

GIS IN THE LANDSCAPE



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INDEX

- INTRODUCTION

- SOURCE LAYERS OVERVIEW

- DIGITAL ELEVATION MODEL PREPARATION

- FACTOR R

- FACTOR K

- FACTOR C

- LS FACTOR

- P FACTOR

- SOIL LOSS CALCULATION – 3D USLE

- SEDIMENT TRANSPORT - SDR

- RESERVOIR TRAPPING EFFICIENCY (BRUNE, DENDY)

- SEDIMENT AMOUNT MEASUREMENT AND CALCULATION

INTRODUCTION

During this course, with the GIS software called “ArcMap 10.3”, we are going to create a model to apply the Universal Soil Loss Equation (USLE) and obtain the annual soil loss of the studied watershed. This is “*Prusanka*”, located in Southeastern Moravia.

This catchment is around 32 km^2 large and from 160 to 330 m high above the sea level.



SOIL LOSS AND SEDIMENT TRANSPORT FROM WATERSHED

USLE: Universal Soil Loss Equation (developed by the U.S Department of Agriculture)

$$USLE: A = R.K.L.S.C.P$$

<i>A... Average annual soil loss</i>	<i>(t * ha-1 * year-1)</i>
<i>R... Rainfall erosivity factor</i>	<i>(N * ha-1 * year-1)</i>
<i>K... Soil erodibility factor</i>	<i>(t * N-1)</i>
<i>L... Slope length factor</i>	<i>(dimensionless)</i>
<i>S... Slope steepness factor</i>	<i>(dimensionless)</i>
<i>C... Crop management factor</i>	<i>(dimensionless)</i>
<i>P... rates erosion control practices</i>	<i>(dimensionless)</i>

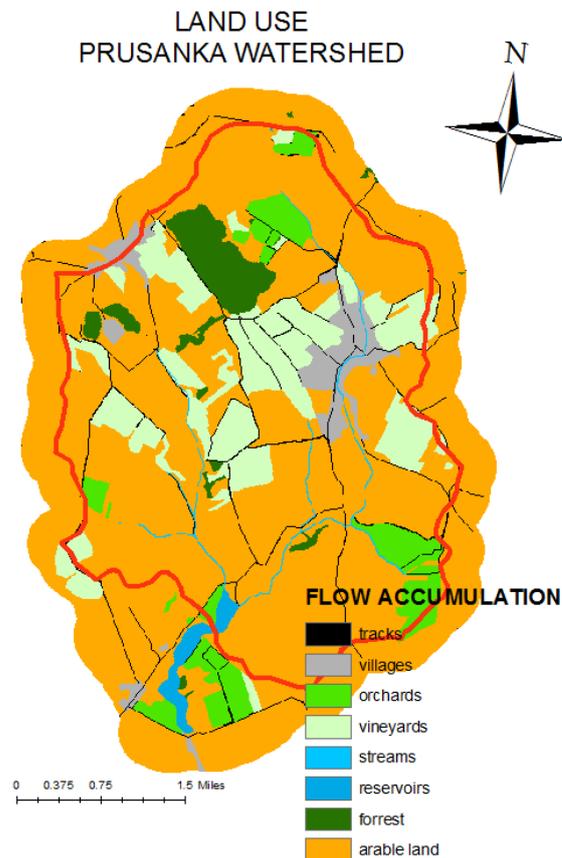
I. SOURCE LAYERS OVERVIEW

The first chapter is dedicated to get familiar with the software environment as well as knowing the layers on which we will work. These can be found already in the “Catalog”, as preliminary materials to launch our project:

RASTERS

Layers able to manage a large amount of data in every pixel of information. These layers are defined uniformly and continuously. Suitable for studying changing phenomena along the space.

- **PRUSANKA_LANDSAT_453** – Landsat image in false colors
- **ORTHOPHOTO_3M** – Contracted orthophoto
- **LANDUSE** – Land use map of the catchments



VECTORS

Vectors are efficient in storing maps, since they only distinguish between limits of features, not about what is inside. Much lighter than rasters.

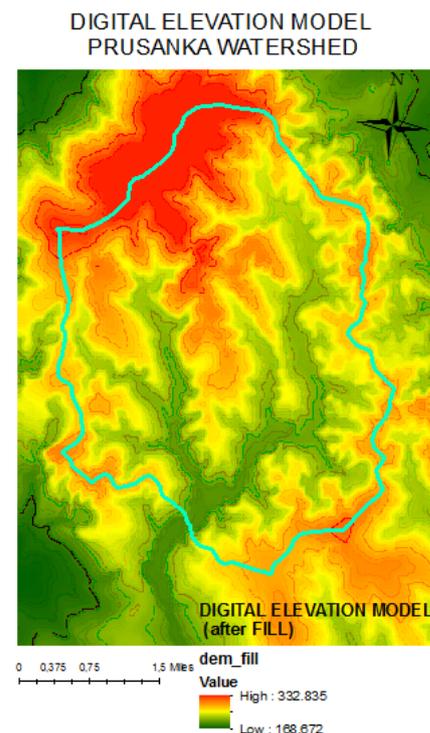
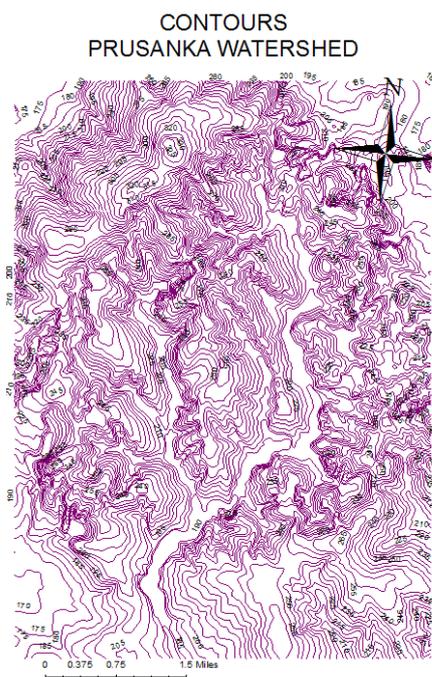
- **CONTOURS** – 1:25000 military map
- **RESERVOIR** – Reservoir outline
- **SEDIMENT LAYER** – Sediment depths in measured samples
- **SOIL_MAP** – Soil bonity map
- **WATERSHED** – The catchments area

II. DIGITAL ELEVATION MODEL PREPARATION

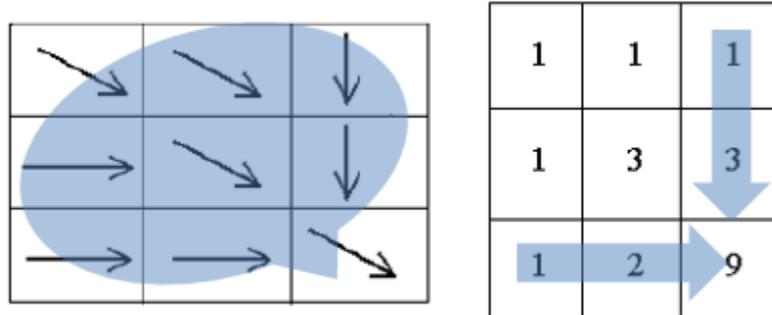
From the “*contours*” layer, and using the tool “**TOPO TO RASTER**”, we create the layer called “*TopoToR_cont1*”.

The model is created using interpolation from the values of the “*contours*” layer, but it is not 100% accurate, creating irregularities in the terrain and disturbing the runoff.

To fix these small irregularities, we apply the tool “**FILL**” to the before layer, establishing hydraulic connectivity of the surface, which is necessary for the rainfall-runoff modelling. Once applied the tool “**FILL**”, we get the layer called “*dem_fill*”.



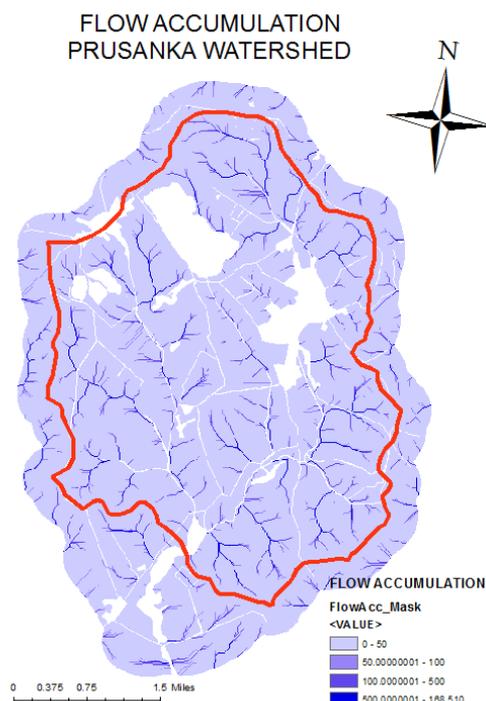
Now, we can use “**SLOPE**”, creating the raster “*slope*” from the Digital Elevation Model, with steepness values in every pixel . Then, we apply the tools “**FLOW DIRECTION**” and “**FLOW ACCUMULATION**” to this new layer. The first one produces a raster with the different values of the direction that the runoff water would follow. The second one measures the quantity of water accumulated in every pixel:

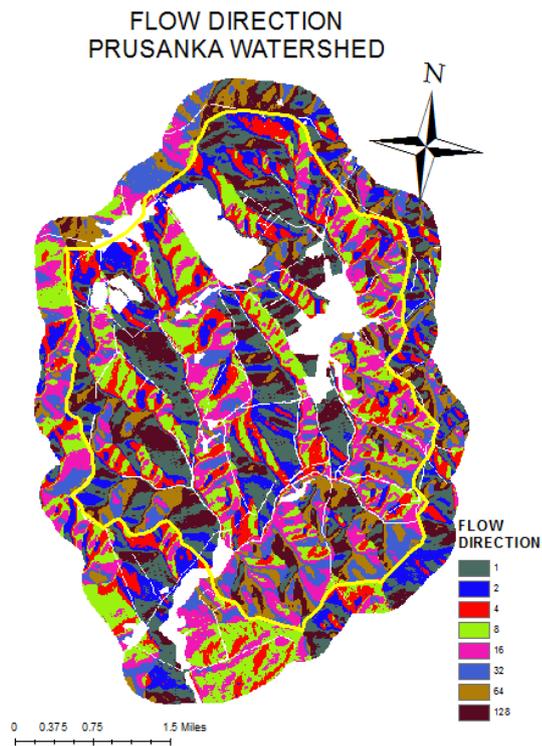


Also, we need to correct these calculations. We apply the tool “**RECLASSIFY**” to the “*landuse*” layer to refuse tracks, villages, streams, reservoirs and forests from the calculation. This tool produces the layer “*Mask*”.

Old value	New value
0 – 2	NoData
3 – 4	1
5 – 9	NoData
10 – 161	1

Now, with the tool “**RASTER CALCULATOR**”, we multiply the before layers times the “*Mask*” layer, producing the new laers “*Flow_Acc_dem_fill*” and “*FlowDir_Mask*”.





The pictures show the differences before and after applying the “*Mask*” layer.

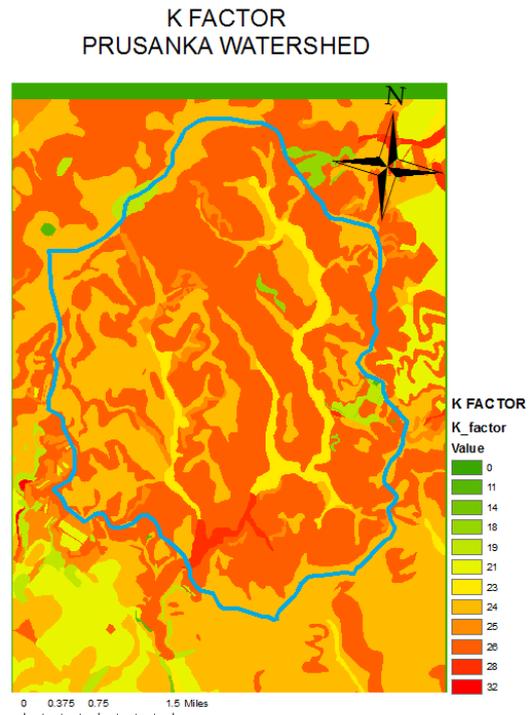
I. FACTOR R

This parameter is called “*Rainfall erosivity factor*”. It is based on rainfall kinetic energy. We use a predetermined value $R = 35 \text{ N} \cdot \text{h}^{-1} \cdot \text{year}^{-1}$

I. FACTOR K

It represents the “*soil erodibility*”. To calculate it, first we need to apply the tool “*POLYGON TO RASTER*” to the “*soil_map*” layer, to convert it into a raster. Then, we will use the tool “*RECLASSIFY*” to assign to each category of soil a K value. For that, we load directly a preset spreadsheet with all the K values.

Soil category	K	Soil category	K
1	0.24	21	0.11
3	0.25	22	0.19
4	0.14	40	0.18
5	0.21	41	0.25
6	0.24	58	0.28
7	0.19	60	0.23
8	0.26	61	0.25
19	0.25	62	0.28



I. FACTOR C

The C factor represents the use and management of the soil. It is the vegetation impact on soil loss reduction.

Bare soil $C = 1.0$

Total protection $C = 0.0$

We use the tool “**RECLASSIFY**” again, assigning the C factor values from the “*landuse*” categories:

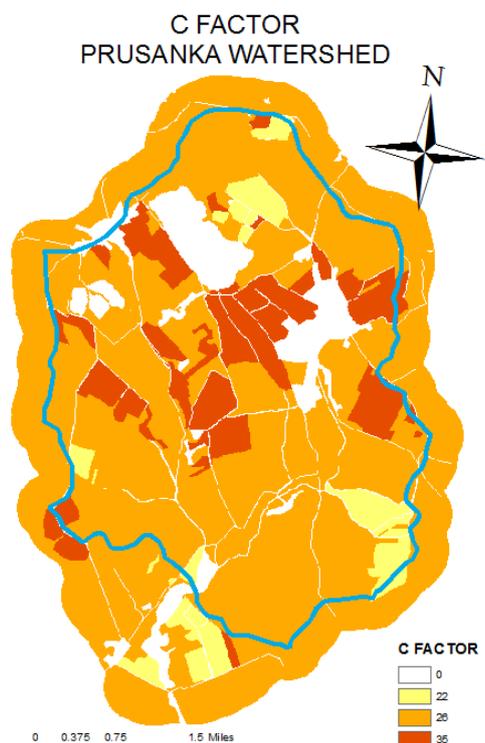
Orchards $C = 0.22$

Vineyards $C = 0.35$

Arable Land $C = 0.26$

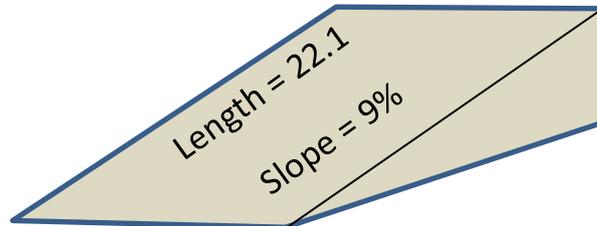
Other categories not used $\rightarrow C = 0$

<u>Arable land:</u>	
Corn	40 % - 0.50
Winter wheat	30 % - 0.12
Alfa-Alfa	15 % - 0.02
Spring barley	15 % - 0.15



I. LS FACTOR

It contains the “*slope length*” (L) and “*slope steepness*” (S) factors.

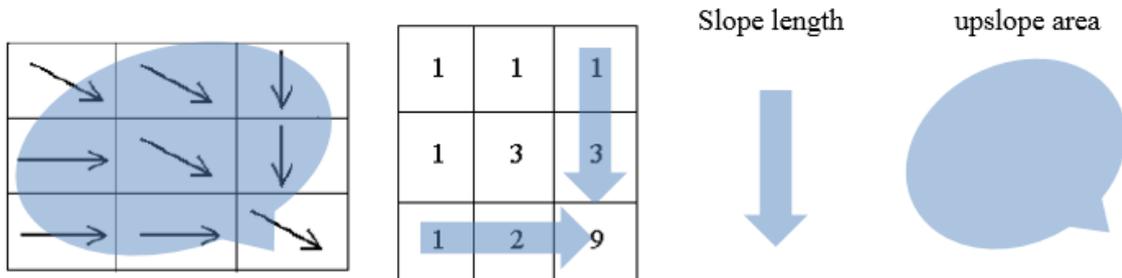


$$L = \left(\frac{\text{slope length}}{22.1} \right)^m, \text{ } m \text{ between } <0.1 - 0.7> \text{ based on slope}$$

$$S = 10.8 * \sin \theta + 0.03 \text{ for slope } < 9 \%$$

$$S = 16.8 * \sin \theta - 0.5 \text{ for slope } > 9 \%$$

θ = slope angle (deg/rad)



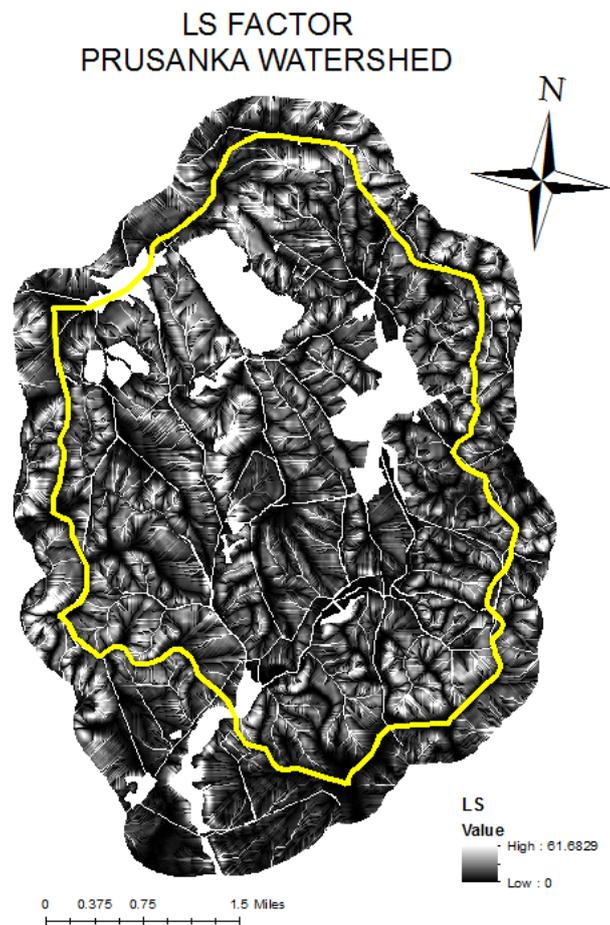
In 3D topography:

$$LS = \left[\frac{\text{norm. upslope area}}{22.1} \right]^m \left[\frac{\sin(\theta)}{0.09} \right]^n$$

$m <0.4 - 0.7>$ and $n <1.0 - 1.4>$ are calibrating parameters.

Finally, we will use the tool “RASTER CALCULATOR”. From this method, we get the raster called “LS”, computing the layers and values like this:

$$LS = ((\text{"FlowA_mask"} * 15 / 22.1) ** 0.5) * (\sin (\text{"Slope"} * 3.14 / 180) / 0.09) ** 1.2$$



I. P FACTOR

It is a *Management factor* (values from 0 to 1).

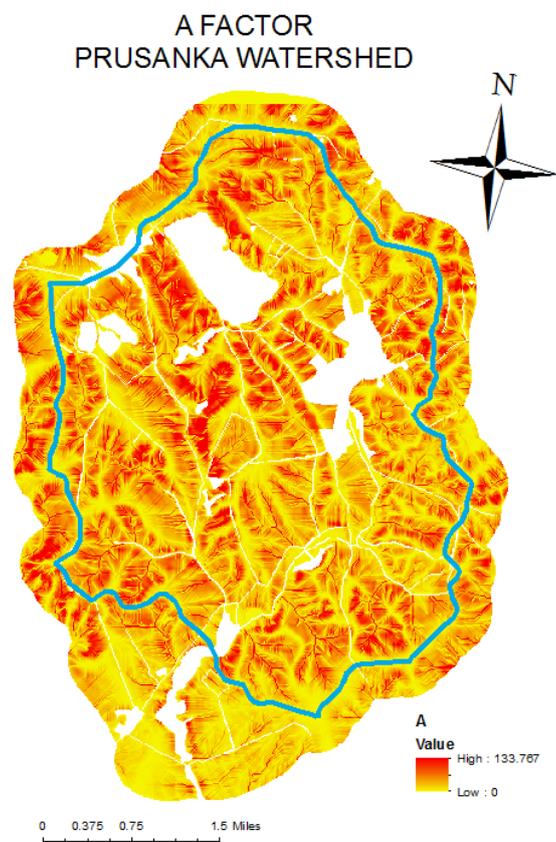
The P factor is only used if we have extra information. If there are no conservation practices: $P = 1.0$

I. SOIL LOSS CALCULATION – 3D USLE

Now we compute the values obtained to get the A value, which is the *average annual soil loss* ($t * ha^{-1} * year^{-1}$).

Now, we apply the tool “**RASTER CALCULATOR**”, which allows to operate among rasters and numerical values:

$$A = 35 * "K_factor" * "LS_factor" * "C_factor" * 1 / 100 / 100$$



With the “*A_factor*” raster, we can apply on it the tool “**ZONAL STATISTICS (AS TABLE)**”.

We get the average soil loss value **12635.27 t/ha*year** from the table “*A_watershed*”, which means this amount of soil leaves its original position inside the watershed during 1 year.

The total soil loss is **561567.393947 t/year**, which is obtained multiplying the average soil loss value times the area of the watershed in ha, also included in the “*A_watershed*”.

I. SEDIMENT TRANSPORT - SDR

SDR is the sediment delivery ratio. The smaller is the catchment, the bigger SDR value is up to 100%.

$$SDR = \frac{\text{sediment yield}}{\text{total soil loss}} = \frac{SY}{A} [\%], \rightarrow SY = A * SDR$$

$$SDR = \text{function}(\text{area}, \text{relief}, \text{CN}) = a * F^b * (RR)^c * (CN)^d$$

$$a = 1,366 * 10^{-11}; b = -0,0988; c = 0,3629; d = 5,444;$$

F is the watershed area in square km. Tool: “**CALCULATE GEOMETRY**”.

$$F = 32,53 \text{ km}^2$$

RR: ratio of the watershed:

$$RR = \frac{\text{average watershed boundary altitude} - \text{watershed outlet altitude}}{\text{maximal stream length}}$$

To compute the “average watershed boundary altitude”, we divide the average and minimum heights. We need to convert the “*watershed*” layer (polygon) into a line, so we use the tool “**POLYGON TO LINE**” creating the vector “*watershed_boundary*”. After that, we use the tool “**ZONAL STATISTICS (AS TABLE)**” applying the values of the raster “*dem_fill*” to the “*watershed_boundary*”, getting the table “*watershed_boundary_elevation*”, where we can get the average altitude.

To get the “watershed outlet altitude”: tool “**IDENTIFY**” on the layer “*dem_fill*”.

To compute the divisor, we use the tool “**MEASURE**”.

So now we only have to calculate the ratio of the watershed like this:

$$RR = \frac{257 - 190}{9.90} = 6,77 \text{ m/km}$$

CN is the average SCS (Soil Conservation Service) curve number value within the WATERSHED. To get it, we use the tool “**RECLASSIFY**” over the “*landuse*” layer, applying the following pre-established values:

1 – tracks = 92	5 – streams = 100
2 – villages = 90	6 – reservoirs = 100
3 – orchards = 76	7 – forests = 65
4 – vineyards = 81	10 – 161 – fields = 80 (average)

We get the raster “*CN*” and apply over the “*watershed*” the values of “*CN*” with the tool “**ZONAL STATISTICS AS TABLE**”:

$$CN = 80,18$$

$$SDR = 1,366 * 10^{-11} * 32,53^{-0,09881} * 6,77^{0,3629} * 80,18^{5,444} \\ = 0,4498 \sim 0,45$$

Now we can calculate the Soil Yield (SY), which is the amount of soil leaving the field:

$$SY = SDR * A = 0,45 * 12635,27 = 5685 \frac{t}{year}$$

RESERVOIR TRAPPING EFFICIENCY (BRUNE, DENDY)

$$TE = 100 \cdot 0,97^{0,19 \log(C/I)}$$

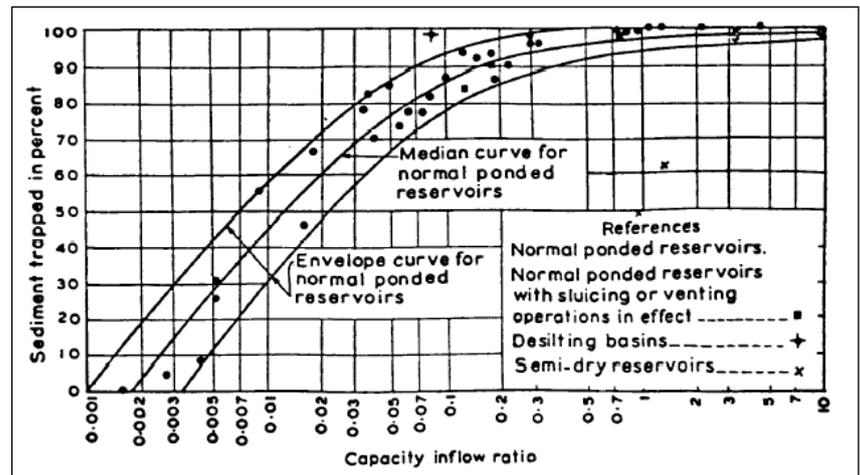
C (volume) = 142 000 m³

I (outflow) = 1 419 120 m³/year

I=0,0416667 m³/s=42 L/s

Sediment bulk density: 1,2 t/m³

Reservoir duration: 25 years



$$SY = 5685 \frac{t}{year} = 5685 * 1,2 = 4738 m^3/year$$

$$Total Load (25 years) = 4738 \frac{m^3}{year} * 25 years = 118437,5 m^3$$

$$TE = 100 * 0,97^{0,19 \log(\frac{C}{I})} = 100 * 0,97^{0,19 \log(0,1006)} = 85,24\%$$

$$Sediments Trapped = Total Load * TE$$

$$Sediments Trapped = 118437,5 m^3 * 0,8524 = 100956,13 m^3$$

SEDIMENT AMOUNT MEASUREMENT AND CALCULATION

From the catalog we will include the new layers: “*sediments*” and “*reservoir*”.

From the “*sediments*” layer, we use the tool “**CREATE TIN**”, to create a TIN surface. We will convert that TIN surface into raster, using the tool “**TIN TO RASTER**”. This raster is called “*sediment_raster*”.

After that, within the area of the reservoir, we apply “**ZONAL STATISTICS (AS TABLE)**” *once again, so we can get values as the average height:*

Area of the reservoir = 124310.720477m²=12,43ha

Volume of the reservoir= 142 000 m³

Average height=94.387244 cm

Now, we compare the results that we got from the previous chapter using the trapping efficiency and the measured ones:

Sediment amount = area*height average/100

Sediment amount = 111864 m³

Sediment Amount = Area * Height Average/100 = 111864 m³

As we can observe, the difference is not really remarkable

$$118437,5 - 111864 = 6573,5 \text{ m}^3$$