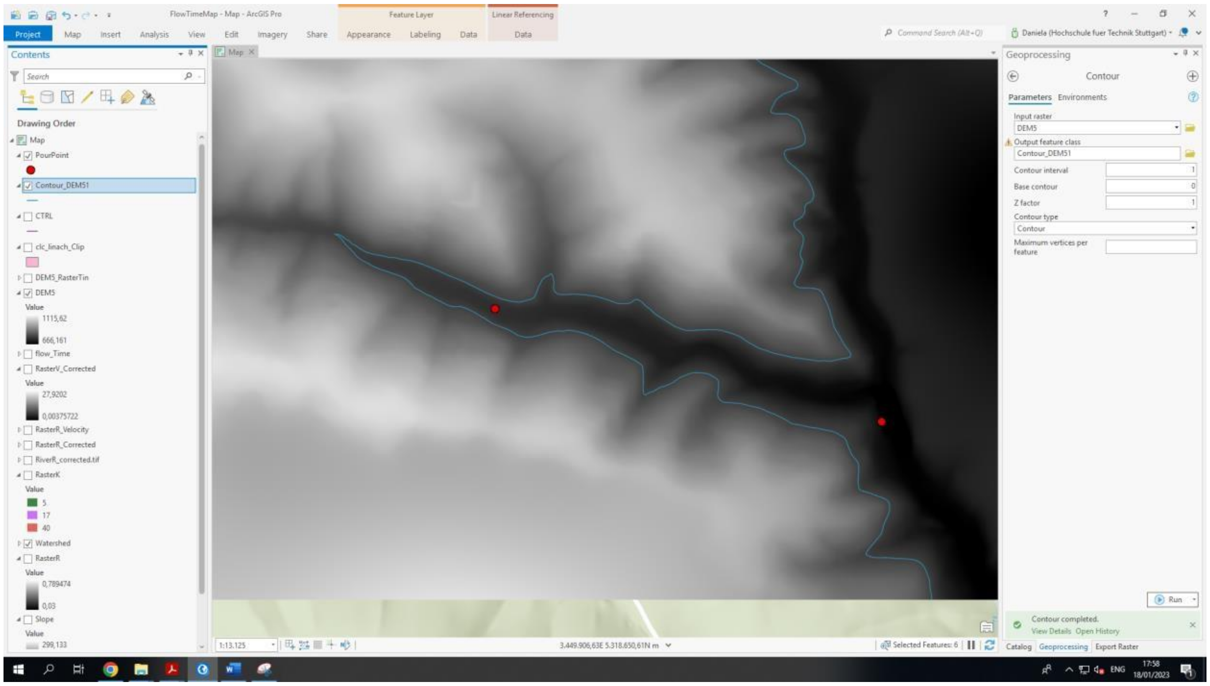


Figure 29 contour line 847 generated from DEM

To calculate the volume and surface covered by the water, the *polygon volume* tool is used with the inputs are TIN surface and the polygon, and calculate below surface is set as the parameter. Here are the results:

No	Parameters	Freeboard elevation 847m	Freeboard elevation 880m
1	Water Surface Area (m^3)	97,989.67	401,521.59
2	Surface Area covered by Water (m^3)	101,746.58	427,874.87
3	Reservoir Volume (m^3)	992,611.04	8,537,927.45

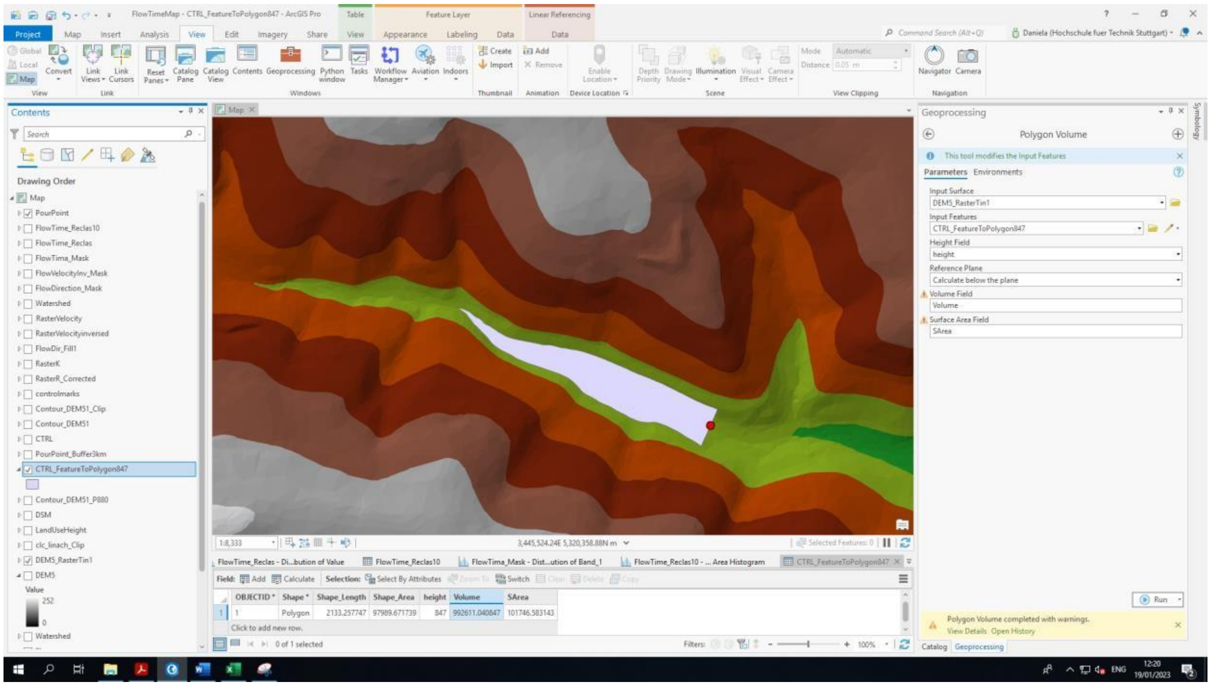


Figure 30 The water surface with freeboard 847 m elevation

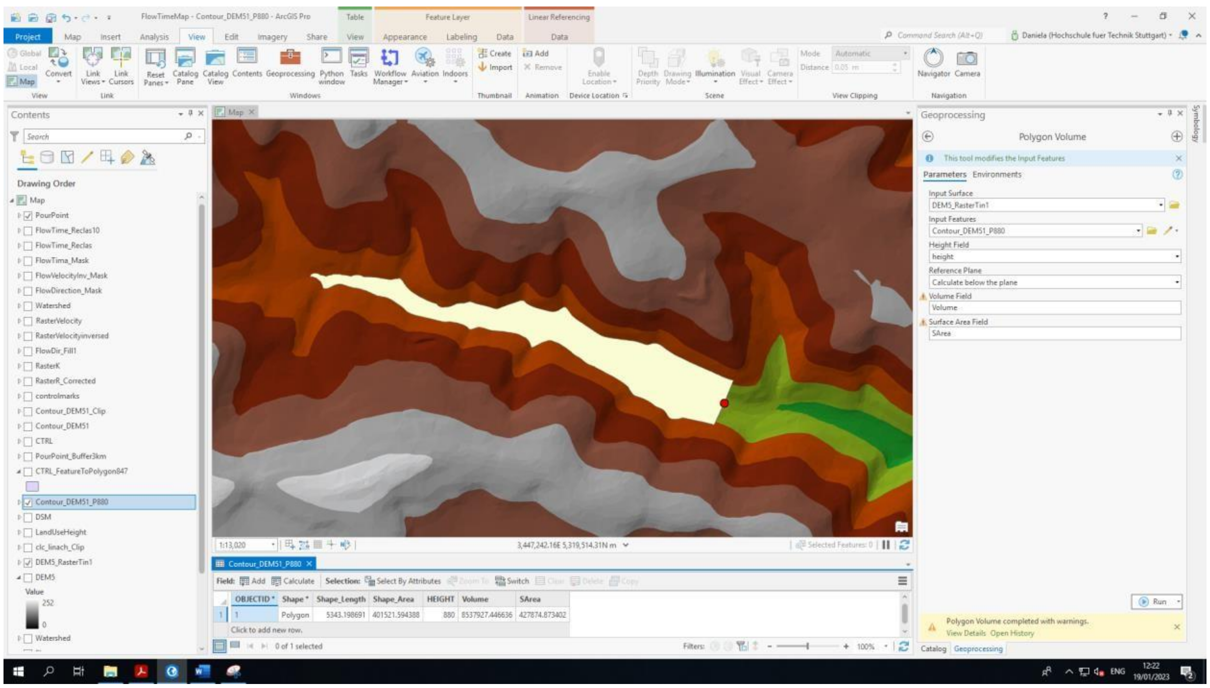


Figure 31 The water surface with freeboard 880 m elevation

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5. Location of control points

The view shed analysis tool is performed to determine the best location of the control points for surveying the dam, at an 880 m height. First the control marks need to be created, they are located in the center on top of the free board and in the two extremes, as shown in Figure 32.

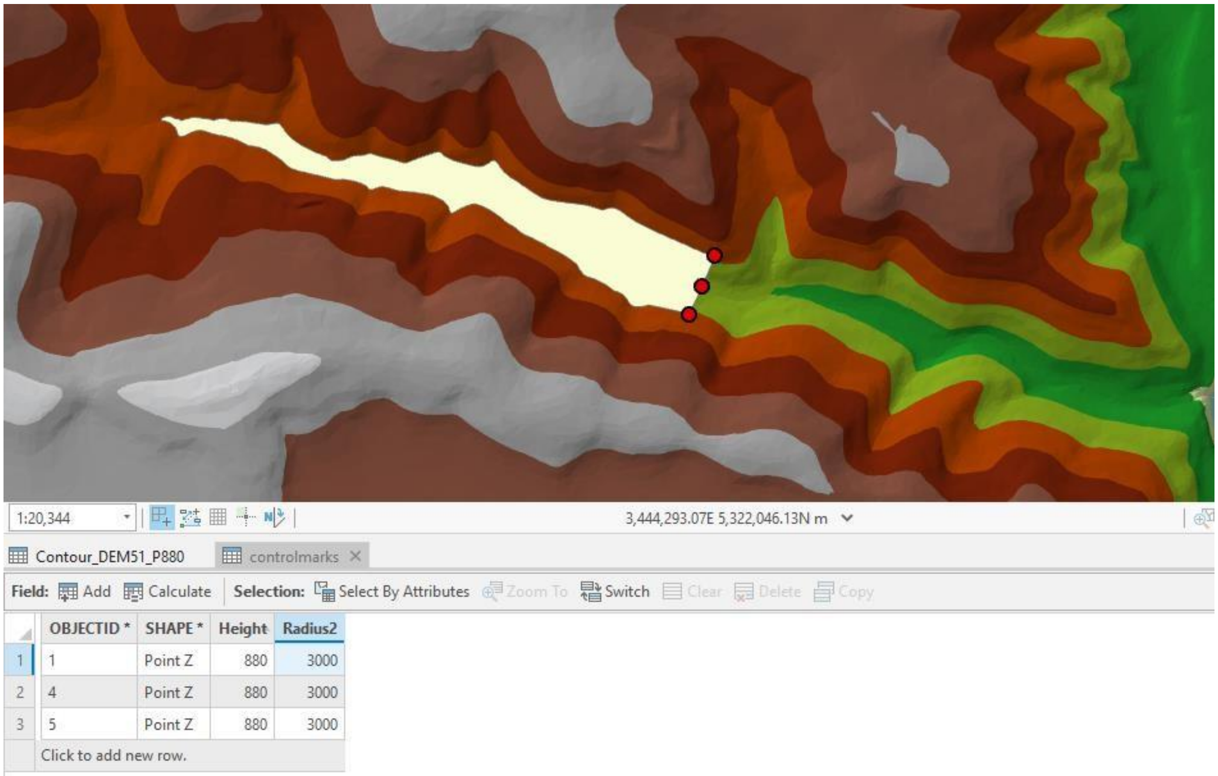

Figure 32. Creation of control marks in the free board of the dam

The cover land needs also to be considered in this analysis; a new raster (Figure 33) is creating taking into a count the average height of conifer (10 m).

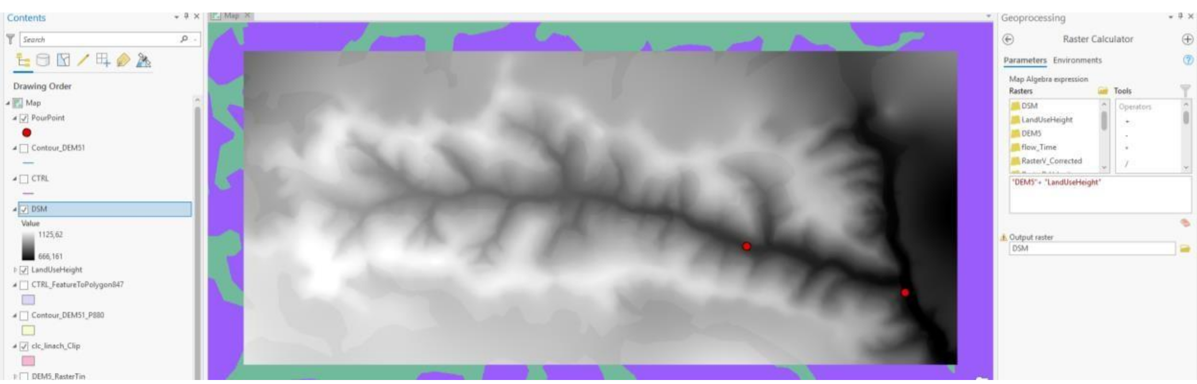

Figure 33. Creation a new height raster, considering the average height of conifer (10m)

The creation of the Viewshed requires as input a TIN, so this is created with a z tolerance of 1 m (Figure 34).

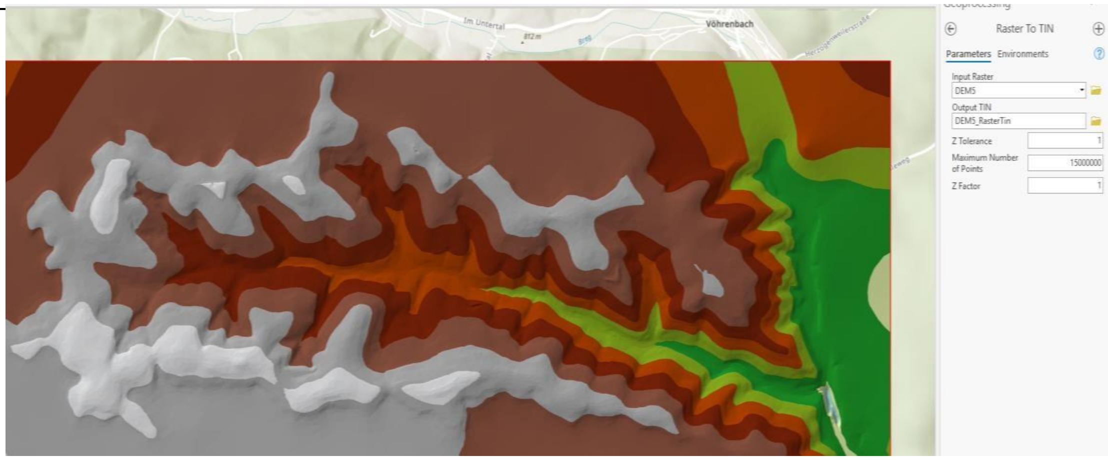

Figure 34. Generation of a TIN using the DEM

The criteria for the possible areas where is possible to see all three or at least two control marks are: The area should be within a distance of 3 km, the height of the cover land (10 meters) and they cannot be situated inside the Dam. After running the Viewshed tool, the area of the Dam needs to be excluded, this is made using extract by mask, and also, the areas where is only possible to see one mark (Figure 35).

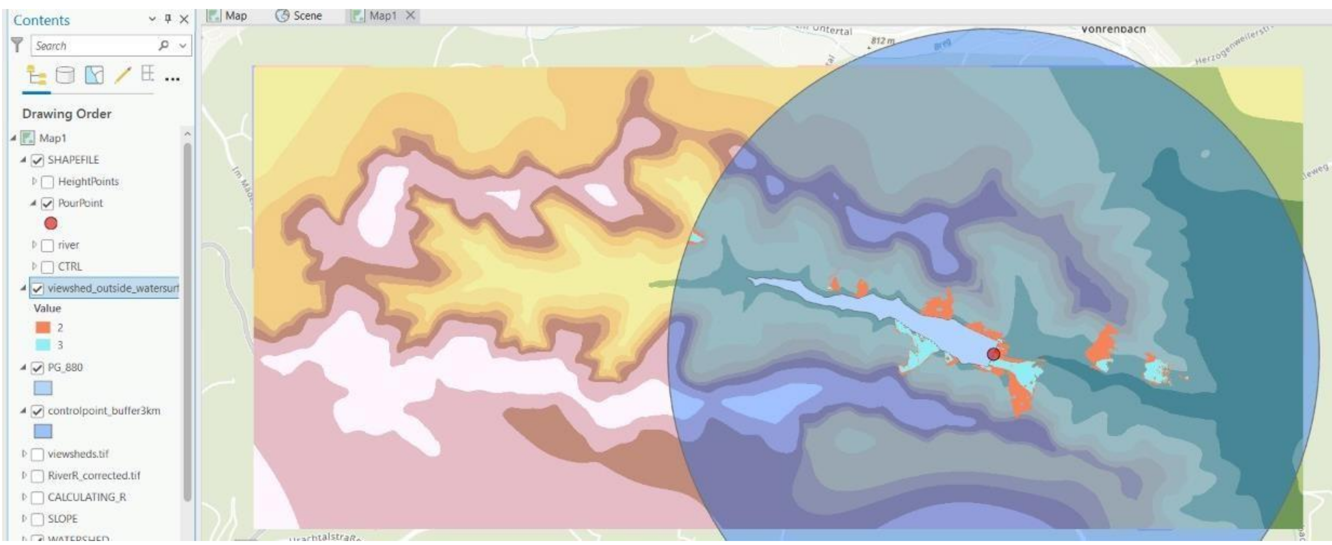

Figure 35. Generation of the zones where two or three control points can be observed.

6. 3D View of the new water reservoir

The following map present the project in 3D view when the new water reservoir is filled.

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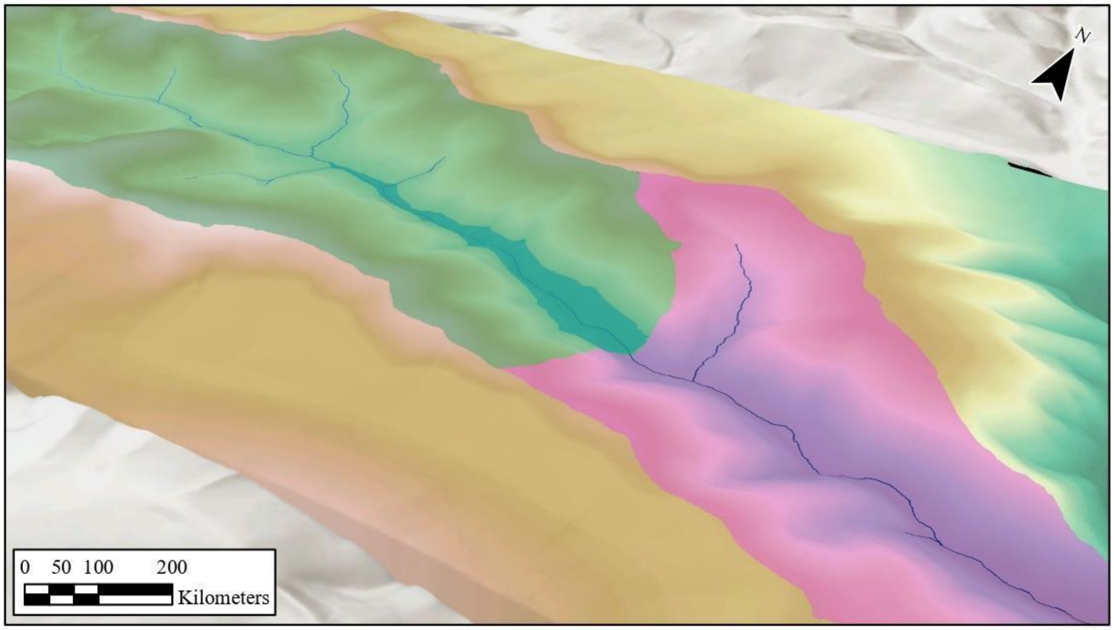

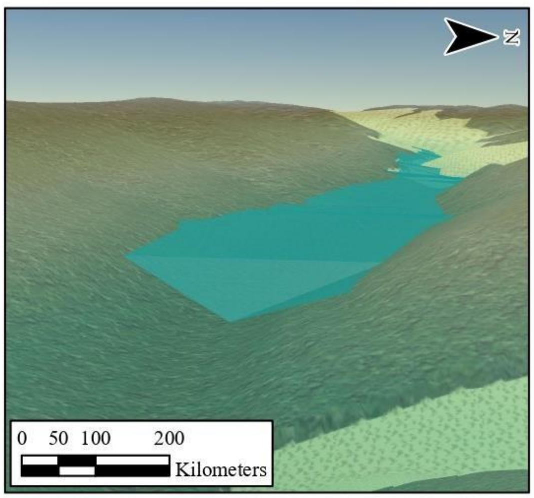

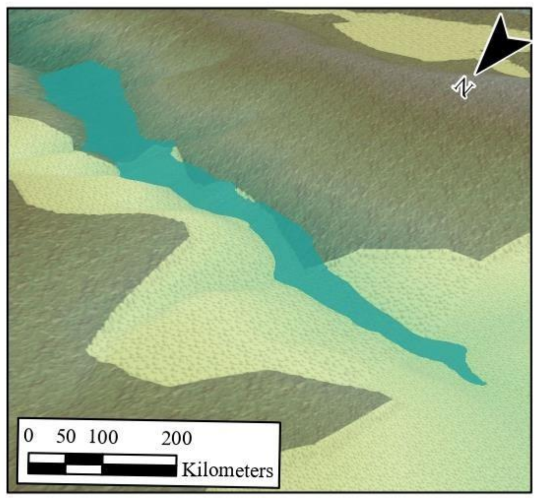

Hydrological Analysis for a Dam Construction Project in Linach, Germany

Hochschule für Technik Stuttgart
GIS-Practice
Prof. Dr. D. Schröder

Presented by:
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27.01.2023

Legend

Water reservoir (height 880 m)

Watershed

Linach Dam

Breg river

DEM 5m

1115.62

753.767

Cover Land

Pastures

Coniferous Forest