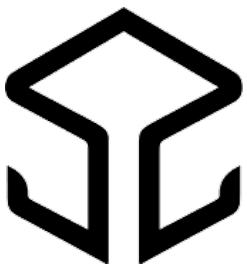


# 2019

## Project MetFure. Research Report



# NIBIO

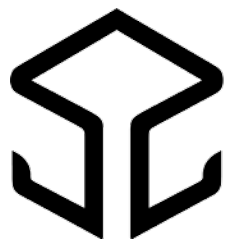
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Date: 13th of June  
2019

# Research report

# Project MetFure

|                          |  |
|--------------------------|--|
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| Date:                    | 13th of June 2019                              |
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**NIBIO**

## Preface

In front of you lies the research report on the development of a method to map gully erosion. This research report has been written as a product for my bachelor internship and as a manual for colleagues who wish for an accessible method to map and quantify gully erosion at NIBIO in Ås, Norway. I have worked on this project since March the 25<sup>th</sup> 2019 until July the 5<sup>th</sup> 2019.

At the beginning of my internship, I only had a slight idea on what I was getting myself into. I knew that a method had to be developed to measure gully erosion with drones and roughly which software could be used for it. It was the first time for me to be abroad for a longer period, so I was a bit nervous in the beginning and needed more aid and help from my colleagues to get the hang of all the work that needed to be done.

Thanks to Robert Barneveld and Jannes Stolte I managed to apply the software necessary to get a model of gullies. I learned a lot about how to apply Photoscan to create height models. I also learned how to successfully apply SAGA to create profiles and how to use Excel for further calculations on gully erosion. The successful application of LISEM is also a skill I picked up while I was here at NIBIO. To model catchments, and thus gully erosion in Skuterud.

I would like to thank Jannes Stolte and Robert Barneveld for their aid, patience and their expertise that helped contribute to this product!

I would also like to thank Rémon Saaltink, my family and friends for his enthusiastic support and feedback during this internship abroad.

All your aid and help during this internship has encouraged me greatly to deliver this research report and manual to you.

May it aid you well.

Maurice Pals,

Ås, 3th of June 2019.

## Summary

Project MetFure is a project within NIBIO that is striving to develop a method to measure, map and quantify gully erosion, utilising drone photogrammetry. The reason behind this project is that the need existed for a faster method to map gully and quantify gully erosion. Drone-photogrammetry offered a solution to this problem.

Still, there was no set method to map and quantify gully erosion using drone photogrammetry to this day. So, the goal was to develop a set method, using drone photogrammetry and new software to map and quantify gully erosion.

To come up with a set method, multiple approaches and tests have been carried out to effectively use the software. These tests include, comparing conventional measurements to drone measurements and a lot of working with software like Photoscan, SAGA and LISEM. The working and testing with this software have led to a manual that describes the method to map and quantify gully erosion from beginning to end.

The end results are the manual with the method for quantifying and mapping gully erosion along with a couple of recommendations on how to measure and map these processes. These are, to keep an eye out for grass tufts when measuring gullies with drones. The drone cannot distinct grass from soil accurately, so this is something to keep in mind. The deviation between the conventional measurements and drone measurements on average is about 1 centimetre, which is caused by vegetation.

For this reason, it is safe to assume that, when measuring larger gullies with the drone, this deviation will not occur if these larger gullies are "fresh" and contain no vegetation when measuring with the drone. The deviation of 1 centimetre also proves to be less of a problem when measuring bigger gullies. For example, when measuring a rill with a depth of 5 centimetre, then a deviation of 1 centimetre makes much more of a difference in the calculation of the rills volume than it does when calculating the volume of a big gully with a depth of 30 centimetres. This proves that measuring bigger gullies with drone photogrammetry provides enough accuracy to get a good idea of the amount of gully erosion that takes place.

Another recommendation is that, when measuring gullies with drones, to set the altitude of the drone according to the slope of the area. The best altitude is 20 meters because this offers the best quality image in relation to the least amount of processing time in the software. When taking off with the drone at the foot of a slope, it is recommended to set the drone height a bit higher to ensure enough overlap of the images is achieved at the higher points of the hill. This is because the drone remains at a stationary altitude once it has taken off.

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## 1 Introduction

NIBIO is doing research on gully erosion and is developing a way to effectively map and quantify this, using drones and software. The study was commissioned by the ministry of agriculture of Norway. The project started on the first of January 2018 and will end on the first of March 2021. This is an important study because gully erosion is a threat to soils and surface waters in Norway. For example, eutrophication of the surface waters occurs when a gully is connected to surface waters. This is a big problem because it affects ecosystems in the surface waters. Eutrophication occurs when there is an abundance of phosphates in the surface waters. Farmers use fertilizers, containing phosphates, on their land and these fertilizers end up in surface waters via catchments (gully erosion). The abundance of fertilizers in the water causes a rapid growth of algae, which will then proceed to cover the water surface. This causes the sunlight to be blocked, which water plants need to survive. The oxygen in the water drops since the water plants that produce it will die due to a lack of sunlight. This causes a lack of oxygen in the water which will then proceed to wipe out the rest of the aquatic life in the area. Mapping and monitoring the gully erosion that carries phosphates to the surface water is therefore essential to prevent the eutrophication of the surface waters.

There is still is not an easy method for mapping and quantifying rill- and gully erosion. For this reason, there is the need for more knowledge on rill- and gully erosion and which new technologies can be of use to model it. The coming weeks will mainly compose of experiments with drones and the use of applicable software to quantify gully erosion. Some calculations will also be made utilising LISEM, to quantify soil- and gully erosion.

The goal of this study is gaining more knowledge on quantifying rill- and gully erosion and developing a method to map and quantify it effectively. The areas in which the study will take place are Skuterud and Mørdre. These areas are representative of other agricultural areas in Norway and contain some rills to measure with drones.

The developed method for mapping and quantifying gully erosion shall be recorded in a manual. Also, the way the method has been developed will be recorded. This manual will offer employees within NIBIO an anchor to map gully and rill erosion more effectively.

This study will contribute to a better understanding of the way gully erosion should be quantified. This contributes the rest of society with a means to easily monitor gully erosion, utilising drones and software. Within the first 4 weeks of the study period, an attempt will be made to scan the entire area of Skuterud and Mørdre. This must be done within 4 weeks because the farmers will start ploughing the area after that period. After the land has been ploughed, the rill and gully erosion will not be measurable anymore.

## 2 Research questions

To give this research more direction, a couple of research questions have been set up. The research questions can also be used as a reading guide.

### Main question:

What kind of method should be used to increase the effectivity of quantifying the furrow erosion with drones?

### Sub-questions:

1. What is the best altitude for drones to map soil erosion with a good quality and in as little time possible? (paragraph 3.1 and 3.2)
2. Where are the gullies in Skuterud? (paragraph 4.3)
3. How does one calculate the volume of the gully's that where mapped with the drones? (paragraph 4.1 and attachment II)
  - a. How does one calculate the volume of the gullies? (paragraph II.5 and 4.1)
  - b. Which software is needed for which steps? (paragraph II.1 till paragraph II.4 and 4.1)



### 3 Approach

In this chapter, the development of the method for quantifying gully erosion is substantiated. It is also explained how the best methods we're chosen. The method has been developed while mapping ephemeral gully erosion. For more about ephemeral gully erosion, see attachment I, paragraph I.3.

#### 3.1 Determining the optimal flight method for drones

The eventual flying method for mapping gully erosion is decided within the first two weeks of the internship. Nine test flights have been carried out on the campus of NMBU. An overview of the test flights is given in Table 1.

Table 1 Overview of test flights (DJI GO, is the original app to plan flights with for drones of the DJI-brand.)

|                 | <i>Planned flight with Precision Flight with scan of entire area. (speed = 10 m/s) (pictures after every few meters)</i> | <i>Manual flight with DJI GO-app with only the important area (variable speed) (recording)</i> | <i>Manual flight with PrecisionFlight with only the important area (variable speed) (recording)</i> |
|-----------------|--|--|---|
| <i>altitude</i> | 10 meters  | 10 meters  | 10 meters   |
|                 | 15 meters  | 15 meters  | 15 meters   |
|                 | 20 meters  | 20 meters  | 20 meters   |

With each test flight, the drone is told to map a certain stone in the area. The test flight that has the most detailed image of that certain stone will be the method that is going to be used to map gully erosion. The stone is about 10 centimetres high. The aim is a clear picture of about two to three pixels per cm<sup>2</sup> to use the method for mapping gully erosion.

After performing the 3 flight methods on three different altitudes. The pictures and movies were converted into a model of the area, using Photoscan. It immediately became clear that the areas mapped, while filming with a camera, were way less accurate than when using pictures. The 3D models of the films are bend and not reliable to use for further use. That leaves the planned flights with PrecisionFlight as the only reliable option.

In addition, three models were made of the area with three different altitudes in Photoscan. The altitude of 20 meters provided a clear image of the area with a resolution of 0,8 mm per pixel. This is deemed enough to calculate the gully volume in the next steps. More over this test in paragraph 3.2.1.

#### 3.2 Determining the method for quantifying gully erosion using software.

In this paragraph it is described how the methods for the manual are developed. This chapter focusses mostly on the effective utilisation of software.

##### 3.2.1. Developing the usage of Photoscan.

The aim of this step is to generate a Digital Elevation Model (DEM) with a resolution of about 0,8 cm per pixel.

The best way to utilise Photoscan is determined with multiple tests. Three flights are made on three different altitudes; 10, 20 and 30 metres. Of these flights, three different models are made. Of every flight, multiple models were made with different quality of resolution. The resolution of multiple combinations of altitude and processing-quality of the dense cloud in Photoscan are given in table 2. Generating the dense cloud is by far the most time-consuming step in Photoscan. It is important to experiment with different dense cloud qualities, for it will save a lot of time. Only the ultra-high and high qualities are chosen here because any lower qualities will not suffice for the quantifying of gully erosion.

Table 2 resolution of every image with different combinations of altitude and dense cloud quality.

| <b>altitude</b>                  | <b>10 metres</b> | <b>20 metres</b> | <b>30 metres</b> |
|----------------------------------|------------------|------------------|------------------|
| <b>Resolution of dense cloud</b> | x                | x                | x                |
| Ultra-High:                      | 3,95 mm/pixel    | 6,75 mm/pixel    | 10,3 mm/pixel    |
| High:                            | 7,9 mm/pixel     | 13,5 mm/pixel    | 20,7 mm/pixel    |

Another important factor when generating a model is time. To show a relation between the amount of time and the quality of the model, an overview is made of the amount of time that was used to generate the different models (table 3). A lower altitude while flying means that more pictures of the area are taken. more photos mean longer processing times in Photoscan.

Table 3 amount of time consumed while generating models in Photoscan

| <b>altitude</b>         | <b>10 metres (194 photos)</b> | <b>20 metres (78 photos)</b> | <b>30 metres (37 photos)</b> |
|-------------------------|-------------------------------|------------------------------|------------------------------|
| <b>Quality of model</b> | x                             | x                            | x                            |
| Ultra-High:             | 35,7 hours                    | 14,25 hours                  | 6,3 hours                    |
| High:                   | 7 hours                       | 3,6 hours                    | 2,7 hours                    |

Using the processing times from table 3, the average processing times of photos per hour were calculated and put into table 4.

Table 4 average processing speed in photos per hour

| <b>Number of photos processed</b> | <b>194 photos</b> | <b>78 photos</b> | <b>37 photos</b> | <b>Average processing time</b> |
|-----------------------------------|-------------------|------------------|------------------|--------------------------------|
| <b>Processing speed</b>           | Photos/hour       | Photos/hour      | Photos/hour      | Photos/hour                    |
| Ultra-High:                       | 5.4               | 5.5              | 5.9              | 5,6                            |
| High:                             | 27.7              | 21.7             | 13.7             | 21,0                           |

The average processing times for the models differ with each quality setting. When wanting an ultra-high-quality image, the average processing time is around 5,6 photos/hour in Photoscan. The number of images that need to be progressed do not affect the **average** processing time of 5,5 photos/hour.

However, when generating a model in High quality, the **average** processing speed differs per number of photos taken. When generating a large quantity of photos, the average amount of photos processed per hour rises as well.

Knowing that Photoscan processes around 5,6 photos per hour in ultra-high quality. One can calculate the processing time beforehand. The relation between height, scale of the area and with that the number of photos, can be used to determine a fitting resolution of the model, and with that, save time processing the model. The formula used here is:

$$(\text{ultra high}) \text{ processing time in hours} = \frac{\text{amount of photos}}{5,6}$$

Since the average processing time on high quality differs per number of photos taken, there is not a definitive way to formulate a formula to calculate the processing time beforehand. However, the tables do give an insight in the process. This is enough to make a rough guess of the expected calculation time.

### 3.2.2 Developing the usage of SAGA

SAGA is a program that allows the modelling of charts and certain 3D aspects of it. The calculation method of the gully's volume is developed in SAGA. Robert Barneveld developed most of the steps to calculate the gully's volume in SAGA. These steps are documented in the manual

### 3.2.3 Developing a method with LISEM

LISEM is software that allows one to simulate catchments of all kinds of areas. The goal is to simulate the catchments of Skuterud to see where in Skuterud it is necessary to check for gully erosion. A strong base with all the files needed is already available for Skuterud. From here, the first simulation was made of the catchment. The focus in this simulation is around gully erosion.

Still, some files must be adjusted to run a good simulation of the catchment in Skuterud. These files represent multiple parameters that are recognisable for the area. These are:

- Crop height (ch.map)
- The leaf area index (lai.map)
- Percentage of vegetation covering the soil. (per.map)
- The soil profile (profile.inp and profile.map)
- Characteristics per soil type, like permeability (The SWATRE tables)

For more info about these files, see the literature study, paragraph I.14. A detailed explanation is given of each filetype.

These map files need to be adjusted to match the conditions of when gully erosion occurs. For gully erosion occurs during the end of winter, start of spring. This time of year, it is still cold and wet. This means, a less permeable soil because of the frozen subsoil. A low k-value is required. There is also less vegetation during this time of year, which causes less interception. How to change these values is explained in the manual, paragraph II.6.2.

## 4 Results

The manual for the best method is given in the following paragraphs. In this chapter, the method for mapping and quantifying gully erosion will be explained step by step in a compact manner. The manual explains every step in high detail, this can be found in attachment II.

### 4.1 The method for mapping and quantifying gully erosion.

In this paragraph the theory and results behind the method are summarized. From the first steps to last.

#### 4.1.1 flying the drone

To effectively map gully erosion in the field. the drone needs to fly at an altitude of about 20 metres. This results in the least processing time with the software and a relatively fast flight. This altitude also does not compromise the resolution of the image.

#### 4.1.2 making a DEM in Photoscan

The following process must take place in Photoscan. The Photos that were made with the drone are imported to Photoscan and then the following steps must take place via the Batch processing feature;

1. Photo alignment (Ultra-high quality)
  - Here, the software will try to find overlapping aspects within the images to align them to get one big image of the area.
2. Dense cloud generation (Ultra-high quality)
  - In this step, Photoscan finds lower and higher points that were measured by the drone and are saved in the images and then proceeds to make a dense point cloud. This dense cloud is the skeleton of the Mesh (3D-Model)
3. Mesh building (Ultra-high quality)
  - The mesh is a 3D model of the area that is being generated from the Dense cloud.
4. DEM generation (Ultra-high quality)
  - The Digital elevation model (DEM) is the height model that is needed to calculate the gully's volume. This DEM is generated using the Mesh.
5. (optional) orthomosaic generation (Ultra-high quality)
  - The orthomosaic can function as a clear image of the area. This can be useful to clip the rill or gully with a polygon in saga. It is also possible to spot vegetation and other characteristics of the soil with this layer, but it is not necessary for the calculation of a gully's volume.
6. Export of DEM and orthomosaic in a directory in the "WGS 84 / UTM zone 32N (EPSG:32632)" coordinate system format

Ultra-high quality of these models allows for the best calculations of the gully's volume in SAGA. An example of a DEM is given in figure 1

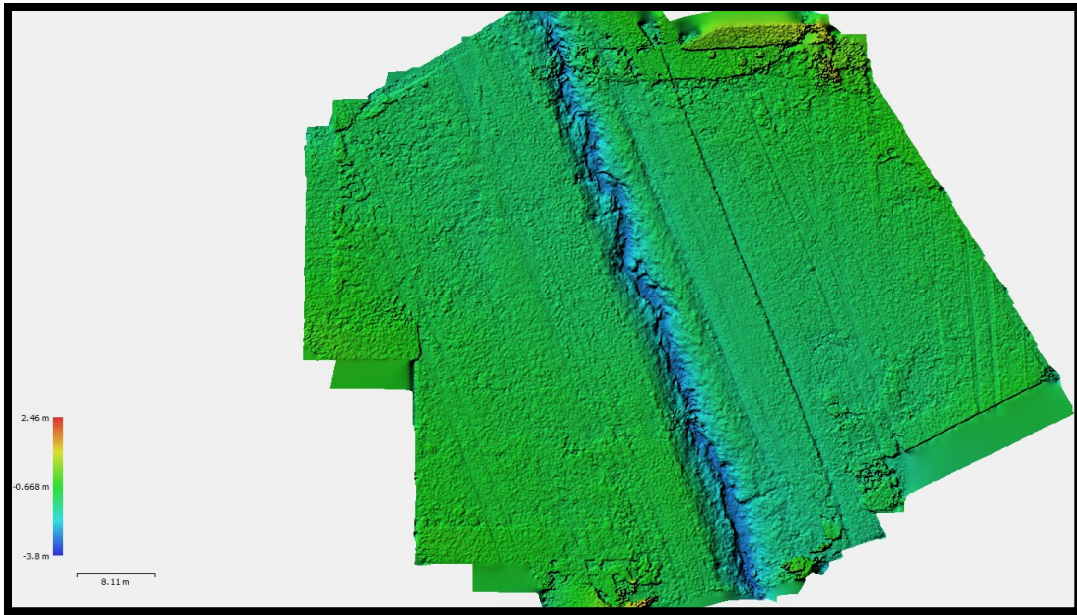


Figure 1, A Digital Elevation Model (DEM) of a creek near an agricultural field, Created in Photoscan.

#### 4.1.3 Calculating a gully's volume in saga

The calculation for the gully of the volume has been developed in SAGA. in this paragraph, the calculation is summarized shortly. To get the volume of the gully, the map layers need to be modified in a couple of steps.

The first step is to cut the area interest out, it is possible to import the orthomosaic for this task or use analytical hillshading to spot the rill in the DEM.

Then the DEM must be resampled. Resampling basically means setting a new resolution for the DEM by making the pixels bigger. By increasing the size of the pixels, the different heights per cell will be flattened according to the average height of the multiple pixels the new pixel will envelop. The bigger cells will then be resampled again to their former size, but they will keep the same values in these cells. Figure 2 depicts this process schematically.

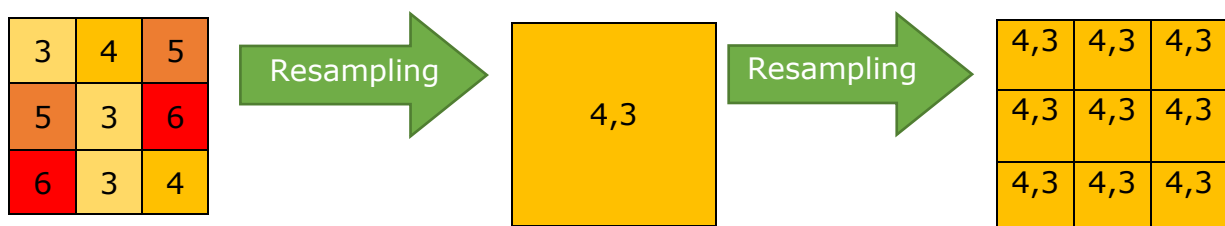


Figure 2, Resampling a 9 Dem cells into 1 DEM-cell (making it bigger) creates a new average value per cell, flattening the surface, resampling it back to the last resolution will keep the same)

The second Resampled DEM will be subtracted from the original DEM-part with the gully/rill. This will present us with the gully's volume.

It is not reliable to straightforwardly subtract the resampled DEM from the original DEM. For this reason, only the exact location of the gully in the resampled DEM and original DEM must be subtracted from each other.

This must be done in multiple steps because the DEM is a grid layer and the gully in the DEM needs to be transformed in a shape to cut out the gully in the DEM. Analytical hillshading can be used to spot the gully in the DEM. After the DEM and resampled DEM are roughly cut with a polygon around the gully, the next steps must be taken;

1. Fill sinks (Planchon/Darboux)
  - This function fills sinks and holes in the area that are not a rill or furrow.
2. Downslope area function on original DEM.
  - This is an algorithm that follows the lowest slope in the area (so a rill or gully is the logical way to follow). It is an interactive tool, so it is important that the start of the gully is clicked to get a schematic line of the gully.
3. Conversion of grid values to points.
  - The layer that the Downslope area function created must be converted to points. This can be done by selecting points with values on the data of the downslope area layer. If all data that is 0 is considered as no data, then one can easily select the rill/gully and create points on it.
4. Conversion of points to lines.
  - Once these points are created, the points can be converted into lines to create a line following the gully.
5. Creating a buffer around the line until it overlaps with the gully.
  - The line that is created will then be used to make a buffer that overlaps the gully. Be sure the buffer is only as big as the gully itself to get a more exact answer on the gully's volume.
6. The shape of the buffer is then used to cut the rill and gully out of the original DEM and Resampled DEM.
7. The grid difference function is then used to subtract the cut versions with the buffer of the resampled DEM from the original DEM.
8. The grid difference layer that appears is then used to calculate the volume with the grid volume function in SAGA.

Now the volume of the rill is calculated. For a deeper explanation on the trustworthiness of the grids and drone measurements, read the discussion in chapter 5. For the exact walkthrough to calculate the volume of gullies, see attachment II.



## 4.2 Theory on detrending the cross section of gully profiles to compare drone measurements and conventional measurements.

To compare conventional measurements with the drone measurements, the gully needs to be detrended. This method is developed and is one of the results that this research report contains. Detrending basically is removing the slope in of an area without removing the details like crevices, gullies or rills. Detrending the slope will make it easier to calculate a gullies volume for the quantification of (ephemeral) gully erosion.

If the slope is removed, it is possible to compare the profile of the gully very accurately. This is done in the with conventional measurements and drone measurements of gullies in chapter 5.

First some explanation about what kind of geometrical calculation needs to be performed on the data, that is at hand. Removing a slope without changing the volume of a gully can be done by considering slope as a triangle. An example is given in figure 3.

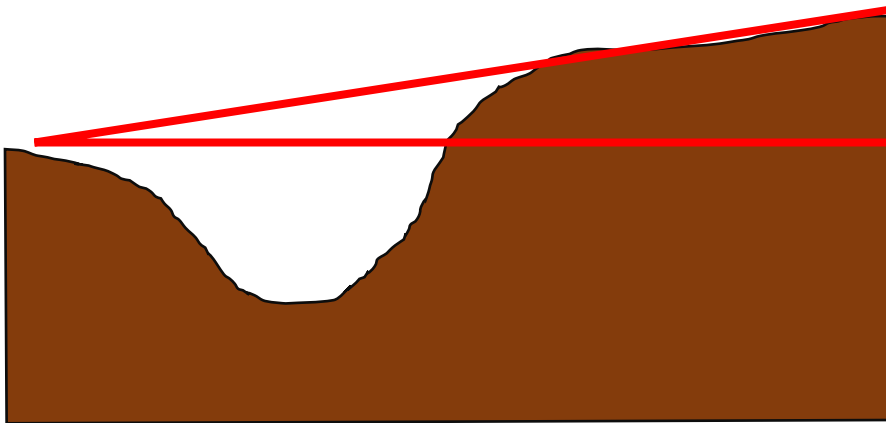


Figure 3, The slope of the profile of a gully.

For a better overview, the same triangle is given one more time but without the gully in the background with a description of all angles. (figure 4)

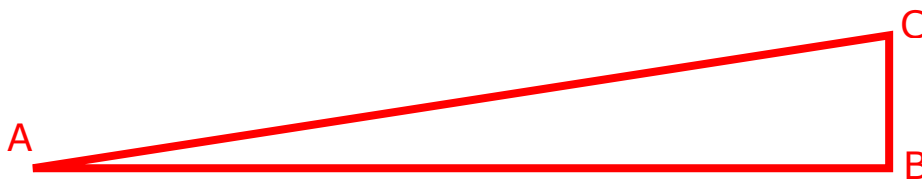


Figure 4, Depiction of the slope at a gully.

The first step to detrending is calculating the tangent of Angle A. The formula for calculating the tangent of a rectangular triangle is:

$$\text{Tangent} = \frac{\text{Opposite side}}{\text{Adjacent side}}$$

Side AB is as long as the line that was made in SAGA. Meaning the last number in the attribute table in the DIST\_SURF column. This can be like 80 centimetres for example.

Side CB should be the elevation relative to point A. This can be determined using the Z column from the attribute table. To determine the length of side CB just subtract the Z value of angle C from the Z value of angle A. In other words: Subtract the first value from the last value of the Z column in the attribute table.

**\*A tip\***

*It is easier to the first value as 0. And start counting from counting the elevation from there for it will give a better overview of the gully when making a cross section in the form of a chart. More about this will be explained in the next paragraph when this calculation will be put into practice in Excel.*

Once the Tangent of angle A is calculated, one can then remove the slope to create a flat area, while the gully maintains the same volume. This requires one more calculation, using the tangent. This formula is used to create a detrended point utilising the specific values from the attribute table of that point:

$$\text{Detrended point} = Z - \text{Tangent} * \text{DIST\_SURF}$$

By using this formula for every point in the attribute table, one can create a chart that serves as a detrended cross section of the profile. Allowing further analysing of the gully profiles.

After the detrending the gully profile will look something like figure 5

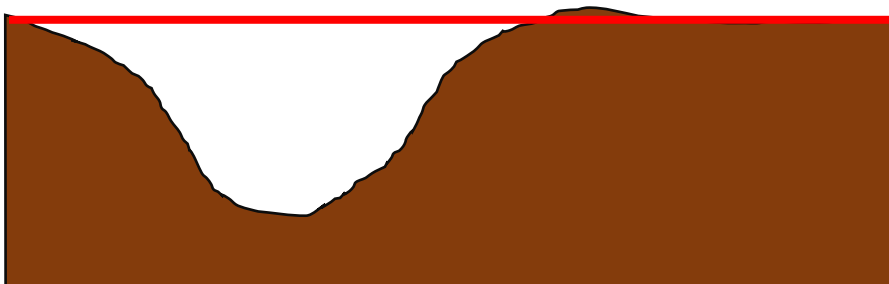


Figure 5, Detrended gully.

The flat line over the surface allows for a stable value to measure the depth of the gully at all points. Which will improve the accuracy of the calculation for the gully's volume.



### 4.3 Checking the gully's locations with LISEM.

A simulation is made of the area of Skuterud when it comes to gully erosion. The goal of this simulation was to check whether the predicted catchment locations in LISEM would appear in the same locations in the field. Figure 6 shows the simulation made with LISEM.

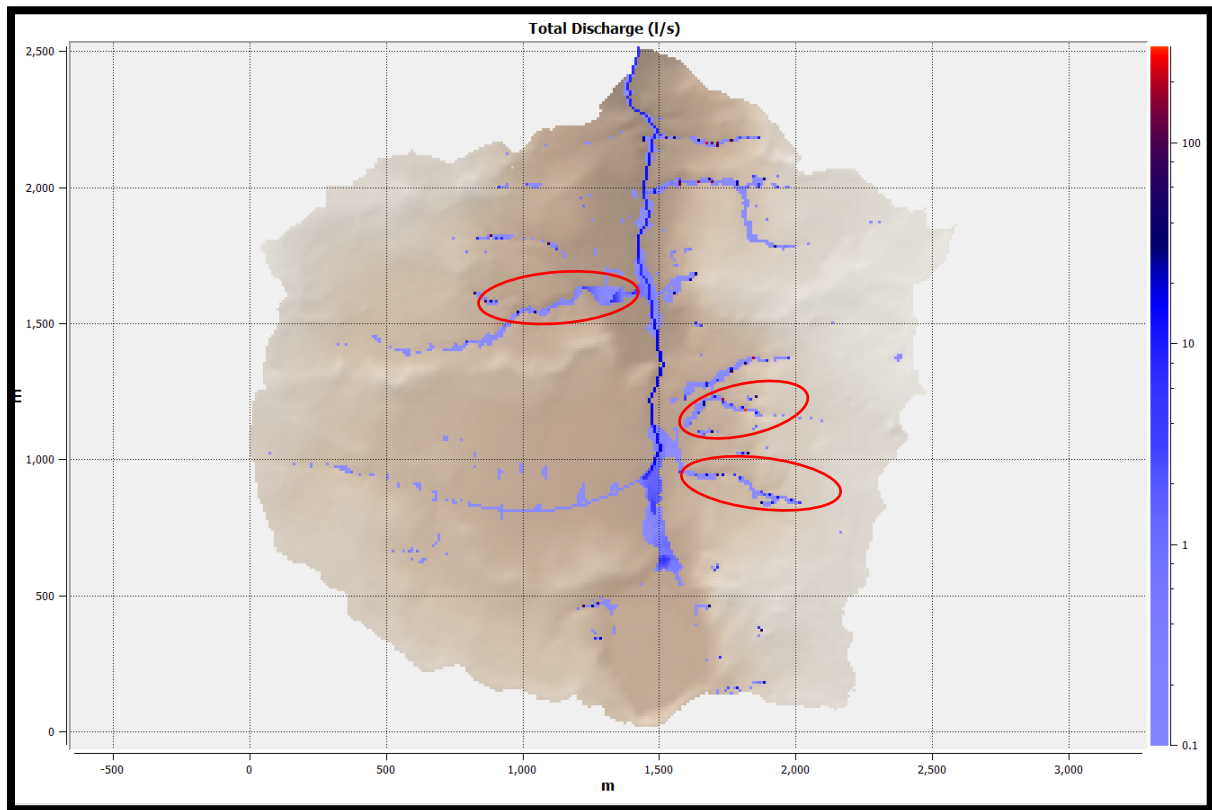


Figure 6, Gullies/Rills in Skuterud.

Due to rainfall, the following catchments started to appear according to LISEM. The catchments that were seen in the field are, encircled in the map. These catchments were only small rills. This is because due to a lack of rainfall and snowmelt during the end of last winter, this was measured in the measuring stations from NIBIO around Skuterud.

It takes some knowledge on how LISEM works to find out how to make simulation like this one. That is why this is also explained in the manual, in attachment II, paragraph II.6

## 5 Discussion

In this chapter, the results and method are interpreted, and contradictory results examined and explained. The discussion mainly focusses on the validity of drone measurements in comparison to the conventional measurements.

Three conventional measurements of gully-profiles were taken in the field to test the drone imagery for accuracy. These measures were taken in Skuterud. The goal here is that the drone measurements will not deviate from the conventional measurements for more than 1 cm on average to successfully measure rills.

Two kinds profile measurements were made:

1. One using the conventional measurements method with a scale
2. The other profile measuring method was made using drone photogrammetry.

Making a profile from the data the drone collected requires quite a few steps in SAGA and Excel. Figure 7 shows gully profiles that were measured conventionally in the field. These portray the rill's profile.

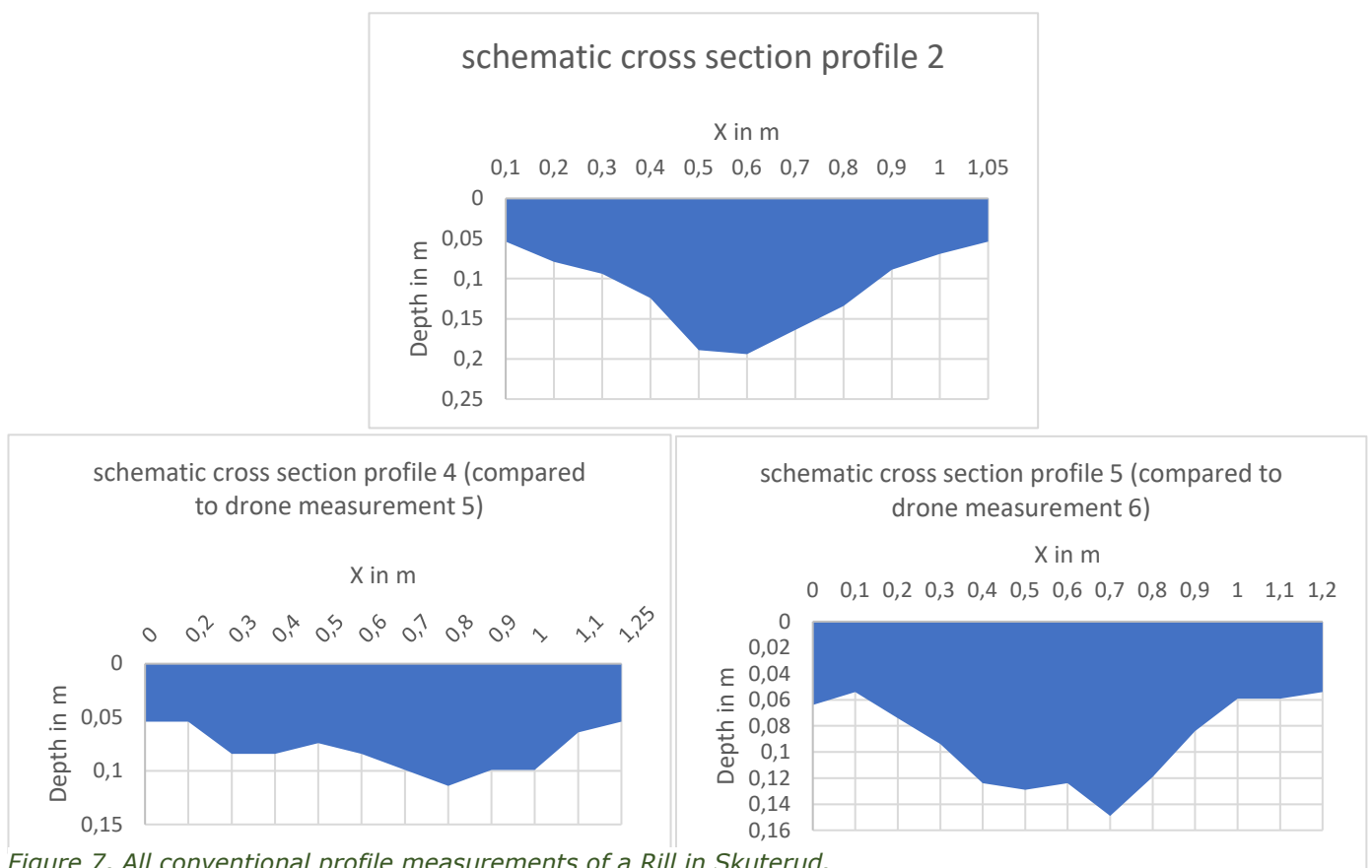


Figure 7, All conventional profile measurements of a Rill in Skuterud.

For a description on the research design of this experiment, read attachment III.

The drone measurements compared to the conventional measurements are portrayed in the following charts. The first chart in figure 8 displays profile 2 using the two methods of measurement.

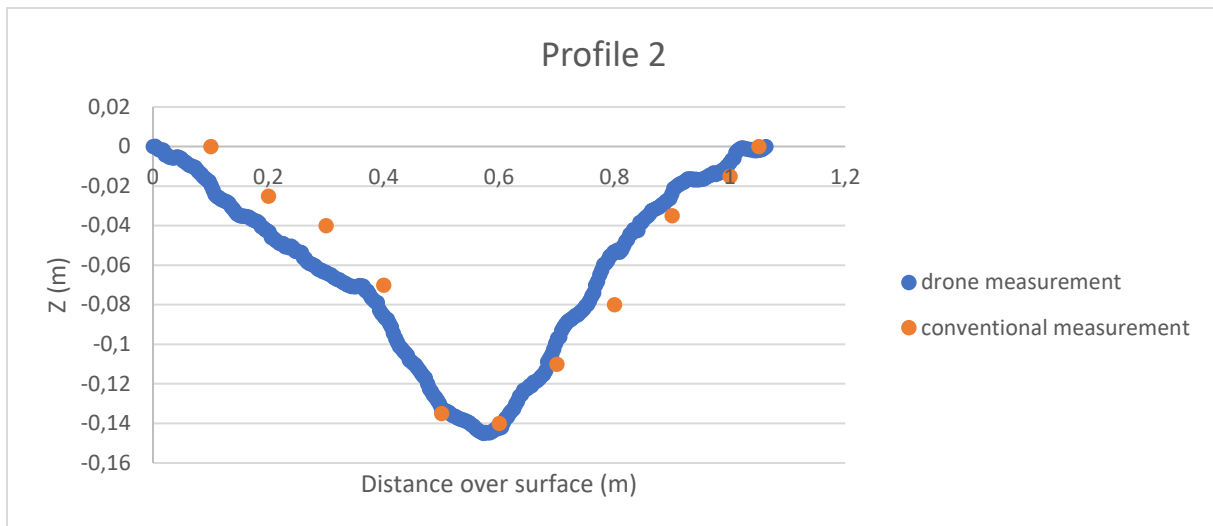


Figure 8, Cross section of profile 1.

The drone has captured the Rill's profile and shape well. The average absolute value is about 1,1 centimetres. (the average deviation from the conventional measurements)

The fifth profile measurement is shown in figure 9. The average absolute value of the drone measurement is about 1,4 centimetres in relation to the conventional measurements.

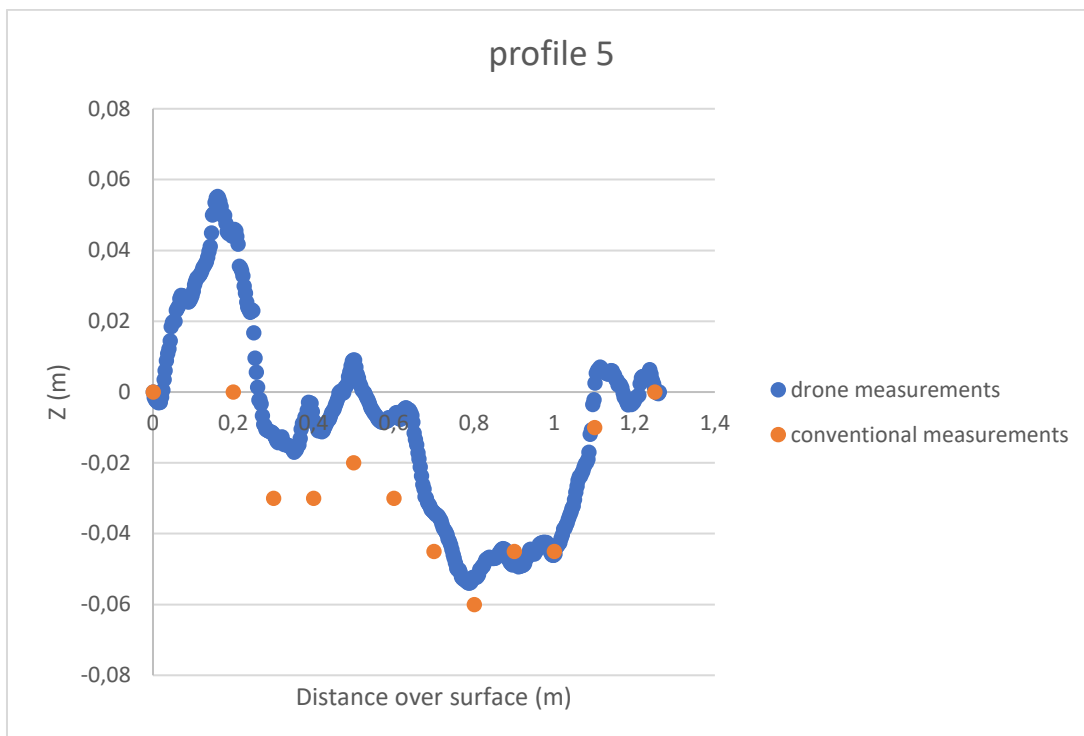


Figure 9, Cross section comparison of profile 5.

There is no deviation when it comes to distance over surface. This can be proven since the start and end of the of the drone measurement and conventional measurement are at identical locations. The conventional measurements have a standard deviation of 1,4 centimetres on average. Still this is not accurate

enough since the goal is a maximum deviation of 1 cm. The peak at the start of the chart (c. 0.2 m distance), is caused by tufts of grass.

When it comes to figure 10, there is the least amount of deviation between the conventional and drone measurements.

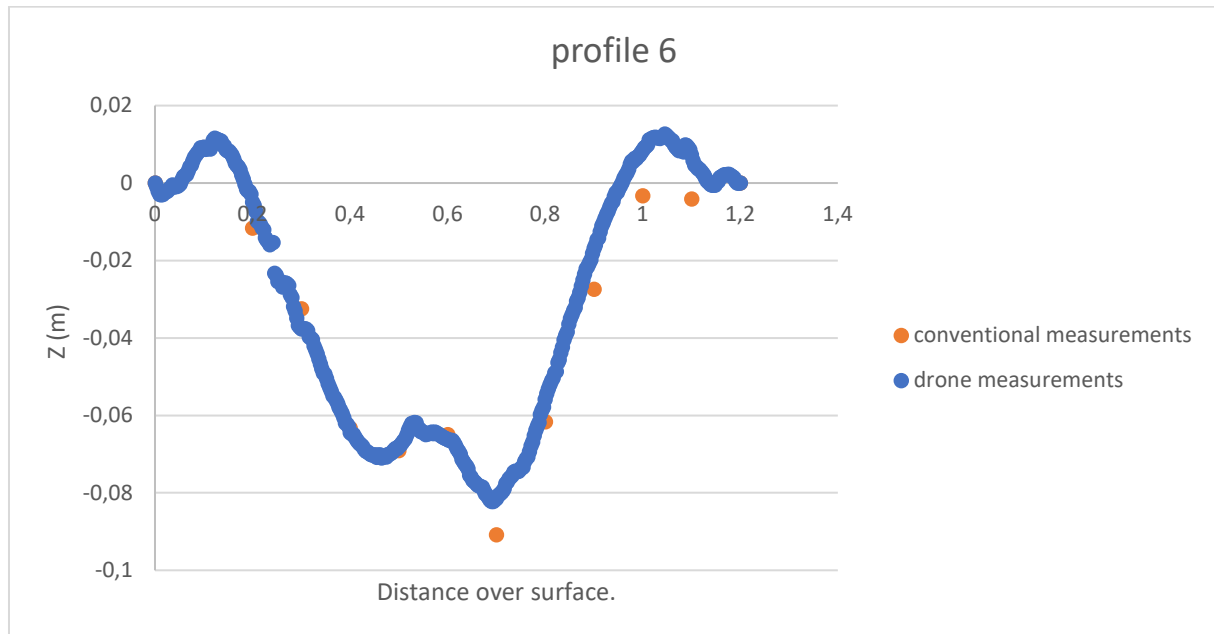


Figure 10, Comparison conventional / drone -measurements.

On the sides of the gully there are some slight deviations from each measurement. This is likely caused by tufts of grass. The standard deviation of the drone measurements in relation to the conventional measurement is 0,4 centimetres.

In conclusion, the drone measurements differ a couple of centimetres in relation to the conventional measurements. After examining the areal pictures, it is very likely that these deviations are caused by tufts of grass. This is something to keep in mind when measuring rills next time. This can be prevented to start and end the conventional measurements on (more) bare spots of land. These are more easily distinguished by the drone.

This rill was very small (only about 10 centimetres deep). When measuring large gullies (around 30 to 50 centimetres deep) this slight deviation will not cause much problems when calculating the gully's volume. This is because the big gullies do not contain the vegetation that cause the deviations in the drone measurements. This means it can be presumed that drone photogrammetry is suitable for measuring big gullies. Another advantage is that drone photogrammetry is much faster than the conventional method and allows for the generation of height models unlike with the conventional methods.

The standard deviation of < 1,4 cm is a problem for measuring small rills but the speed of drone photogrammetry and this slight deviation in relation to the measuring of bigger gullies does not outweigh the speed of drone measuring in comparison to any conventional means.

## 6 Conclusions

The conclusions of this report are based on a couple of recommendations. These are things to keep in mind while flying the drone or when calculating the gully's volume.

For starters, when flying the drone, it is recommended to look at the slope of an area before releasing the drone in the air. The drone will only fly on an altitude of 20 metres from its starting point and will not go higher or lower to match the altitude based on the slope of the area. If the drone needs to fly upwards a slope on route, it is recommended to set the altitude a bit higher than 20 metres to ensure enough overlap of the imagery further up the hill.

Another recommendation is that it is important to keep in mind that grass tufts can compromise the drone's accuracy when measuring a rill of gully. The drone will see grass tufts as elevations in the area, while this is not the case. This is something that was dealt with during the research on the drone's accuracy when measuring gully erosion in the field in comparison to conventional measurements.

Since the deviations between conventional measurements and drone measurements were around 1 cm each, and were mostly caused by tufts of vegetation, it is safe to assume that larger gullies are suitable to measure with drone photogrammetry. This is because large gullies are about 30 cm deep and contain no vegetation that will cause the drone measuring to deviate. Also, a deviation of 1 cm would not impact the outcome of the volume calculation of these gullies as much as with little rills, which proves that drone photogrammetry is acceptable for the measuring of larger gullies. Especially because drone photogrammetry is a much faster method than any conventional means.

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## **Attachment I: Study of literature**

To effectively participate in the MetFure project. There existed a need of more knowledge about the subject "Gully erosion" and the modelling-programs that are used to map the Gully erosion. In this attachment, the research conducted on these subjects is summarized. There is also information about NIBIO and what this research institute does.

### **I.1 About NIBIO**

NIBIO is an abbreviation of "The Norwegian Institute of Bio-economy Research". NIBIO researches a wide spectrum of subjects. Their main aim is to contribute to food security and safety, sustainable resource management, innovation and value creation through research and knowledge production within food, forestry and other bio-based industries. (NIBIO, 2019)

NIBIO is divided in a couple of divisions. These divisions are:

- The Division of food Production and Society
- The Division of Biotechnology and Plant Health
- The Division of Environment and Natural Resources
- The Division of Survey and Statistics
- The Division of Forestry and Forest Resources.

The MetFure project takes place within the Division of Environment and Natural Resources. To tell something more about this division, this division performs research on the following subjects;

- Soil;
- Water;
- Waste;
- Vegetation;
- Green technology;
- And climate.

The Division of Environment and Natural Resources aims to find, present and make use of research-based knowledge. The gained knowledge will then be used to secure a safe environment and to protect and utilise natural resources in the best possible way.

The Division of environment and Natural Resources contributes to the development of bio economy in Norway and abroad. Their contribution consists of the documentation and development of biology based environmental technology and natural processes. These technologies and systems can then be used for things like sustainable recycling of waste derived from the industry into energy resources. Another thing that this division is doing is the realisation of urban greening. Urban greening is important because it contributes to the mitigation of extreme weather effect and provides better chances to utilise local resources.

The Division of Environment and Natural Resources consists of several departments. These departments are called:

- Bioresources and Recycling Technologies



- Soil and Land use
- Soil Quality and Climate Change
- Terrestrial Ecology
- Water Resources
- Ecosystems in the Barents region

The MetFure Project takes place within the department of Soil and land use. (NIBIO, 2019)

The focus of this department is creating a better understanding of the water pathways and soil processes that lead to nutrient and particle transport. The goal in mind here, is to contribute to the reduction of environmental effects that negatively impact the usability of the soil, especially for agricultural purposes. Examples of these processes are soil erosion and nutrient loss. The Department of Soil and Land use aims to increase their understanding of these processes so that measures can be taken to protect agricultural fields etc. (NIBIO, 2019)

## I.2 About the MetFure Project

The internship's focus rests on the MetFure Project. This Project's main goal is the development of a **method** and testing of drone-photogrammetry to quantify furrow erosion (rill- and gully erosion). (This is **Fure**-Erosjon in Norwegian, hence the name of this project). After quantifying the furrow erosion, there will be an estimation of the contribution of this type of erosion to the total soil loss in Norway.

The project has a couple of sub-goals:

1. Gaining more knowledge about during which weather conditions, which climate conditions and where on the farmland furrow erosion occurs.
2. Gaining more insight in the amount of runoff of particles and nutrients that is caused by furrow erosion to surface water.
3. The developing of a manual for management and the individual farmer to be able to map out erosion while making use of a regular camera.

The group that is targeted for is project is the agricultural and waterway administration from local to national level. (NIBIO, 2019)

The MetFure Project is part of the JOVA program. The JOVA program is the Norwegian Agricultural Environmental Monitoring Programme. (the Norwegian abbreviation is JOVA). The JOVA programme aims to monitor and document the environmental effects that are originating from agricultural practices.

The results from JOVA are taken by the government for in their policy with the farmers. The results from the JOVA programme are also important for the next measures that should be taken with the implementation of the Water Framework directive. (WFD, KRW in de Netherlands.) (NIBIO, 2019)

### I.3 Different types of soil erosion

Furrow erosion is caused by furrow irrigation. Furrow irrigation is a type of irrigation that makes use of furrows within agricultural fields. An example can be seen in Figure 11. It is one of the oldest methods to irrigate agricultural fields. Water is being sprayed into the furrows from one side of the field. And the runoff water is let out on the other side of the field.



Figure 11: A crop field being irrigated with the furrow irrigation method. (Quora, 2018)

These furrows are often the starting point where rill erosion appears, followed by gully erosion. (read I.4 for a more detailed explanation) Many definitions are used for this kind of erosion without a clear distinction between rills and gullies. (Øygarden, 2001). Here at NIBIO, rills are classified as small furrows that are about 10 cm deep and do not encounter surface waters. Gullies however, do encounter surface waters and are deeper than rills. The deepest gullies in Norway are about 50 cm deep.

One of the most common used definitions (to separate rills from gullies) is that gullies are deep enough that normal soil tillage will not be able to remove them. If tillage can remove them, then it is called rill erosion (less than 30 cm deep). Rill erosion is sometimes called ephemeral gully erosion.

Definitions and distinction vary with every study. Within this study, the definition of rill erosion will be utilised. Rill erosion is entirely caused by flow and not by the impact of raindrops. Ephemeral gullies are short-lived since the area is annually being restored by tillage. Classical gully erosion however, is more permanent. Ephemeral erosion develops where water naturally concentrates in furrows in ploughed fields. Other locations where rill erosion may occur are field roads or thalwegs. (Øygarden, 2001)

Another type of erosion is sheet erosion. sheet erosion occurs when thin layers of soil are removed from sloping land. the velocity of surface run-off is about 0,3 to 0,6 meters per second when sheet erosion appears. The direct impact of raindrops causes the soil to move downhill. (splash erosion). When time gradually progresses, sheet erosion starts to become detectable and can be observed. For example, the exposure of subsoil and roots.

#### **I.4 The development of gullies in a nutshell**

In Norway, gully erosion is a problem, due to heavy rainfall and the melting snow. In the beginning of spring, there is a lot of water that needs to run off. The rills within the agricultural fields cannot carry all the water. The reason for this is because the top layer of the soil (Topsoil) is very porous due to the melting of the ice within the soil. However, the layer underneath the top layer (Subsoil) is still frozen, which prevents further infiltration of water. The water cannot infiltrate further into the soil, so rills join, and large gullies start to appear upon the surface. Another factor is that, at the time the snow is melting, there are no crops in the field, so there is little to no capacity to absorb the waterflow. The furrows start to erode, and the nutrients and soil start to wash away due to the large amount of water. Large gullies start to appear because of the erosion (Figure 12). (Øygarden, 2001)



*Figure 12: Gully erosion on an agricultural field at the end of the winter (clay). (Fieldcropnews, 2017)*

These gullies cannot be eliminated by any normal means like tilling or ploughing because they are too deep. These gullies are mostly deeper than 30 cm. (Geyik, 1986)

The waterflow transports the nutrients, particles and phosphates to the lowest point in the area, which is usually a lake or a river. Here, the extra nutrients, soil particles and phosphates end up in the surface water. This creates new problems.

## **I.5 Eutrophication**

Phosphates are common in the fertilisers that are used in the agriculture. They increase plant growth. After the harvest, a lot of these phosphates remain in the soil. When this soil encounters processes like gully erosion, the phosphates are being transported with the waterflow to surface waters. The problem that occurs next is eutrophication. Eutrophication is what happens when an excess amount of organic matter is present within the surface water. (In this case, Phosphates are the cause for the eutrophication.)

When there are too much Phosphates in the surface water, the number of algae in the surface water will increase rapidly. The number of algae will be so large that the entire surface of the water will be covered. No sunlight can get through the water surface anymore, resulting in the dying of flora underwater. The rotting flora uses up de oxygen in the water which result in the death of fish. (University of Wageningen, 2019)

For this reason, it is important to take measures against gully erosion and to protect the surface waters against it.

## **I.6 Protecting the soil**

Another reason for wanting to take measures against gully-erosion is, wanting to protect the soil and its ability to grow crops on it. Gully erosion takes nutrients and usable soil away and the streams render that part of the soil useless. Especially when there is a lot of water that needs to run off, like during heavy rainfall and the thawing of snow. Phosphates in the soil are crucial for providing people with enough food. The amount of Phosphates on this earth is not limitless. For this reason, there is the need to utilise the phosphate sources in a sustainable way. Gully erosion is a waste of phosphate that could otherwise be used for agricultural purposes.



## **I.7 Factors that influence the origination of gully erosion**

When formulating the measures against gully erosion, one should always know how the gully erosion originated and which factors contributes to that origination.

The origination of gully erosion depends on a lot of factors:

- The amount of topsoil thawed,
- The permeability of subsoil,
- Whether the pores in the top soil are already saturated with water or not,
- The weather conditions,
  - o the amount of rainfall,
    - monthly distribution of rainfall
    - rainfall intensity and run-off
  - o The amount of snowmelt,
- Topographical factors
  - o Shape of catchments
  - o Size of catchment, (A large catchment means a large amount of run-off.)
  - o Length and gradient of the slope. (Longer slopes mean more accumulation of water towards the base), (The steeper the slope the higher the velocity and erosive power of the run-off)
- The type of soil,
- The amount of vegetation left during the winter season. (more vegetative cover means more interception of rainfall)
- How often the agricultural field is being ploughed,
- Knickpoints in the slope,
- The changing of land use,
- The gradual changing of the climate,
- Tracks of vehicles and livestock
- (Other) measures that were already taken against gully erosion

(Geyik, 1986) (Øygarden, 2001)

All these factors (and possibly even more) dictate the risk of originating gully erosion. So, while formulating a strategy to counter gully erosion, one should consider these factors before implementing measures. Some measures might be more effective than others when taking the originating factors into account.

## **I.8 Taking measures against gully erosion**

Multiple measures can be taken to reduce the risk of gully erosion. The best measure depends on the factor that is the most normative for the origination of the gully erosion.

For example, planting vegetation alongside gullies improves the structural strength of the soil and makes it harder for the gully to erode any further. An example is winter grass.

## **I.9 The drone that is used for quantifying gully erosion**

The MetFure project is about developing a method with drones to map furrow erosion in agricultural soils. So naturally, there is going to be some flying done

with these drones. There will be made use of the DJI Mavic Pro drones for this. (Figure 87)



*Figure 13 The DJI Mavic Pro drone.*

This drone can fly manually and on automatic pilot. It can reach top speeds of 65 kilometres per hour. It can fly for up to 30 minutes at a time. So, bringing extra batteries when out doing measurements in the field, is essential. More about measuring with drones in sub-paragraph I.10.3.

This Drone has a couple of cameras on it. It had one camera on the downside that is used for landing. There is one bigger camera on the front that is used for filming and taking pictures. There are also two smaller cameras on the front that are used for detecting obstacles to prevent the drone from crashing.

### **I.10 Relevant software**

In this paragraph, the relevant software that is used within this project is being described. These programs are all free except Photoscan pro.

#### **I.10.1 Open LISEM**

Open LISEM is a program that has been developed for the mapping and calculating of erosion. LISEM is an abbreviation for the Limburg Soil Erosion Model. It is a model that simulates runoff, shallow floods and sediment dynamics in rural and urban catchments. The model is designed for the management of disaster risks, the model should not be used for long term estimates. (University of Twente, 2019) Once a couple of parameters like flowrate, the volume of the gully and the steepness of the slope are known, it is possible to let this program run a simulation of the erosion. it will then also calculate things like the amount of sedimentation and erosion, but also the number of particles and nutrients that are being taken away by the rill- and gully erosion.

LISEM uses the maps from PCRaster (I.10.6) to simulate the amounts of run off etcetera. Models that are also utilised in LISEM are the pF curve (water retention)

### I.10.2 QGIS

QGIS is a program in which one can create maps. The raw data that is obtained through measurements and calculations can be used in QGIS to get an overview through a map. First the raw data + coordinates should be put in an Excel file. Then the data can be read into QGIS to form a map. These maps provide a nice overview of the calculations that were made.

### I.10.3 Precision flight

Precision flight is the App that is used for scanning of the field. This app sets the route and scanning area of the drone. The app connects with the drone and sets out the route it needs to fly. The route can be easily set, by drawing a polygon on a smartphone. The smartphone is then plugged into the controller of the drone. (Figure 14)



*Figure 14 DJI Mavic Pro Drone controller with a smartphone plugged into it.*

Once the route is set, the drone is ordered take off and it will take pictures of the landscape beneath it every few meters. It will continue to do this until the entire marked area is photographed and measured. The altitude of the drone also is an important parameter for detail in the image. The higher the altitude, the less detail in the image, the faster the drone will be finished photographing the area. If the altitude is lower, then the image will be more detailed, but the drone will have to make more rounds to measure and photograph the entire area. Finding the best ratio between the amount of detail and flight time is also a part of the MetFure Project.

#### I.10.4 Photoscan

After the drone has finished photographing and measuring the area, the data is stored on an SD card on the inside of the drone. The pictures and data should then be moved onto a computer and be imported to Agisoft Photoscan Professional. (Photoscan for short)

Photoscan is the program that uses the measurements and data from the drone to make a 3D model of the area. This 3D model's detail is very high. (If flown with a with a low altitude)

When flown with an altitude of about 20 meters. The Picture resolution is about 0,6 centimetres per pixel.

Photoscan can build DEM- and orthomosaïc based models. These files can then be used to make maps and analysis in SAGA or QGIS.

Fun fact: Photoscan Pro costs about 35000 NOK, which is approximately 3500 euros. Photoscan is also used in the videogame industry to make 3D rendered areas in high detail.

#### I.10.5 SAGA

After the first 3d model is made, SAGA can be used to adjust image of the area even further. For example, there is an option where it is possible to add colours to the differences in height of the area. SAGA is a GIS program that can calculate with 3D surfaces. For this reason, SAGA will be used for the calculation of the volume of gullies. SAGA will be used to ready the 3D model from Photoscan for the quantifying of gully erosion. the 3d model will be modified with this software to calculate the volume of the gully efficiently.

#### I.10.6 PCRaster GIS

This program is used as a data source in LISEM. PCRaster is a program that requires written commands to utilise. PCRaster will be used to make maps of certain areas like Skuterud or Mørdre. This is a complex process, so most of the maps will be provided by the supervisors. These maps can then be used in LISEM for simulations.

#### I.11 pF-curve

The pF-curve shows the relation between pressure and water content in the soil. Also known as the  $\Theta$  expressed in  $m^3/m^3$  and pressure ( $\Psi_H$ ) in the soil. 2 numbers are important here; Wilting point (At a pressure of 1600 KPa) and field capacity at a pressure height of 10 KPa. The plant available water content is



between these two values. This is the target value farmers would like to have. In Figure 15 is an example of a pF curve.

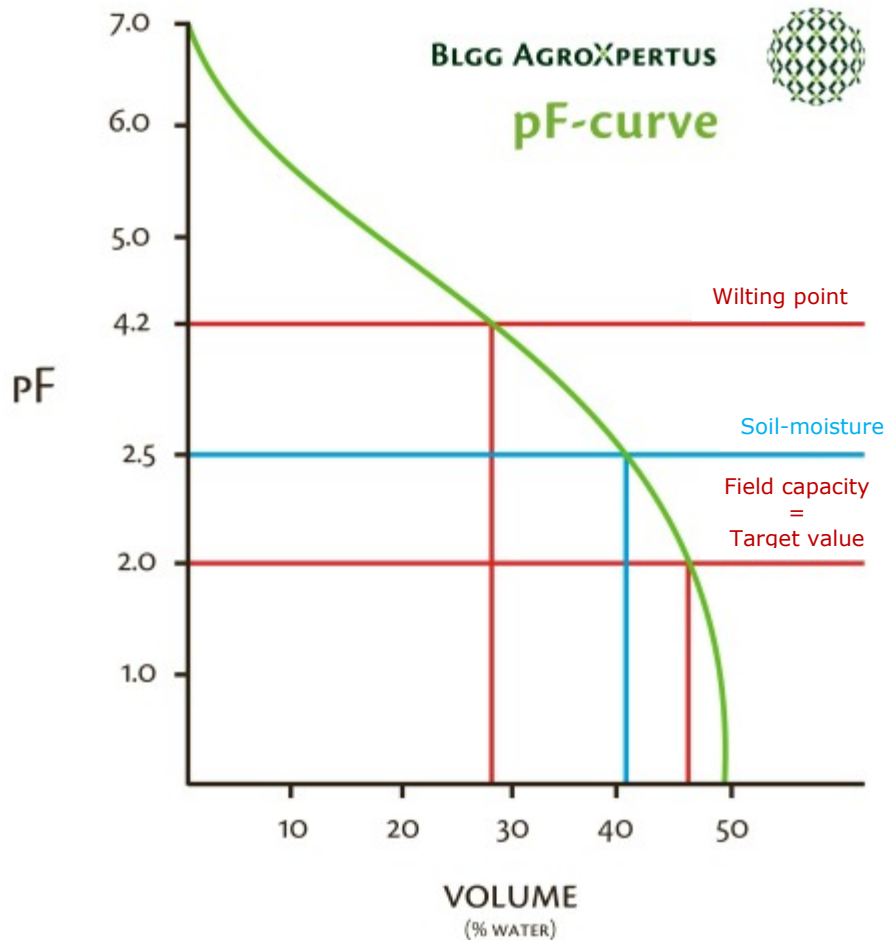


Figure 15: pF-curve (Eurofins Agro, 2014)

### I.12 pF-curve and LISEM

LISEM also makes use of this relationship to calculate if there will be any ponding. If the pF is 0,0 than that means that the soil is saturated with water. In this case, when there is a lot of precipitation over time, the saturation of the soil will cause ponding over the surface. LISEM simulates this process in the form of maps and charts over a given period. The permeability of the soil ("k" expressed in m/day) is also an important factor in this process, as it determines the speed of that the water will be drained into the soil. Soil types with very small pores, such as clay, have a very low "k-value".

LISEM also calculates the k-value of every soil horizon. Then it proceeds to run its simulation with the given amount of rainfall, amount of water in the soil and the shape of the landscape. This is how LISEM runs its simulations.

### I.13 How LISEM simulates a catchment

LISEM uses maps to simulate run-off for catchments. LISEM does this by using cells in the maps with different properties. An example of a map with different kinds of cells is given in figure 16.

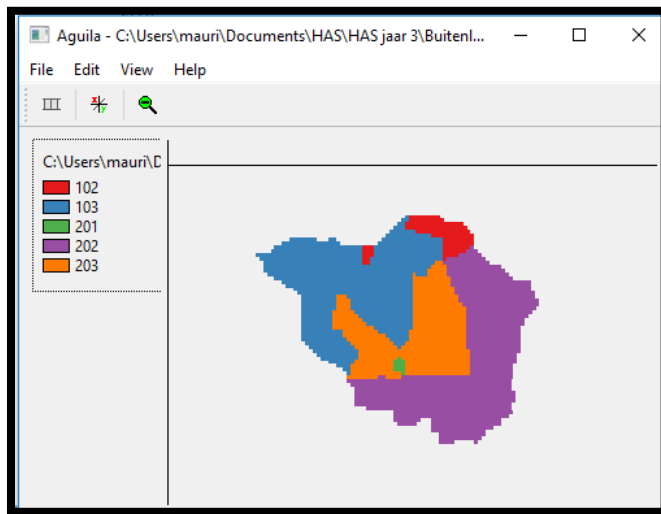


Figure 16: Profile-Map of Gryteland (piece of farmland in Skuterud)

The profile map depicts an area in Skuterud with different soil profiles. In this map are 5 different soil-profiles to be seen: 102 and 103, which are clay-ish types of soil. 201, 202 and 203 are sandy soils. This map is made up of cells, with each cell being defined by soil type. The same goes for any other map file in LISEM. Every map consists of these cells.

Every cell has a description of the soil profile underneath the cell. This can be interpreted as a column of different soil types. An example of profile type 102 is given in figure 17.

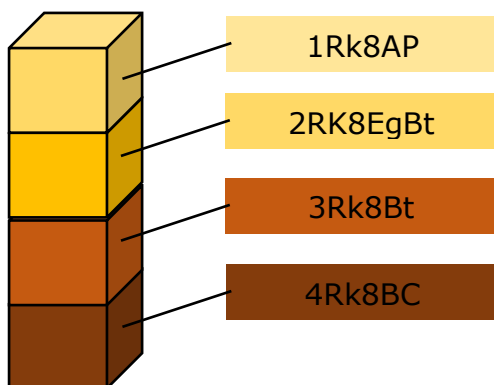


Figure 17 The soil profile of a cell in a map

The soil types are classified in the Norwegian way. The cell types are defined in the profile.inp file. This is a text-file that LISEM uses to run simulations. This file always has the same lay-out.

## I.14 Important LISEM files.

The files used in LISEM to simulate catchments are called Map-files. These are maps using cells every few meters. These cells contain all kinds of soil physical and relevant data. The most important factors (map-files) that need to be adjusted when simulating a catchment for gully erosion are:

- Crop height (ch.map)
- The leaf area index (lai.map)
- Percentage of vegetation covering the soil. (per.map)
- The soil profile (profile.inp and profile.map)
- Characteristics per soil type, like permeability (The SWATRE tables)

### Ch.map

The crop height map describes the height of the crops in every cell of the map. Crop height is an important factor for making an estimation of the run-off's catchment and gully formation. This is because crop height determines the amount of interception that takes place. A higher crop height means more interception and less splash erosion. (splash erosion = erosion caused by the falling of raindrops) (University of Twente, g.d.)

### Lai.map

the leaf area index is a map that quantifies the storage capacity of the canopy. If the value of the map is 6, for instance. Then that means that the vegetated part of the grid cell has a storage capacity of 6. The value can differ between 0 and 12. (University of Twente, g.d.)

### Per.map

The Abbreviation of this map already says it already. The **percentage** of soil covered by vegetation. The percentage is displayed in this map as a value between 0 and 1. So if the soil is covered by 50% of vegetation, then the value of the cell is 0,5. (University of Twente, g.d.)

### Profile.inp and profile.map

This map and file are already explained in paragraph I.13 as an example how the pcraster-maps work. The profile.inp file offers a description of the soil profile of each map and uses the SWATRE tables. The profile.inp file has a layout that describes the type of soil in each soil layer. (University of Twente, g.d.)

### SWATRE tables

The SWATRE tables are the tables that contain the characteristics of each soil type, including permeability (k). When simulating gully erosion in LISEM, it can come in handy to manually lower the k value in the SWATRE tables. This lowers the permeability of the soil. This is necessary because in the winter, the soil is frozen, which prevents most of the water infiltration to the soil. (University of Twente, g.d.)

### **I.15 Stakeholders within the MetFure Project/NIBIO.**

NIBIO is an independent organisation that performs research on behalf of the ministry of agriculture in NIBIO. Because they are independent, there are little stakeholders that will have an influence on the way NIBIO performs its research.

A few stakeholders are the ministry of research and farmers. NIBIO has no influence on the practices farmers should perform. But they do have opinions on matters that can lead to discussions with farmers. These “social dilemma’s” happen sometimes.

For example, the farmer wants a clear ground to prevent weeds to take nutrients that could otherwise be consumed by the crops. This also looks tidier in the agricultural field. This means less vegetation on the soil. Less vegetation however, means that the soil is more prone to succumb to gully erosion. This is where the discussions take place within NIBIO and the farmers. It also raises questions on how much influence weeds have on the crop yield and prevents the removal of weeds more damage than gully erosion?

Another important stakeholder is the ministry of agriculture and the Norwegian water authority. These are technically the commissioners of the research that needs to be performed within NIBIO. These authorities only commission the field of research, like “more research what causes eutrophication in the area”. NIBIO then proceeds to further specify the research into set projects like the MetFure project to develop a method to quantify and map gully erosion. This ultimately contributes to a better understanding the way gully erosion can be mapped to monitor the problem. Because gully erosion causes the eutrophication of surface waters. At the end of the year, NIBIO submits a report to these authorities that explains what kind of research has been performed.

## Attachment II, Manual for mapping and quantifying gully erosion.

This is the manual on mapping and quantifying gully erosion using drone photogrammetry.

### II.1 The optimal flight method for drones

The best method to map gully erosion with the drone depends on a couple of factors. These factors are the altitude of the flight and the type of software used during the flight.

An altitude of 20 meters gives the best results with the least amount of flight time. The accuracy while flying with the "DJI MAVIC PRO drone" is about 8 mm per pixel at this height.

The PrecisionFlight app should be used to map the area where gully erosion would occur. It is available for free in the App store. The route for mapping gully erosion is set properly according to the following instructions.

The first step is to start up the app. The first thing seen will be the screen in figure 18.

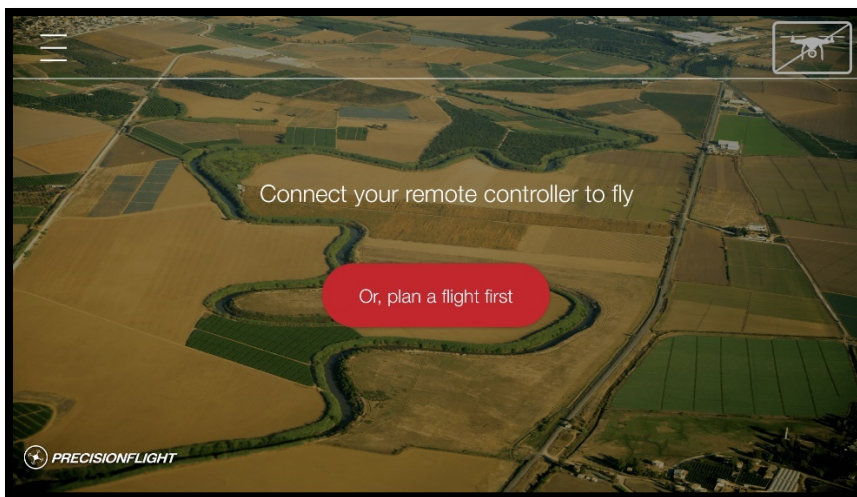


Figure 18, The starting screen.

Connect the phone to the remote controller of the drone. Then, connect the drone with the remote controller. To connect the drone with the remote controller, one should press the power button twice, and hold the button down when pressing for the second time. (this is done with both the remote controller and the drone.)

Once connected, the flight route can be planned. Select "plan a flight" (or choose a flight that was already made.). When mapping gully erosion it is important to select the Grid survey type, as seen in figure 19. This survey type allows the drone to map an entire area.

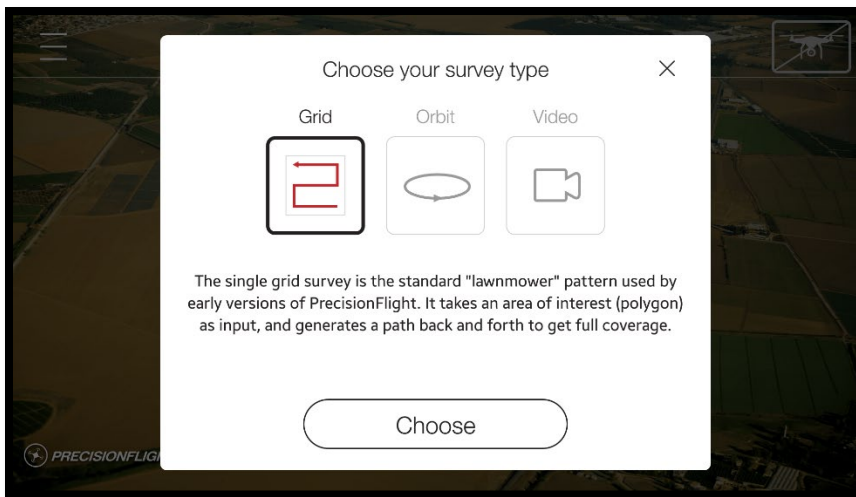


Figure 19, Selecting the survey type

The settings for the flight plan can now be configured. The altitude, and with it the resolution of the image, are set by 20 metres. As seen in figure 20.

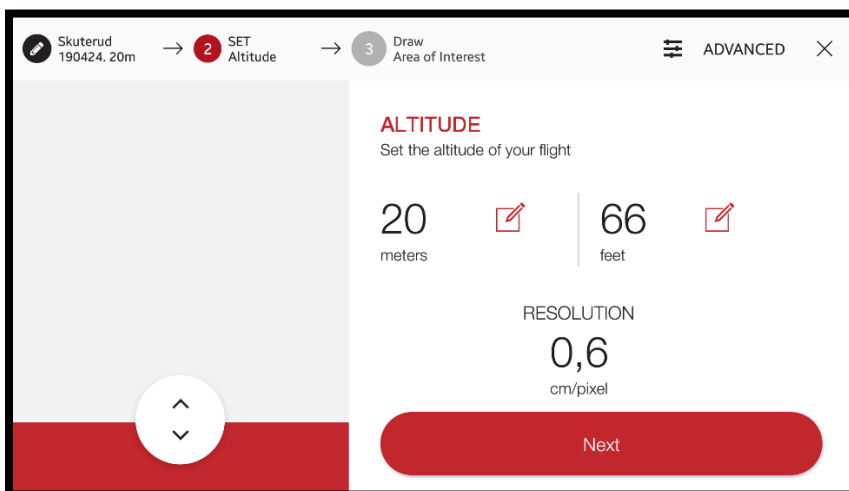


Figure 20, Setting the altitude of the drone

It is important to keep in mind the drone will fly on the same height from its point of take-off. So, when dealing with elevated areas, it is mandatory to set the altitude according to the amount of elevation in the area. For example, when an area with an elevation of around 10 metres must be mapped, from a **lower** point of take-off. It is wise to set the flying altitude to 25 to 30 metres at the **lower** starting point to make sure there is enough overlap between the images.

When taking off from a **higher** point, it is wise to set a lower altitude to ensure all images still have a good resolution.

After setting the altitude of the drone. The last step is to draw the area of interest. An example of such a drawing is given in figure 21. When drawing a polygon, the flight time and amount of lines are estimated. It is important to bring extra batteries for the drone (or even an extra remote controller) to prevent the risk of having to cancel the fieldwork because of an empty battery.

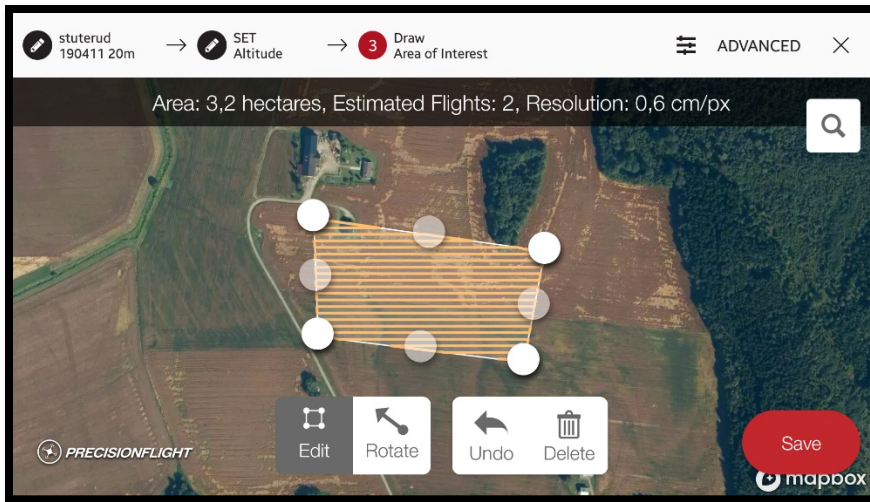


Figure 21, Drawing the area of interest

When the polygon is drawn, make sure there are no obstacles around, such as trees or other tall things. Take note of the estimated flight time when drawing the polygon to make sure to map the entire area in as little time as possible. Having a scan of only the essential area also saves lots of time when generating an elevation model of the area in Photoscan.

When the polygon is drawn, tap "save" and press the "take off" button and swipe up. The drone will fly around, and the progress of the flight will be shown on the app for the remainder of the flight.

After the flight, connect the drone to a computer and export the images to a preferred folder. From here on, the next step shall take place.



## II.2 Generating an elevation model in Photoscan.

The elevation model is also called a DEM-file. The abbreviation means Digital Elevation Model. (DEM). Generating a DEM in Photoscan is easy. And the commands are given throughout a single menu, "workflow".

The first step is importing the pictures to Photoscan. To do that, click "workflow" in the toolbar on the top left corner of screen. Then click "Add Photos..." as seen in [figure 22](#).

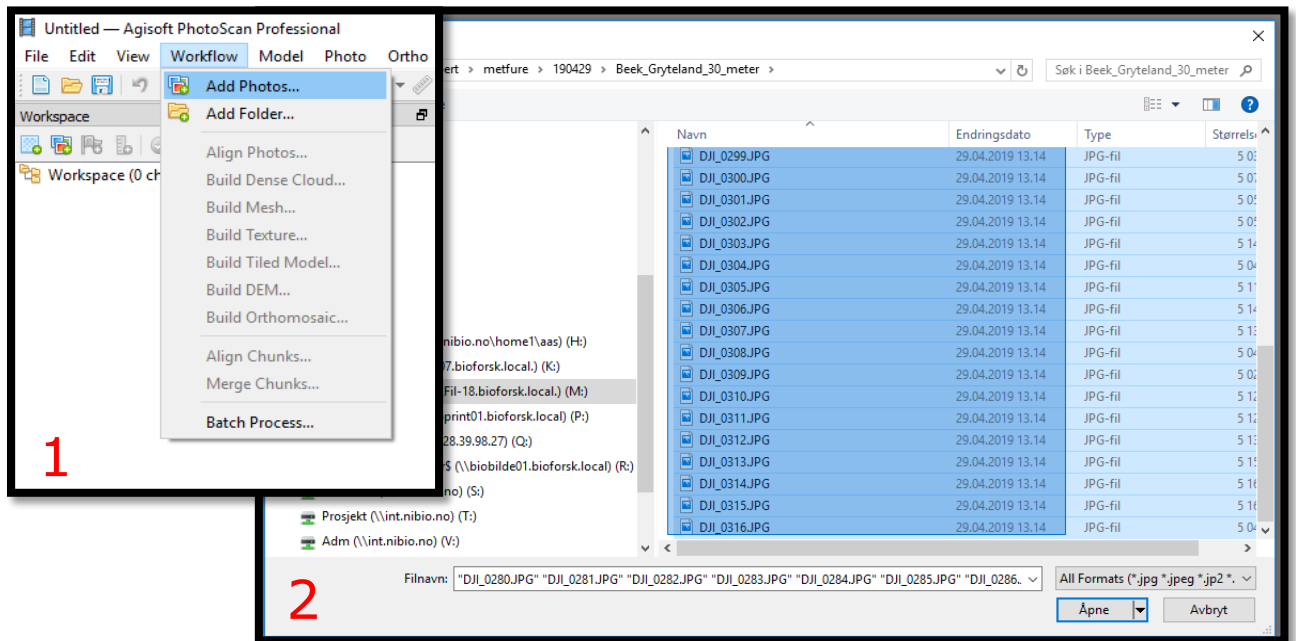


Figure 22, (1:) Workflow → Add Photos, (2:) select photos → click "open".

After the photos are added, the batch process can be set up. This requires the knowledge of knowing which step to put in which order.

Click "workflow" in the upper toolbar and select batch proces. The following menu will appear as seen in [figure 23](#).



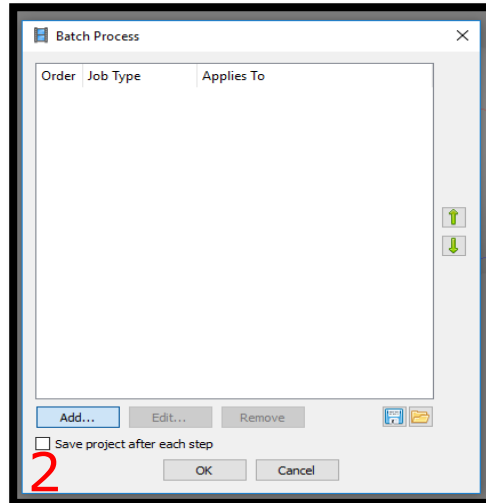
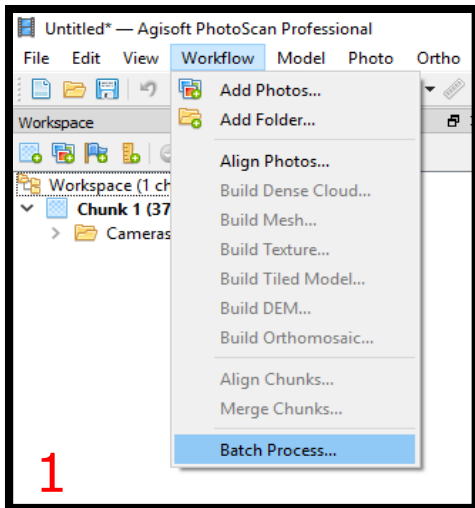


Figure 23, (1:) By clicking "batch process" in the workflow tab, (2:) the batch process menu will appear.

In the batch menu, a couple of tasks are added to complete. This way, one can avoid having to click continuously to be able to progress with every step in the calculation. Click "add" to add the first step of the calculation.

The first step is aligning the Photos that have been imported. Select "align Photos" in Job type. Then choose the accuracy of the alignment in the general-tab. (As seen in figure 24) Keep in mind that, the higher the accuracy of alignment, the more time the calculations will take. A high accuracy is recommended when studying rills in the landscape.

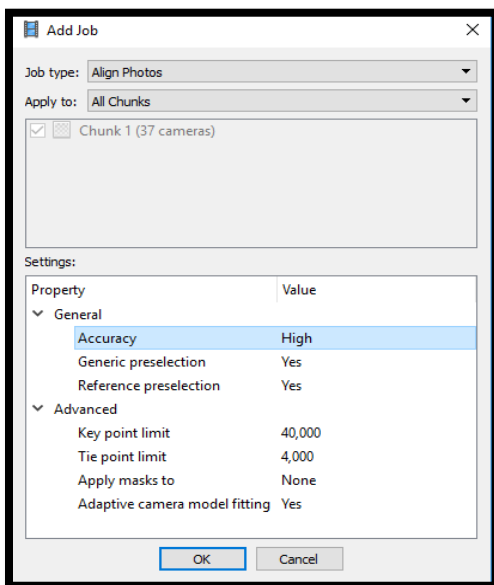


Figure 24, Options for aligning photos

Click "OK" when the accuracy is chosen. The batch process menu will now reappear. Click add again to add another calculation step into the process.

The next job that is performed is the generation of a dense cloud. The dense cloud forms the base of a 3D model of the area. It is a "dense cloud" of

overlapping points in the photos. As seen in figure 25, choose the job type: “Build Dense Cloud” in the menu. Then select which quality the dense cloud should be. Ultra high quality takes a lot of time (sometimes 24 hours when having a lot of photos) to generate, but provides the best looking image. See approach, paragraph 3.2.1 for an overview of resolutions with each altitude, and quality of the dense cloud.

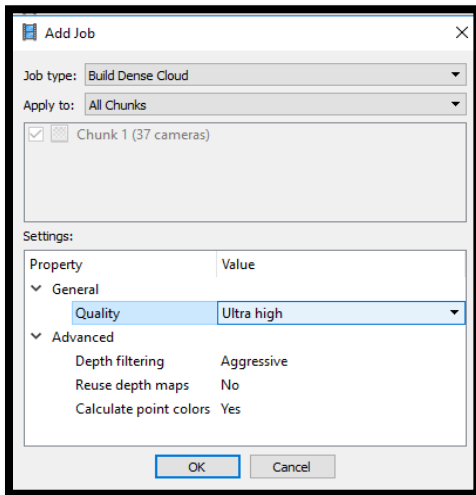


Figure 25, Building Dense Cloud

Click “OK” when done. The batch process menu will reappear. Select “add...” again to add the next step in the calculation, which is “Build Mesh”. In this step the 3D model will be generated from the Dense Cloud. It is recommended to choose for an Ultra high “depth maps quality” when making a DEM later on. (see figure 26)

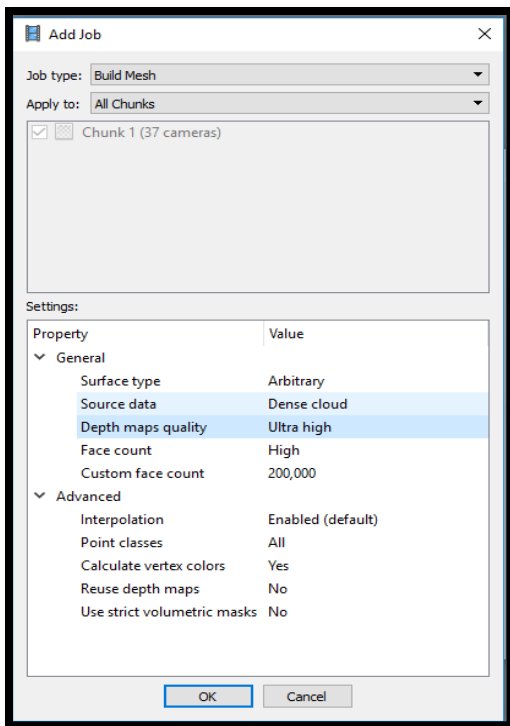


Figure 26, Building Mesh, confirm that the source data is from the Dense cloud.

Click "OK" when done and then add the next job which is "Build DEM". The DEM is generated from the mesh and Dense cloud that were created in the last step. For the best results, be sure to select the Dense cloud as the source data for this job, as seen in figure 27.

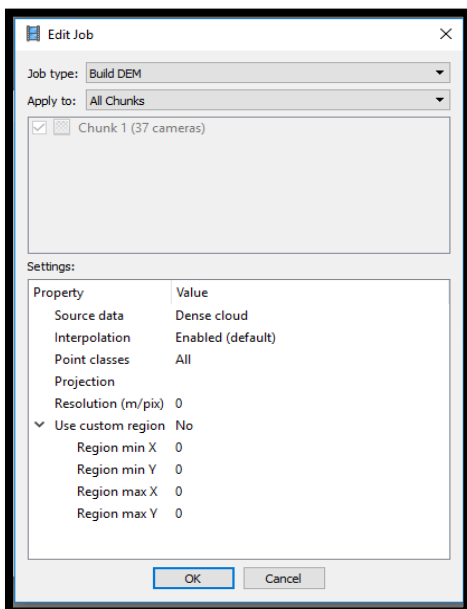


Figure 27, Build DEM

Click "OK" when finished and add the next job. which is "export DEM". After the DEM is generated, it will be exported to a folder of choosing.

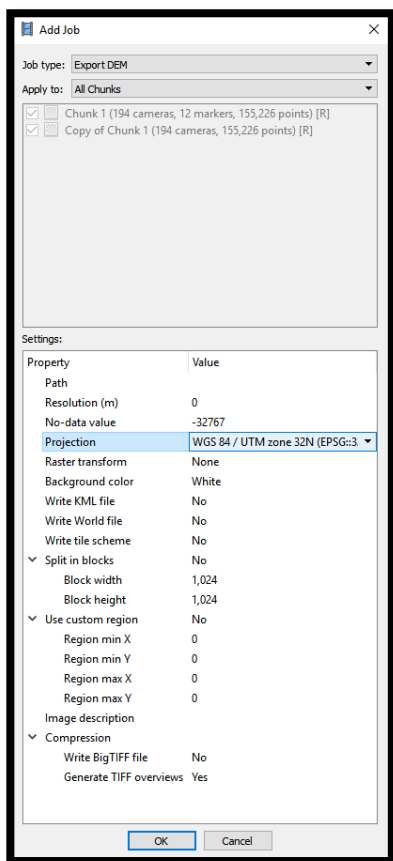


Figure 28, Export DEM

Double click on the empty space, right of the property; "Path", and select a place where the DEM should be saved. (figure 28)

Be sure to select the "WGS 84 / UTM zone 32N (EPSG:32632)" coordinates system since it is the most accurate. This coordinate system is the best for measuring the length and width of the gullies.

Make sure that the DEM is saved as a .tif image. That way it can be easily imported into SAGA later on.

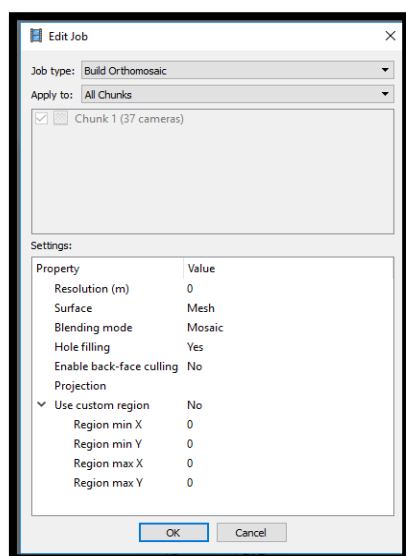


Figure 29, Build Orthomosaic

The DEM can be all one needs to calculate the volume of gullies. But sometimes the rills are so small that they are not visible on the DEM. For this reason, it can be useful to have a detailed picture of the area with the rill to pinpoint its exact location on the DEM. Generating an Orthomosaic can be of help with this.

Click "add..." in the batch processing menu and select "Build Orthomosaic" as the Job type. An example can be seen in figure 29.

Click "OK" and finish the batch process by adding one last step.

Click "add..." and select "Export Orthomosaic" in Job type. (see figure 30) Choose a directory in "Path" and confirm the settings.

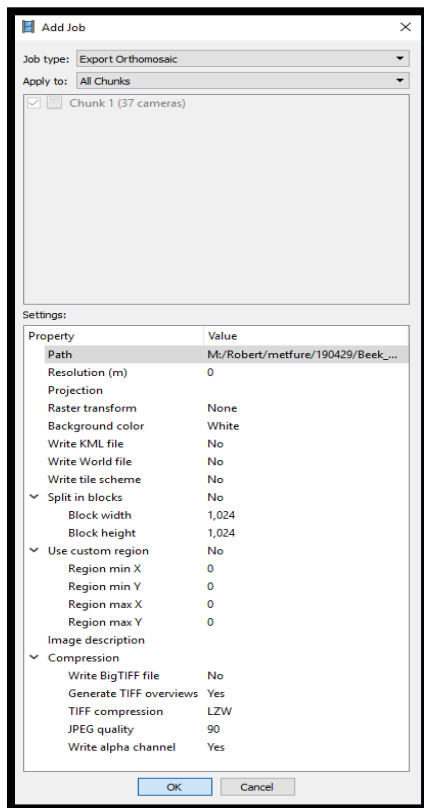


Figure 30, Export Orthomosaic

Check if all of the jobs in the batch process menu are in the right order, as seen in figure 31. If so, click OK and await the results when the processing is done. This could take a long time if a large area is being processed in a high quality.

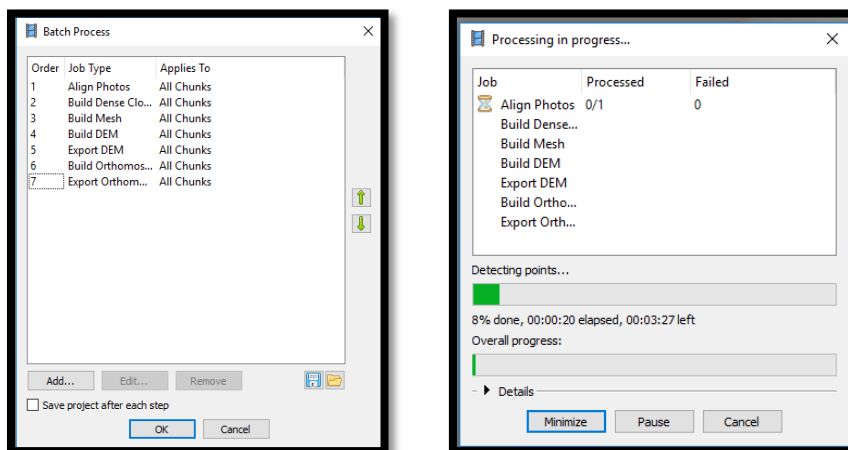


Figure 31, Batch processing menu in the right order and processing menu

For an overview of resolution with each quality and altitude. See approach paragraph 3.2.

Now follows an overview of the results from Photoscan and their uses. In figure 32, a depiction of a mesh is given. In this case it is a high-resolution 3D model of a creek. Here the area can be seen in 3D and in high detail. This also forms the base layer for the DEM.

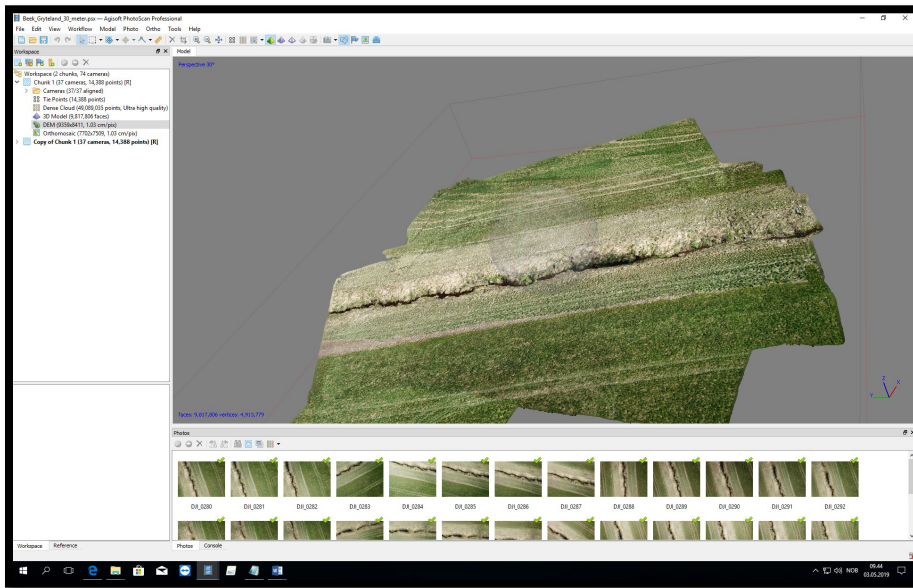


Figure 32, Mesh, 3D model of a creek.

In figure 33 a depiction of the DEM is given of the same creek. With DEM's like these, the volume of gullies, (or this creek for example) can be calculated in SAGA.

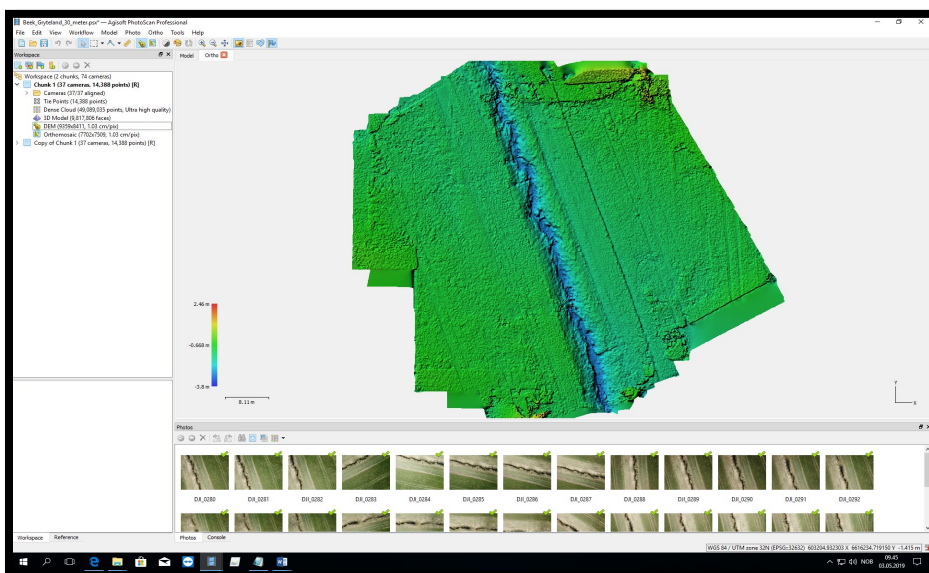


Figure 33, DEM

The visibility of the creek is good enough to distinguish from the rest of the landscape. However, in some cases it will not be visible enough. For this reason, it is good to have an orthomosaic that can be used to compare the DEM to. An image of an orthomosaic is given in figure 34.

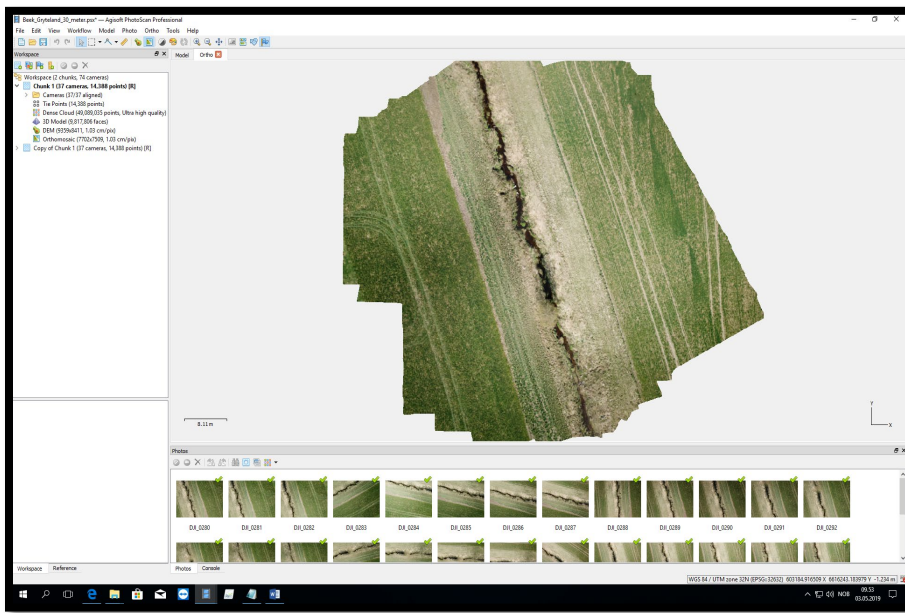


Figure 34, Orthomosaic

The orthomosaic consists of 4 different layers of data. These four layers will have to be added in SAGA, if one wishes to compare it to the DEM.



## II.3 Making cross-sections of a gully

The goal of this step is to compare the conventional measurements to the drone measurements. To reach this goal, a couple of steps must be taken in SAGA to convert the DEM into a quantifiable model for gully erosion. This is basically done using both excel and SAGA.

### II.3.1 Importing the DEM

The DEM that was made in Photoscan needs to be imported to SAGA for further analysis. This DEM is needed to get cross sections from gullies. Import the Tiff-image (DEM-file) to SAGA. this can be done following figure 35.

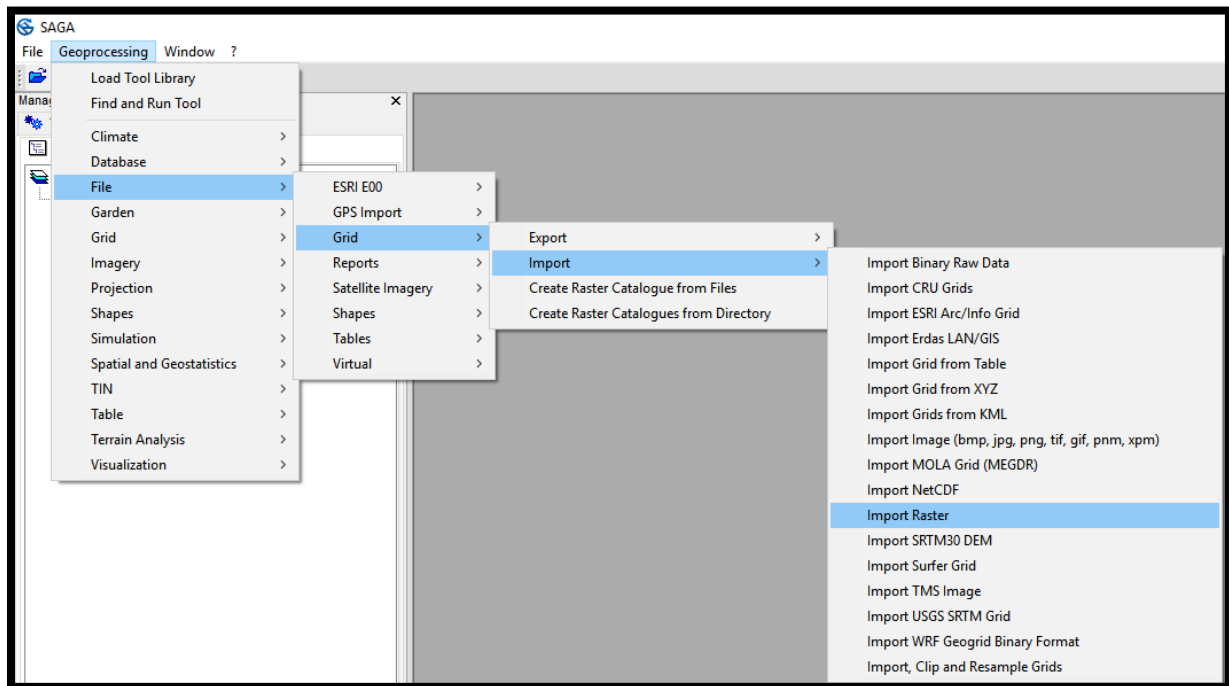


Figure 35, Geoprocessing → File → Grid → Import → Import Raster.

A new menu will appear in which one can set the file directory to import a DEM to SAGA.

Here it is possible to add the DEM file when clicking on the "..." button (see arrow in figure 36). Chose the DEM file that is needed and click "open", and then click "okay" to close the menu and start importing the DEM. This may take several minutes depending on the size of the file.

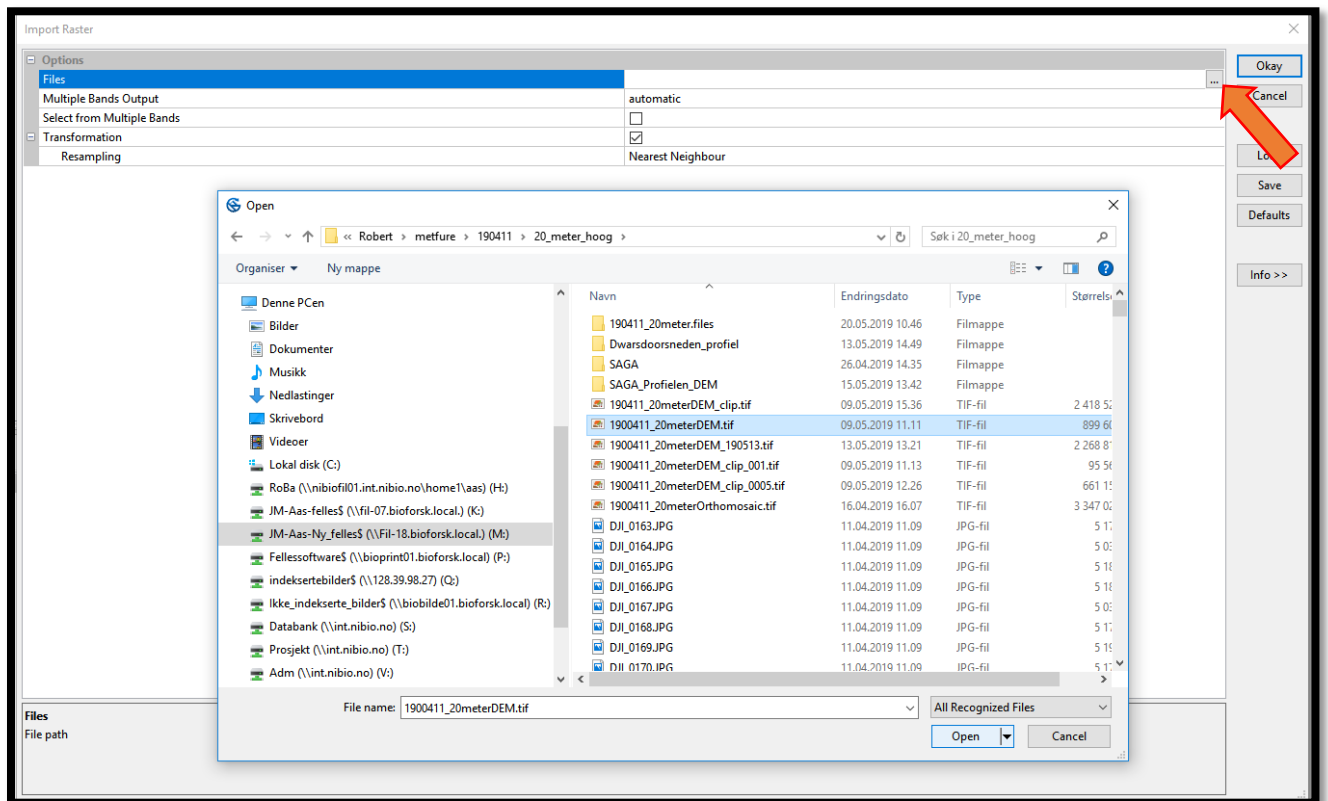


Figure 36, Importing the DEM to SAGA

The imported file should look like this (figure 37). This is a DEM of small creek in Gryteland. The small furrows of the agricultural land are also visible beside the creek. Rills and gullies sizes can vary from the size of a creek to as small as a furrow in agricultural fields. For this reason, there is the need to generate a couple of profiles from the creek and from the furrows next to it in the upcoming examples.

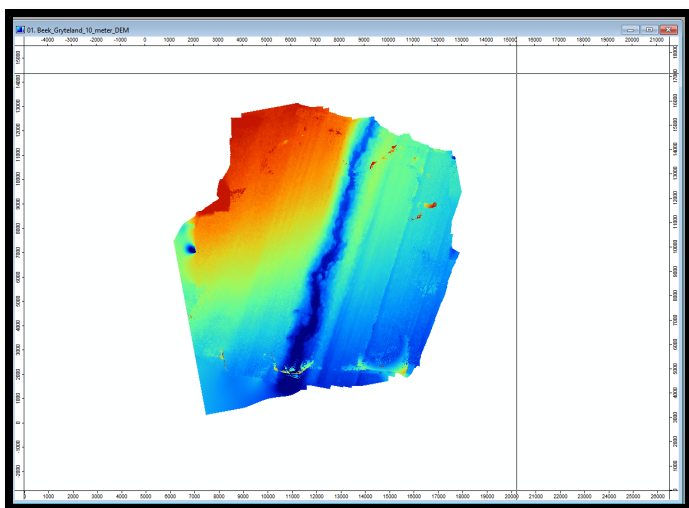


Figure 37, The DEM of the creek in Gryteland (Skuterud)

### II.3.2 Creating a point table in excel

The first step is to create points. These points will later be converted into lines. This line is used to analyse the cross section of a profile of the gully.

These points are given in coordinates. For example, there is a need of 6 cross sections of a gully's profile. A table is made with the coordinates of 2 points per profile, going from one side to the other side of a gully. (see table 5)

Table 5, Coordinates of every profile.

| X            | Y           | ID       |
|--------------|-------------|----------|
| 7622,849680  | 9607,688364 | Creek 1  |
| 8,946,393170 | 9537,099378 | Creek 1  |
| 6,969,901558 | 7190,015589 | Creek 2  |
| 8,311,092295 | 6907,659645 | Creek 2  |
| 6,281,658944 | 4860,579047 | Creek 3  |
| 7640,496927  | 5260,572664 | Creek 3  |
| 10358,172893 | 7842,963711 | Furrow 1 |
| 10905,237536 | 7648,843999 | Furrow 1 |
| 9,969,933469 | 6378,242249 | Furrow 2 |
| 10499,350865 | 6148,828044 | Furrow 2 |
| 9369,927087  | 4754,695567 | Furrow 3 |
| 9934,638976  | 4542,928609 | Furrow 3 |

An important thing is to make sure that the coordinate system in this table is "WGS 84 / UTM zone 32N (EPSG:32632)". This coordinate system is the most accurate and is best for measuring small things in the landscape like gullies and rills. Usually the table looks like the example, table 5. Adding an ID to all coordinates provides more overview and will come in handy in future steps.

It is essential that this table is saved as a csv-file when done working on it in Excel. The columns will be divided by ";" tokens.

### II.3.3 Importing the point table to SAGA

This table can now be imported to saga as a table. Follow the instructions in figure 38 to add a table to SAGA

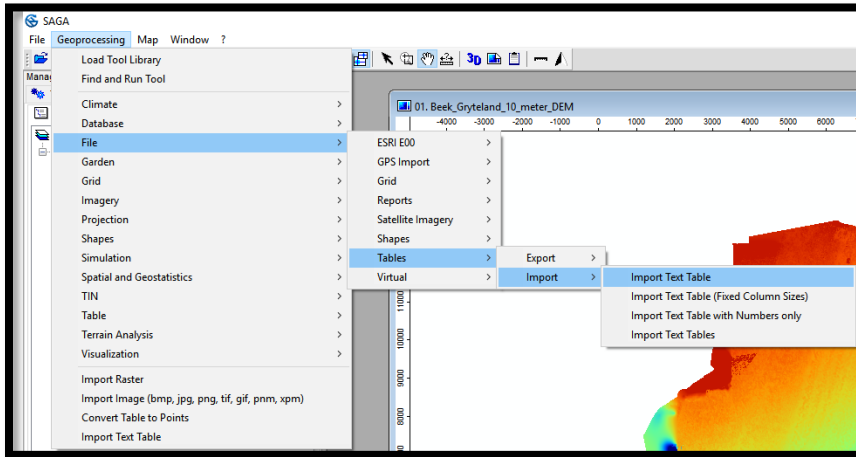


Figure 38, Click Geoprocessing → File → Tables → Import → Import Text Table

The next menu, as shown in figure 39, will appear. Here the directory to the table.csv file needs to be set. Select whether the table contains a headline or not, to make sure every piece of information will be processed. Also, be sure to select the right separator token. In csv files this is usually “;”. Click okay when everything is set.

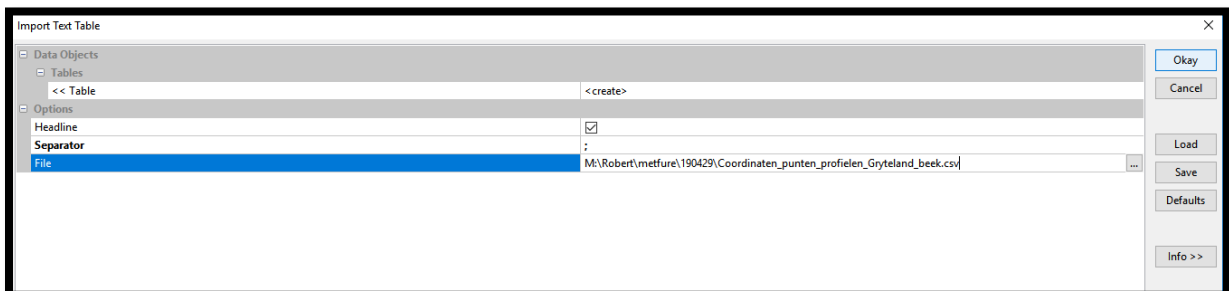


Figure 39, Importing a table to SAGA.

The goal of this table is to convert the coordinates in it into points on the map. This can be done easily as seen in figure 40.

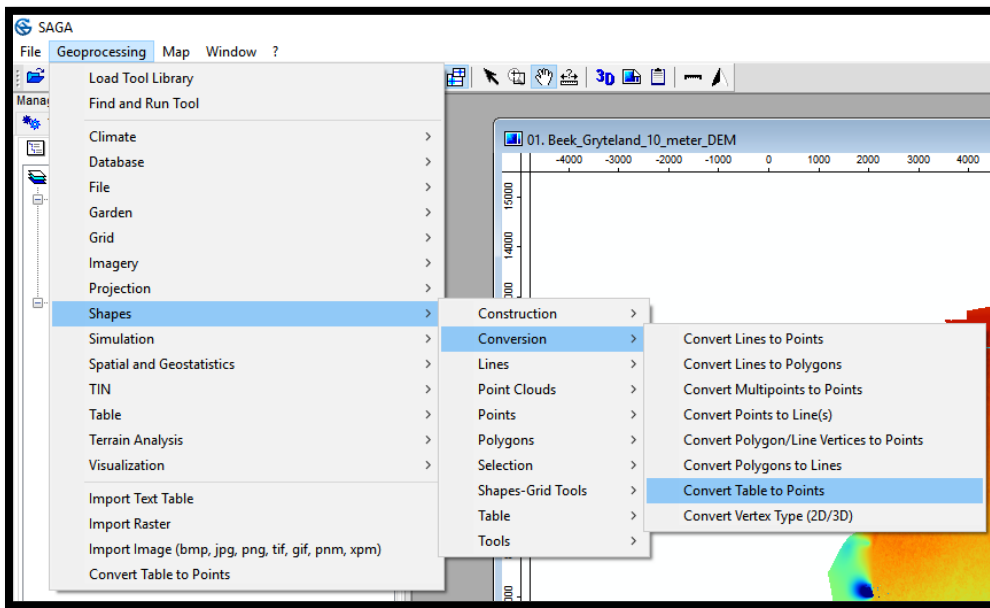


Figure 40, Click: Geoprocessing → Shapes → Conversion → convert Table to Points.

Double click on the points in the left side of the screen, and add them to a map layer. Two points should be visible at each side of a gully or rill. An example is given in figure 41.

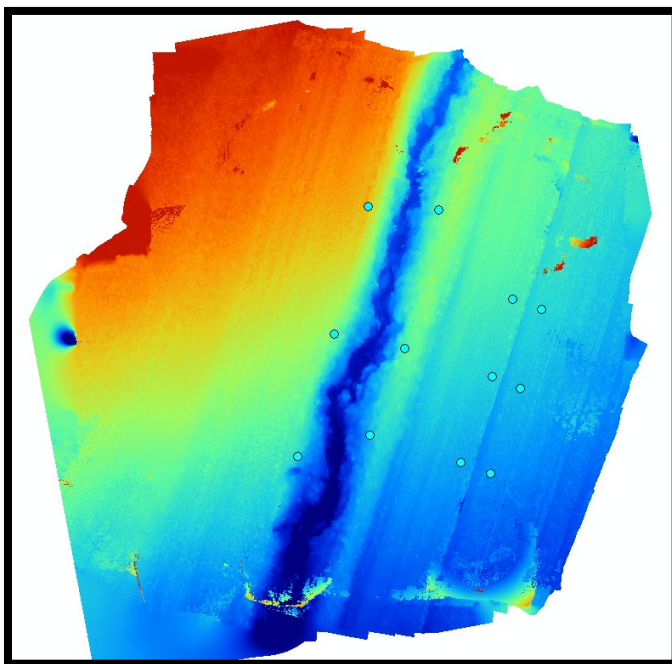


Figure 41, The points are placed with the gully between them.

To get a cross section of the profile of a gully, it is necessary that the points should be converted into lines to analyse the profile with. This is done as shown in figure 42.

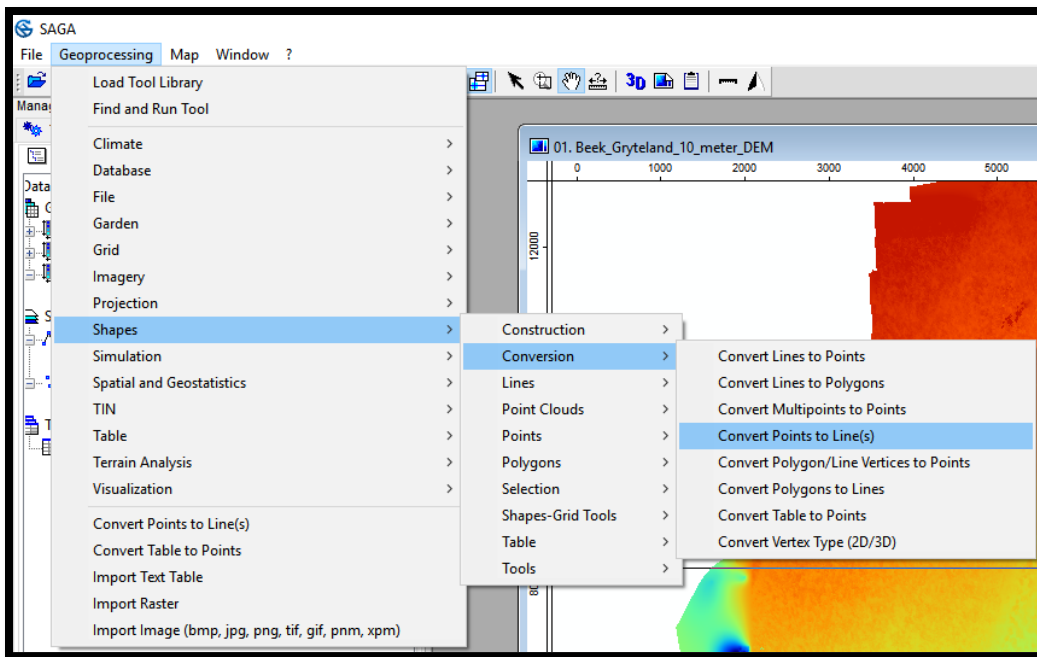


Figure 42, Geoprocessing → Shapes → Conversion → Convert Points to Lines.

A new menu appears like the ones before. (figure 43)

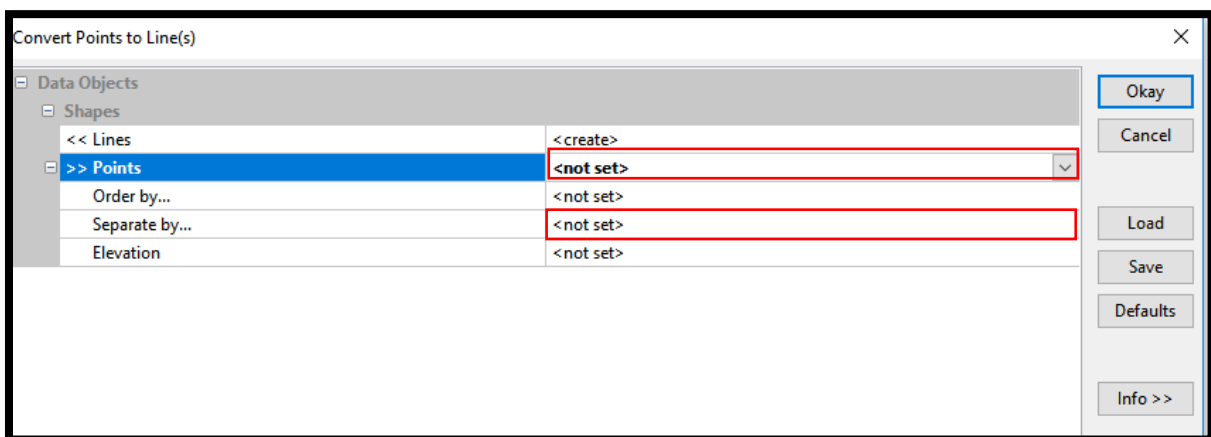


Figure 43, Set the group of points to convert and separate them by ID.

The points need to be selected. Set the point layer in the ">> Points" row. After doing that, it is possible to separate points by ID. Therefore, giving ID's to the coordinates is important, as seen in table 5. Click on the empty row of "Separate by..." and select the attribute the lines should be ordered.

Double click the line shape in the left side of the screen to add them to a map layer. The lines between the points with the same ID should appear and should look like the example in figure 44.

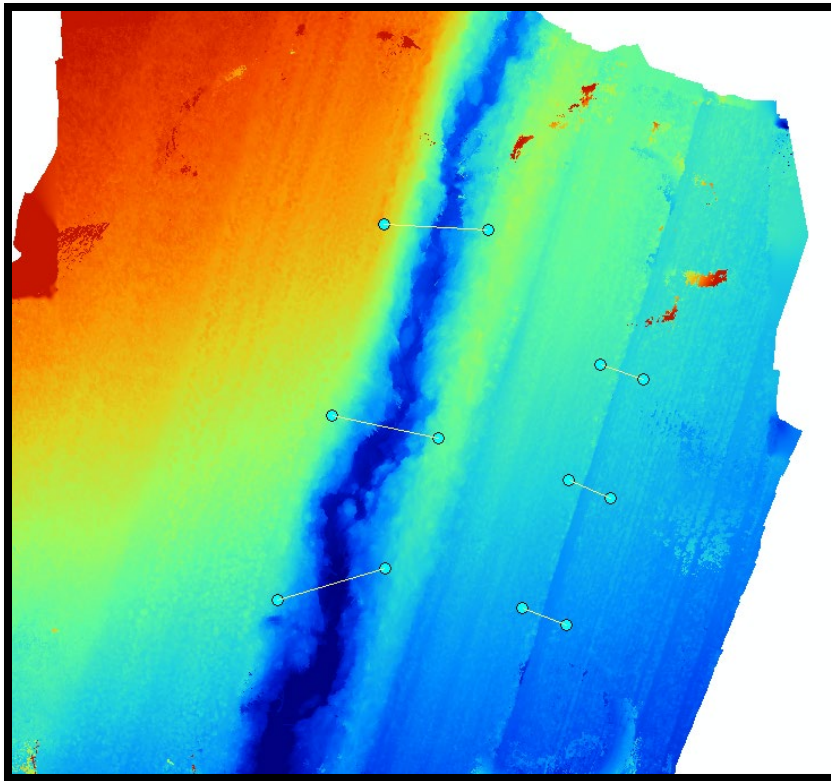


Figure 44, New lines have been added over the furrows.

The lines should cross the gullies in this situation. This allows one to make a profile analysis of the part of the gully where the line is. Go to: Geoprocessing → Terrain analysis → Profiles → Profiles from Lines. A new menu should appear as seen in figure 45.

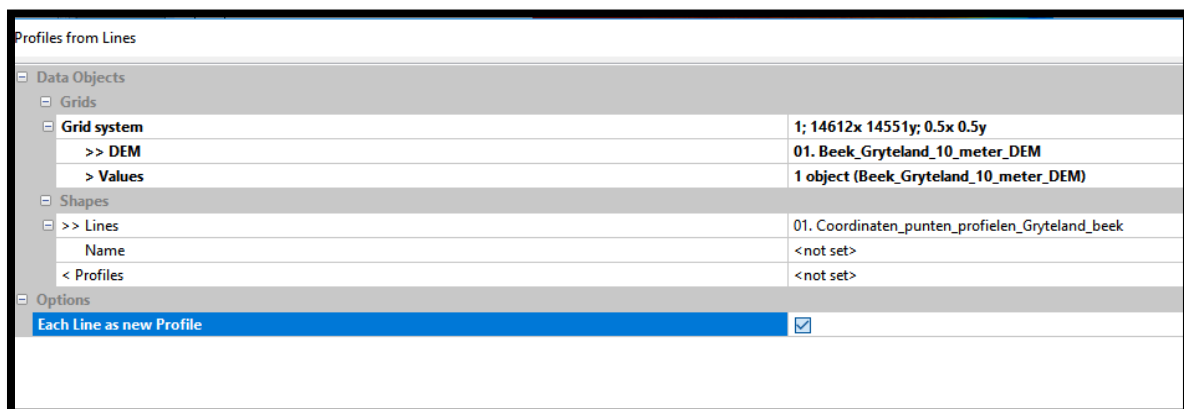


Figure 45, Selecting the necessary things for the analysis of the profile from the lines.

First, select the grid system that needs analysing. Within the grid system is the DEM that was imported to SAGA. Select that DEM in the ">> DEM" row. Then select the DEM again in "> Values". This can be done by double clicking on the row in next to "DEM > Values" and putting the attribute to the right part of the



screen in the menu that follows. (figure 46)



Figure 46, Click the [>] button to select the data from the DEM in the profile analysis.

Now, select the lines that need to be used for the analysis and check the box in the row that says: "Each Line as new Profile" since one table with each profile will come in handy (figure 45). Click okay when done.

New profiles should appear in the left part of the screen, as seen in the red marking in figure 47. The attribute tables within these

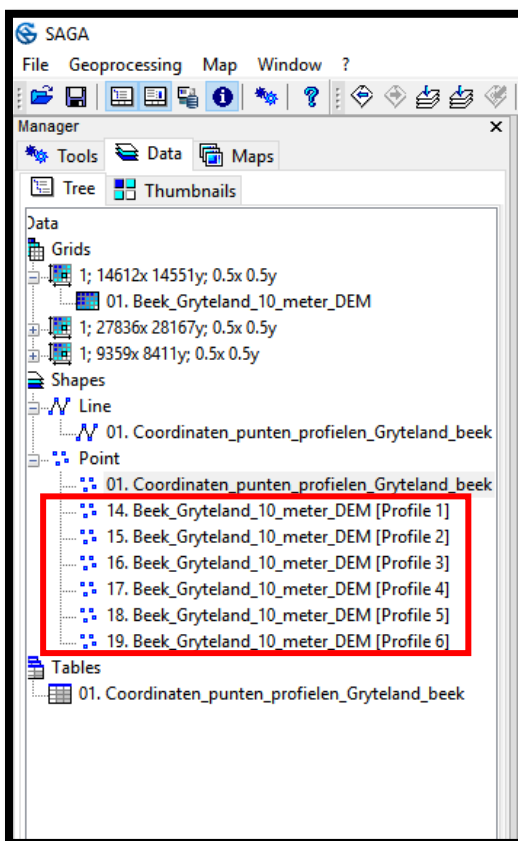


Figure 47, The overview of data, shapes and tables in SAGA.

To view the attribute table, see figure 48.

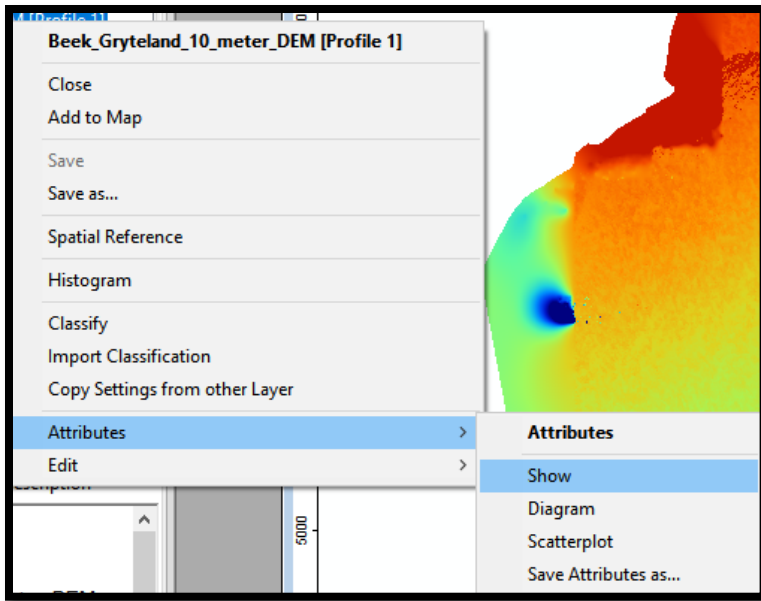


Figure 48, Right click the profile → Attributes → Show.

The attribute table will show with data about the profile, as seen in figure 49.

|    | LINE_ID | ID | DIST      | DIST_SURF | X    | Y           | Z         | rteland_10_m |
|----|---------|----|-----------|-----------|------|-------------|-----------|--------------|
| 1  | 0       | 1  | 0         | 0         | 8946 | 9537        | -5.443062 | -5.443062    |
| 2  | 0       | 2  | 1.001397  | 1.001402  | 8945 | 9537.05287  | -5.446299 | -5.446299    |
| 3  | 0       | 3  | 2.002793  | 2.002801  | 8944 | 9537.10574  | -5.448505 | -5.448505    |
| 4  | 0       | 4  | 3.00419   | 3.0042    | 8943 | 9537.15861  | -5.450641 | -5.450641    |
| 5  | 0       | 5  | 4.005587  | 4.005617  | 8942 | 9537.21148  | -5.457081 | -5.457081    |
| 6  | 0       | 6  | 5.006983  | 5.007048  | 8941 | 9537.26435  | -5.465326 | -5.465326    |
| 7  | 0       | 7  | 6.00838   | 6.008477  | 8940 | 9537.317221 | -5.473358 | -5.473358    |
| 8  | 0       | 8  | 7.009777  | 7.00994   | 8939 | 9537.370091 | -5.484934 | -5.484934    |
| 9  | 0       | 9  | 8.011173  | 8.011448  | 8938 | 9537.422961 | -5.499858 | -5.499858    |
| 10 | 0       | 10 | 9.01257   | 9.012865  | 8937 | 9537.475831 | -5.506159 | -5.506159    |
| 11 | 0       | 11 | 10.013966 | 10.014269 | 8936 | 9537.528701 | -5.510103 | -5.510103    |
| 12 | 0       | 12 | 11.015363 | 11.015678 | 8935 | 9537.581571 | -5.515134 | -5.515134    |
| 13 | 0       | 13 | 12.01676  | 12.017122 | 8934 | 9537.634441 | -5.524819 | -5.524819    |
| 14 | 0       | 14 | 13.018156 | 13.018527 | 8933 | 9537.687311 | -5.528966 | -5.528966    |
| 15 | 0       | 15 | 14.019553 | 14.019974 | 8932 | 9537.740181 | -5.538964 | -5.538964    |
| 16 | 0       | 16 | 15.02095  | 15.021381 | 8931 | 9537.793051 | -5.5437   | -5.5437      |
| 17 | 0       | 17 | 16.022346 | 16.022793 | 8930 | 9537.845921 | -5.549244 | -5.549244    |
| 18 | 0       | 18 | 17.023743 | 17.024195 | 8929 | 9537.898792 | -5.552247 | -5.552247    |
| 19 | 0       | 19 | 18.02514  | 18.025593 | 8928 | 9537.951662 | -5.550558 | -5.550558    |
| 20 | 0       | 20 | 19.026536 | 19.026991 | 8927 | 9538.004532 | -5.552454 | -5.552454    |
| 21 | 0       | 21 | 20.027933 | 20.028391 | 8926 | 9538.057402 | -5.555077 | -5.555077    |
| 22 | 0       | 22 | 21.02933  | 21.029793 | 8925 | 9538.110272 | -5.558347 | -5.558347    |
| 23 | 0       | 23 | 22.030726 | 22.031202 | 8924 | 9538.163142 | -5.563265 | -5.563265    |
| 24 | 0       | 24 | 23.032123 | 23.0326   | 8923 | 9538.216012 | -5.564712 | -5.564712    |
| 25 | 0       | 25 | 24.03352  | 24.033997 | 8922 | 9538.268882 | -5.565575 | -5.565575    |
| 26 | 0       | 26 | 25.034916 | 25.035393 | 8921 | 9538.321752 | -5.565551 | -5.565551    |
| 27 | 0       | 27 | 26.036313 | 26.03679  | 8920 | 9538.374622 | -5.566533 | -5.566533    |
| 28 | 0       | 28 | 27.037709 | 27.038198 | 8919 | 9538.427492 | -5.571146 | -5.571146    |
| 29 | 0       | 29 | 28.039106 | 28.039595 | 8918 | 9538.480363 | -5.572407 | -5.572407    |
| 30 | 0       | 30 | 29.040503 | 29.040992 | 8917 | 9538.533233 | -5.572358 | -5.572358    |
| 31 | 0       | 31 | 30.041899 | 30.042389 | 8916 | 9538.586103 | -5.573333 | -5.573333    |
| 32 | 0       | 32 | 31.043296 | 31.043792 | 8915 | 9538.638973 | -5.577012 | -5.577012    |
| 33 | 0       | 33 | 32.044693 | 32.0452   | 8914 | 9538.691843 | -5.5818   | -5.5818      |
| 34 | 0       | 34 | 33.046089 | 33.046598 | 8913 | 9538.744713 | -5.583341 | -5.583341    |
| 35 | 0       | 35 | 34.047486 | 34.047998 | 8912 | 9538.797583 | -5.585736 | -5.585736    |

Figure 49, Attribute table of a profile.

This table contains coordinates of every few centimetres (X and Y) and the depth of every point (Z). The distance over the surface (DIS\_SURF) has been

calculated already using Pythagoras's formulae with the coordinates. The attribute tables of these profiles must be saved as txt-files. Right click the profiles again, select attributes and then select "save attributes as..." (figure 50)

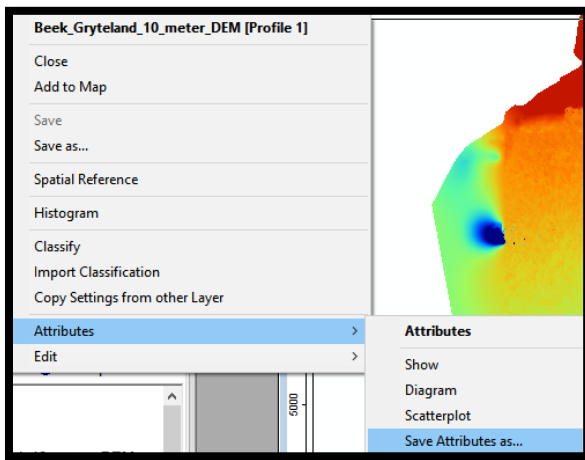


Figure 50, Right click on profile → Attributes → "Save Attributes as..."

The next step is applying a geometrical calculation to the table to make a cross section of the profile of the gully. This is explained in paragraph II.4

#### II.4 Detrending a gully profile.

The goal of this step is to create a cross section of a gully profile to compare to conventional measures, this is an optional step. This step is performed in excel and it is shown in this chapter how it should be done. Paragraph 4.2 provides some theoretical insight on the formulas that are used in this step.

In this paragraph, it is explained how to use the calculation steps from paragraph 4.2 in excel. This calculation will lead to a detrended cross section of a gully's profile. When both the conventional measurement and drone measurements are detrended. It is possible to compare both these measurements with each other to check the accuracy of the drone in relation to the real situation.

The first step is opening the attribute tables that were saved as txt-files in Excel. This can be done via File → Open → Browse → selecting the appropriate file and clicking open. A couple of Errors can be given about the way the txt-file should be displayed in Excel. Click next in this message to see how the data will be displayed. If no data is jumbled, click on "finish".

The attribute table should have about the same layout as figure 51

|    | A       | B  | C        | D         | E          | F          | G         | H           | I         |
|----|---------|----|----------|-----------|------------|------------|-----------|-------------|-----------|
| 1  | LINE_ID | ID | DIST     | DIST_SURF | X          | Y          | Z         | Beek_Grytel | DIST_SURF |
| 2  | 1       | 1  | 0        | 0         | 603194,469 | 6616231,36 | -1,052294 | -1,052294   | 0         |
| 3  | 1       | 2  | 0,007021 | 0,011694  | 603194,476 | 6616231,36 | -1,042942 | -1,042942   | 0,011694  |
| 4  | 1       | 3  | 0,014043 | 0,018935  | 603194,483 | 6616231,36 | -1,041173 | -1,041173   | 0,018935  |
| 5  | 1       | 4  | 0,021064 | 0,026293  | 603194,489 | 6616231,36 | -1,038973 | -1,038973   | 0,026293  |
| 6  | 1       | 5  | 0,028085 | 0,033315  | 603194,496 | 6616231,37 | -1,039009 | -1,039009   | 0,033315  |
| 7  | 1       | 6  | 0,035107 | 0,040355  | 603194,503 | 6616231,37 | -1,038485 | -1,038485   | 0,040355  |
| 8  | 1       | 7  | 0,042128 | 0,047471  | 603194,51  | 6616231,37 | -1,037329 | -1,037329   | 0,047471  |
| 9  | 1       | 8  | 0,049149 | 0,054519  | 603194,516 | 6616231,37 | -1,036717 | -1,036717   | 0,054519  |
| 10 | 1       | 9  | 0,056171 | 0,061651  | 603194,523 | 6616231,37 | -1,035466 | -1,035466   | 0,061651  |
| 11 | 1       | 10 | 0,063192 | 0,068833  | 603194,53  | 6616231,37 | -1,033954 | -1,033954   | 0,068833  |
| 12 | 1       | 11 | 0,070214 | 0,075892  | 603194,537 | 6616231,38 | -1,034675 | -1,034675   | 0,075892  |
| 13 | 1       | 12 | 0,077235 | 0,083167  | 603194,543 | 6616231,38 | -1,036581 | -1,036581   | 0,083167  |
| 14 | 1       | 13 | 0,084256 | 0,090645  | 603194,55  | 6616231,38 | -1,039153 | -1,039153   | 0,090645  |
| 15 | 1       | 14 | 0,091278 | 0,097838  | 603194,557 | 6616231,38 | -1,040717 | -1,040717   | 0,097838  |

Figure 51, Attribute table imported to Excel.

Next to the standard columns in the table, some additional labels will be added for the calculation steps. As seen in figure 52.

|   | A       | B  | C    | D         | E          | F          | G         | H           | I         | J           | K       | L | M         | N |
|---|---------|----|------|-----------|------------|------------|-----------|-------------|-----------|-------------|---------|---|-----------|---|
| 1 | LINE_ID | ID | DIST | DIST_SURF | X          | Y          | Z         | Beek_Grytel | DIST_SURF | correctie Z | detrend |   | tan (O/A) |   |
| 2 | 1       | 1  | 0    | 0         | 603194,469 | 6616231,36 | -1,052294 | -1,052294   | 0         |             |         |   |           | 0 |

Figure 52, Copy DIST\_SURF column to the I-column, and add the correction Z column, detrend column and save an empty cell for the calculation of the tangent.

After the labels for the new columns are added, the first calculation can begin. The goal of this calculation is to make sure that the chart of the cross section of the gully will start at zero. The formulas in Excel should look like figure 53.

|   | H         | I           | J        |
|---|-----------|-------------|----------|
| Z | DIST_SURF | correctie Z |          |
| 2 | -1,052294 | 0           | =H\$2-H2 |
| 3 | -1,042942 | 0,011694    |          |

|   | H         | I           | J        |
|---|-----------|-------------|----------|
| Z | DIST_SURF | correctie Z |          |
| 4 | -1,052294 | 0           | 0        |
| 2 | -1,042942 | 0,011694    | =H\$2-H3 |

Figure 53, Applying a new starting value for Z.

Make sure the formula is copied and pasted across the entire table using the down-right corner of the cell and dragging it to the end of the column. When this is done, one can calculate the tangent with the formula:

$$\text{Tangent} = \frac{\text{opposite side}}{\text{adjacent side}} = \frac{\text{corrected Z value}}{\text{DIST\_SURF (distance)}}$$

The formula is utilised using the last values of the attribute table, as shown in figure 54.

| LINE_ID | ID | DIST | DIST_SURF | X         | Y          | Z          | correctie Z | detrend   | tan (O/A) |          |
|---------|----|------|-----------|-----------|------------|------------|-------------|-----------|-----------|----------|
| 1094    | 1  | 1093 | 7,667321  | 10,017411 | 603201,837 | 6616233,48 | -1,368485   | -1,368485 | 10,017411 | 0,316191 |
| 1095    | 1  | 1094 | 7,674342  | 10,024476 | 603201,843 | 6616233,48 | -1,369269   | -1,369269 | 10,024476 | 0,316975 |
| 1096    | 1  | 1095 | 7,681364  | 10,031645 | 603201,85  | 6616233,48 | -1,370718   | -1,370718 | 10,031645 | 0,318424 |
| 1097    | 1  | 1096 | 7,688385  | 10,038691 | 603201,857 | 6616233,49 | -1,371311   | -1,371311 | 10,038691 | 0,319017 |
| 1098    | 1  | 1097 | 7,695406  | 10,045713 | 603201,864 | 6616233,49 | -1,371289   | -1,371289 | 10,045713 | 0,318995 |
| 1099    | 1  | 1098 | 7,702428  | 10,052734 | 603201,87  | 6616233,49 | -1,371319   | -1,371319 | 10,052734 | 0,319025 |
| 1100    | 1  | 1099 | 7,709449  | 10,059756 | 603201,877 | 6616233,49 | -1,371352   | -1,371352 | 10,059756 | 0,319058 |
| 1101    | 1  | 1100 | 7,71647   | 10,066875 | 603201,884 | 6616233,49 | -1,372529   | -1,372529 | 10,066875 | 0,320235 |
| 1102    | 1  | 1101 | 7,723492  | 10,073526 | 603201,891 | 6616233,5  | -1,367475   | -1,367475 | 10,073526 | 0,315181 |
| 1103    | 1  | 1102 | 7,730513  | 10,082573 | 603201,897 | 6616233,5  | -1,368071   | -1,368071 | 10,082573 | 0,315777 |
| 1104    | 1  | 1103 | 7,737534  | 10,089861 | 603201,904 | 6616233,5  | -1,366116   | -1,366116 | 10,089861 | 0,313822 |
| 1105    | 1  | 1104 | 7,744556  | 10,09724  | 603201,911 | 6616233,5  | -1,363849   | -1,363849 | 10,09724  | 0,311555 |
| 1106    | 1  | 1105 | 7,751577  | 10,104374 | 603201,918 | 6616233,5  | -1,362582   | -1,362582 | 10,104374 | 0,310288 |
| 1107    | 1  | 1106 | 7,758598  | 10,11354  | 603201,924 | 6616233,51 | -1,356669   | -1,356669 | 10,11354  | 0,304396 |
| 1108    | 1  | 1107 | 7,76562   | 10,120789 | 603201,931 | 6616233,51 | -1,354887   | -1,354887 | 10,120789 | 0,302593 |
| 1109    | 1  | 1108 | 7,772641  | 10,127831 | 603201,938 | 6616233,51 | -1,354351   | -1,354351 | 10,127831 | 0,302057 |
| 1110    | 1  | 1109 | 7,779663  | 10,135693 | 603201,945 | 6616233,51 | -1,350814   | -1,350814 | 10,135693 | 0,29852  |
| 1111    | 1  | 1110 | 7,786684  | 10,142773 | 603201,951 | 6616233,51 | -1,349906   | -1,349906 | 10,142773 | 0,297612 |
| 1112    | 1  | 1111 | 7,793705  | 10,149794 | 603201,958 | 6616233,52 | -1,349962   | -1,349962 | 10,149794 | 0,297668 |
| 1113    | 1  | 1112 | 7,800727  | 10,156836 | 603201,965 | 6616233,52 | -1,350491   | -1,350491 | 10,156836 | 0,298197 |
| 1114    | 1  | 1113 | 7,807748  | 10,163884 | 603201,972 | 6616233,52 | -1,351111   | -1,351111 | 10,163884 | 0,298816 |
| 1115    | 1  | 1114 | 7,814769  | 10,171139 | 603201,978 | 6616233,52 | -1,352934   | -1,352934 | 10,171139 | 0,30064  |
| 1116    | 1  | 1115 | 7,821791  | 10,179115 | 603201,985 | 6616233,52 | -1,349149   | -1,349149 | 10,179115 | 0,296855 |
| 1117    | 1  | 1116 | 7,828812  | 10,186191 | 603201,992 | 6616233,52 | -1,350021   | -1,350021 | 10,186191 | 0,297727 |
| 1118    | 1  | 1117 | 7,835833  | 10,193212 | 603201,999 | 6616233,53 | -1,350101   | -1,350101 | 10,193212 | 0,297807 |
| 1119    | 1  | 1118 | 7,842855  | 10,201101 | 603202,005 | 6616233,53 | -1,353696   | -1,353696 | 10,201101 | 0,301402 |
| 1120    | 1  | 1119 | 7,849876  | 10,208807 | 603202,012 | 6616233,53 | -1,356871   | -1,356871 | 10,208807 | 0,304577 |
| 1121    | 1  | 1120 | 7,856897  | 10,218876 | 603202,019 | 6616233,53 | -1,364089   | -1,364089 | 10,218876 | 0,311795 |
| 1122    | 1  | 1121 | 7,863919  | 10,228351 | 603202,026 | 6616233,53 | -1,370451   | -1,370451 | 10,228351 | 0,318157 |
| 1123    | 1  | 1122 | 7,87094   | 10,235401 | 603202,032 | 6616233,54 | -1,371078   | -1,371078 | 10,235401 | 0,318784 |
| 1124    | 1  | 1123 | 7,877962  | 10,246756 | 603202,039 | 6616233,54 | -1,380003   | -1,380003 | 10,246756 | 0,327709 |
| 1125    | 1  | 1124 | 7,884983  | 10,257479 | 603202,046 | 6616233,54 | -1,388108   | -1,388108 | 10,257479 | 0,335814 |
| 1126    | 1  | 1125 | 7,892004  | 10,265212 | 603202,053 | 6616233,54 | -1,391347   | -1,391347 | 10,265212 | 0,339053 |
| 1127    | 1  | 1126 | 7,899026  | 10,275582 | 603202,059 | 6616233,54 | -1,398978   | -1,398978 | 10,275582 | 0,346684 |
| 1128    | 1  | 1127 | 7,906047  | 10,283347 | 603202,066 | 6616233,55 | -1,402294   | -1,402294 | 10,283347 | 0,35     |
| 1129    | 1  | 1128 | 7,913068  | 10,290502 | 603202,073 | 6616233,55 | -1,403669   | -1,403669 | 10,290502 | 0,351375 |
| 1130    | 1  | 1129 | 7,92009   | 10,297601 | 603202,08  | 6616233,55 | -1,404717   | -1,404717 | 10,297601 | 0,352423 |
| 1131    | 1  | 1130 | 7,927111  | 10,304631 | 603202,086 | 6616233,55 | -1,404373   | -1,404373 | 10,304631 | 0,352079 |
| 1132    | 1  | 1131 | 7,934132  | 10,311697 | 603202,093 | 6616233,55 | -1,40517    | -1,40517  | 10,311697 | 0,352876 |
| 1133    | 1  | 1132 | 7,941154  | 10,319347 | 603202,1   | 6616233,56 | -1,408206   | -1,408206 | 10,319347 | 0,355912 |
| 1134    | 1  | 1133 | 7,948175  | 10,326677 | 603202,107 | 6616233,56 | -1,410312   | -1,410312 | 10,326677 | 0,358018 |
| 1135    | 1  | 1134 | 7,955196  | 10,333875 | 603202,113 | 6616233,56 | -1,411897   | -1,411897 | 10,333875 | 0,359603 |
| 1136    | 1  | 1135 | 7,962218  | 10,341183 | 603202,12  | 6616233,56 | -1,413922   | -1,413922 | 10,341183 | 0,361628 |
| 1137    | 1  | 1136 | 7,969239  | 10,348228 | 603202,127 | 6616233,56 | -1,414497   | -1,414497 | 10,348228 | 0,362203 |

Figure 54, Calculating the tangent with the values from the attribute table. (tangent = O/A)

After the tangent has been calculated, the detrended model can be calculated with the formula:

$$\text{Detrended point} = \text{Corrected Z value of specific point} - \text{Tangent} * \text{Distance over surface}$$

In short this is:

$$\text{Detrend} = \text{Correction Z} - \text{Tangent} * \text{DIST\_SURF}$$

The same formula will now be used in Excel to create detrended values of the table. An example can be seen in figure 55.

| LINE_ID | ID | DIST | DIST_SURF | X          | Y          | Z         | Beek_Grytel | DIST_SURF | correctie Z | detrend     | tan (O/A)  |
|---------|----|------|-----------|------------|------------|-----------|-------------|-----------|-------------|-------------|------------|
| 1       | 1  | 1    | 0         | 603194,469 | 6616231,36 | -1,052294 | -1,052294   | 0         | 0           | 0           | 0,03500145 |
| 2       | 1  | 2    | 0,007021  | 603194,476 | 6616231,36 | -1,042942 | -1,042942   | 0,011694  | -0,009352   | =J3-N\$1*13 |            |
| 3       | 1  | 3    | 0,014043  | 603194,483 | 6616231,36 | -1,041173 | -1,041173   | 0,018935  | -0,011121   |             |            |
| 4       | 1  | 4    | 0,021064  | 603194,489 | 6616231,36 | -1,038973 | -1,038973   | 0,026293  | -0,013321   |             |            |
| 5       | 1  | 5    | 0,028085  | 603194,496 | 6616231,37 | -1,039009 | -1,039009   | 0,033315  | -0,013285   |             |            |
| 6       | 1  | 6    | 0,035107  | 603194,503 | 6616231,37 | -1,038485 | -1,038485   | 0,040355  | -0,013809   |             |            |
| 7       | 1  | 7    | 0,042128  | 603194,51  | 6616231,37 | -1,037329 | -1,037329   | 0,047471  | -0,014965   |             |            |
| 8       | 1  | 8    | 0,049149  | 603194,516 | 6616231,37 | -1,036717 | -1,036717   | 0,054519  | -0,015577   |             |            |
| 9       | 1  | 9    | 0,056171  | 603194,523 | 6616231,37 | -1,035466 | -1,035466   | 0,061651  | -0,016828   |             |            |
| 10      | 1  | 10   | 0,063192  | 603194,53  | 6616231,37 | -1,033954 | -1,033954   | 0,068833  | -0,01834    |             |            |
| 11      | 1  | 11   | 0,070214  | 603194,537 | 6616231,38 | -1,034675 | -1,034675   | 0,075892  | -0,017619   |             |            |
| 12      | 1  | 12   | 0,077235  | 603194,543 | 6616231,38 | -1,036581 | -1,036581   | 0,083167  | -0,015713   |             |            |

Figure 55, Calculation of detrended values

The correctness of the calculation can be checked, if the first and last value of the detrend column is 0, then this means the slope of the area around the gully has been removed. The profile of the gullies should look figure 56 this if a chart is made of the data in Excel.

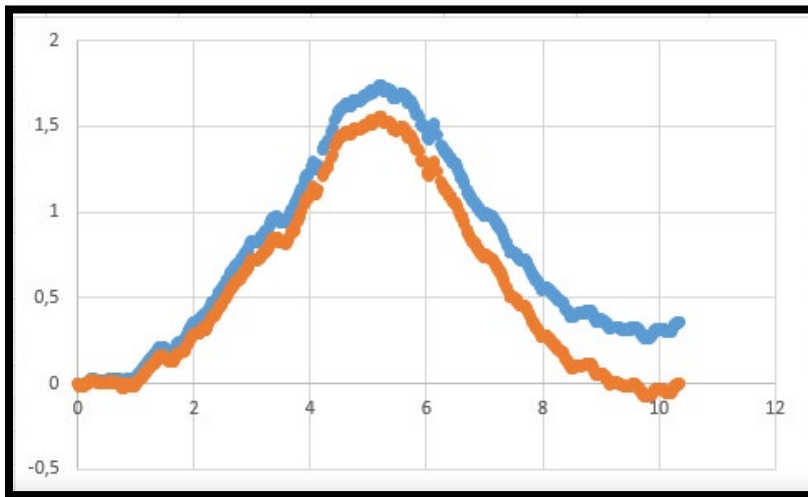


Figure 56 Chart of gully profiles. Blue = original gully with slope, Orange = detrended gully.

Naturally the graph should be inverted for a more realistic display of the gully. This can be done in Excel as well. With the surface around the gully flattened, it is possible to measure the depth of the gully exactly compared to the ground level.

## II.5 Calculating gully's volume

For this step, SAGA is going to be used. Here, the volume of the gully is going to be calculated. This is done by creating two map layers of the area, a layer with filled sinks (except for the gully) and a completely flattened area. These two areas will then be subtracted from each other to get the areas volume. In figure 57, the schematic representation is given of this calculation.

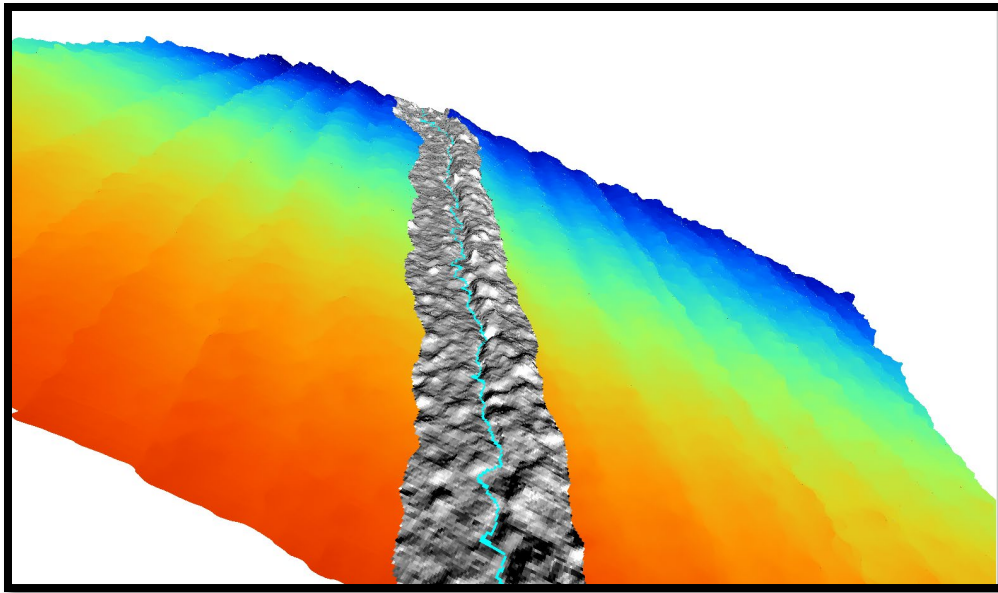
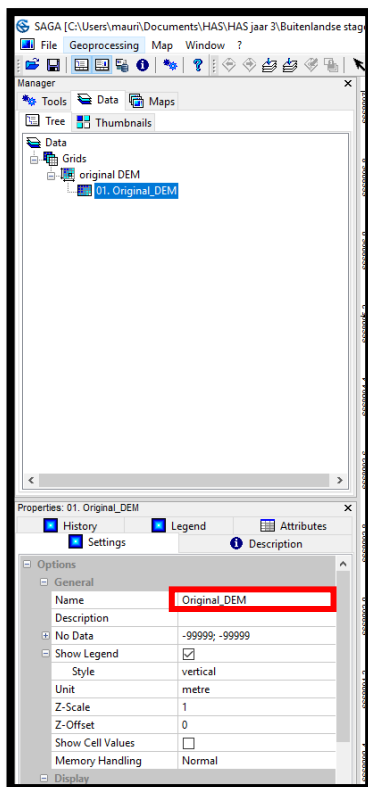


Figure 57, The rill is marked, a buffer is around it with hill shading from the DEM.



The flat DEM will be subtracted from the zone in the buffer to get the gully's volume.

The first step here to calculate the gully's volume is the importing of the DEM of the area. This is already explained in paragraph 4.3.1.

It is recommended to give each layer a recognisable name, otherwise it will be hard to remember which layer which step in the calculation is. This is shown in figure 58.

Figure 58, In the red square, it is possible to change a layer's name.



### II.5.1 Analytical hillshading

To get a better visual of the bumps, crevices and rills/gullies, one can apply analytical hillshading to the DEM. Simply click on Geoprocessing → Terrain Analysis → Lightning → Analytical hillshading. This process should then be applied to the original DEM in the next menu. The result can be seen in figure 59.

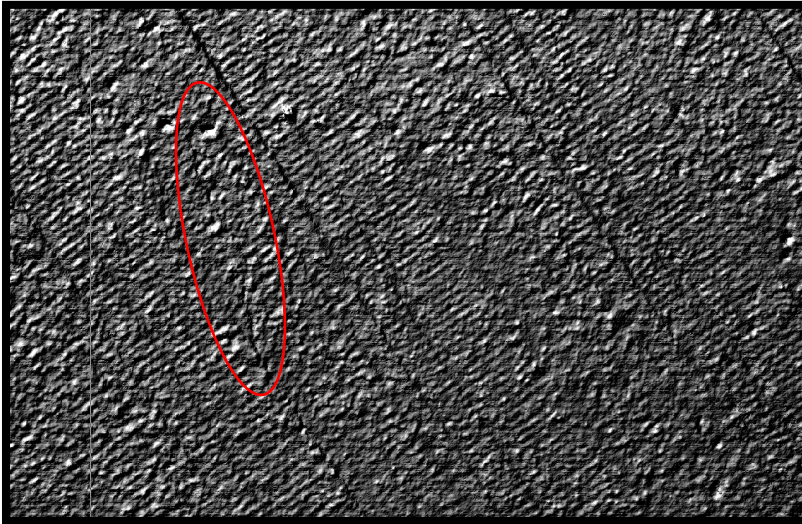


Figure 59, Analytical hillshading of the DEM.

Analytical hillshading allows for a good overview of the rill in the area. The rill can be seen within the red circle if looked at closely.

### II.5.2 Clipping the DEM

When the imported DEM has been clipped, the area the calculations should be done in becomes much smaller. This results in less calculation time. To clip the DEM, a shape is needed. This shape can be added via geoprocessing → Construction → Create New Shapes Layer.

This opens a new menu. Choose a name for the shape and select “polygon” as the shape type. Click “okay” when done. A new shape layer will appear in the data tree on the left side of the screen. Double click on the new shape layer to add it to the DEM.

Now click the “action” cursor icon to start drawing a polygon around the rill or gully. (figure 60)

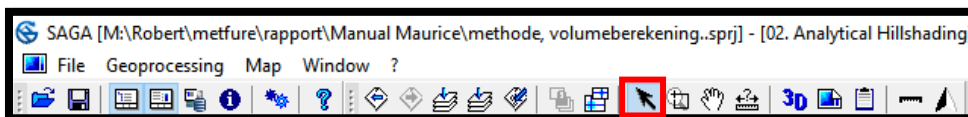


Figure 60, the location of the action cursor in the upper toolbar.

The analytical hillshading layer may provide insight on the location of the gully than the DEM. After the polygon is drawn, “right-click” to finish drawing. Right click on the shape layer of the polygon, click edit, and then uncheck edit selection to finish editing. The polygon will now appear as a filled shape.

Now the clipping of the DEM can start. Click Geoprocessing → Shapes-Grid Tools → Spatial Extent → Clip Grid with Polygon. A new menu will appear, as shown in figure 61.

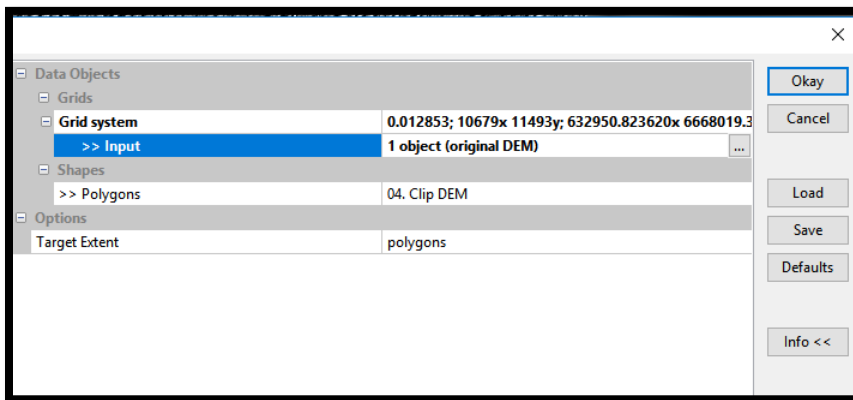


Figure 61, Select the grid system with the original DEM in this menu, also select the polygon to clip the DEM with.

Click okay when done setting the inputs. The A new layer will appear in the right screen. This is the clipped DEM. It is also possible to clip other grid layers the same way.

### II.5.3 Resampling the DEM

The first step is to resample the original DEM. Resampling basically means setting a new resolution for the DEM by making the pixels bigger. By increasing the size of the pixels, the different heights per cell will be flattened according to the average height of the multiple pixels the new pixel will envelop. The bigger cells will then be resampled again to their former size, but they will keep the same values in these cells. Figure 62 depicts this process schematically.

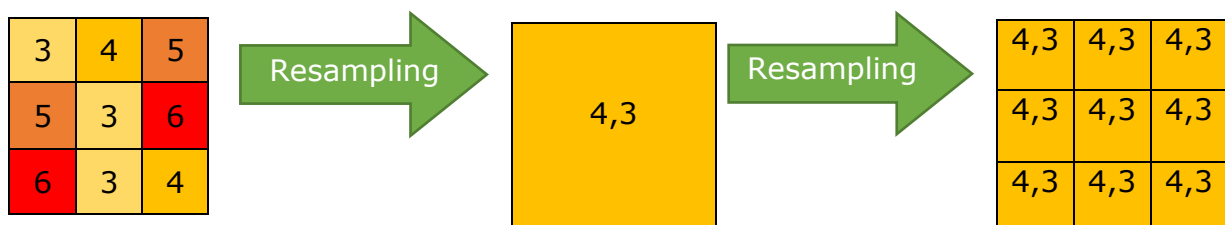


Figure 62, Resampling a 9 DEM cells into 1 DEM-cell (making it bigger) creates a new average value per cell, flattening the surface, resampling it back to the last resolution will keep the same)

The second Resampled DEM will be subtracted from the original DEM-part with the gully/rill. This will present us with the gully's volume.

To do this in saga, go to the Geoprocessing tab, click Grid, Grid System, and then "Resampling" (figure 63)

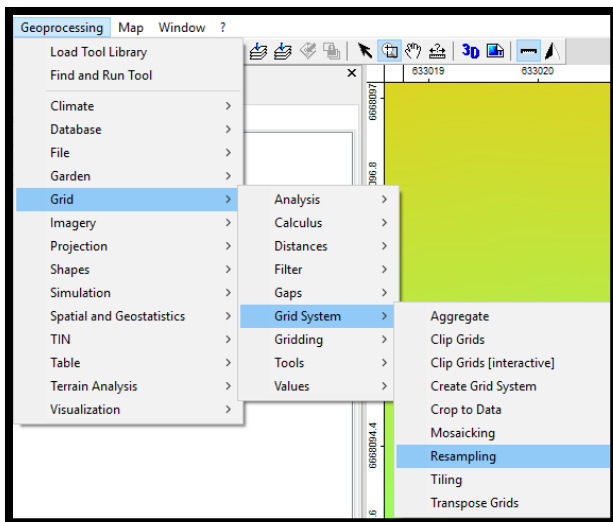
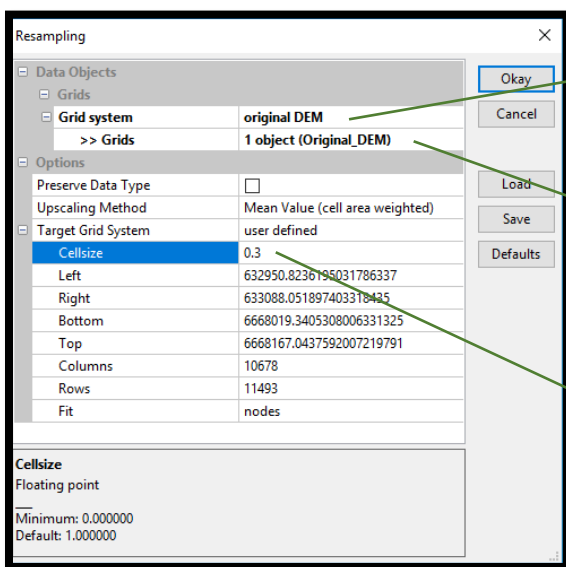


Figure 63, Geoprocessing → Grid → Grid System → Resampling.

A new menu will appear, as shown in figure 64. Here a couple of options need to be adjusted.



1. Select the grid system of the original clipped DEM here

2. Select the object to analyse from the grid layer here. In this case, this is the clipped DEM. (By moving the object to the right side of the screen in the sub

3. Modify the cell size to a suitable size. The rill in this case is 10 cm wide, so 0.3 m should be enough to overlap the rill with cells after resampling.

Figure 64, Resampling menu.

After these steps are completed, click "Okay".

A new layer will appear on the right side of the screen. Be sure to name it accordingly. "Resample DEM 1", for example.

Now the resampled DEM needs to be resampled back to its original resolution to be able to successfully subtract the two DEMs from each other later to get the volume of the gully. This can be done by opening the resampling menu again and select "grid or grid system" at Target Grid System. And then select the grid system that contains the original DEM with the original resolution.

Click okay to resample the resampled DEM back to its original resolution. (just as depicted in figure 64)

### II.5.4 Filling sinks (Planchon/Darboux, 2001)

This is a method in saga that can be used to fill sinks in the area. To access this method, follow the instructions in figure 65.

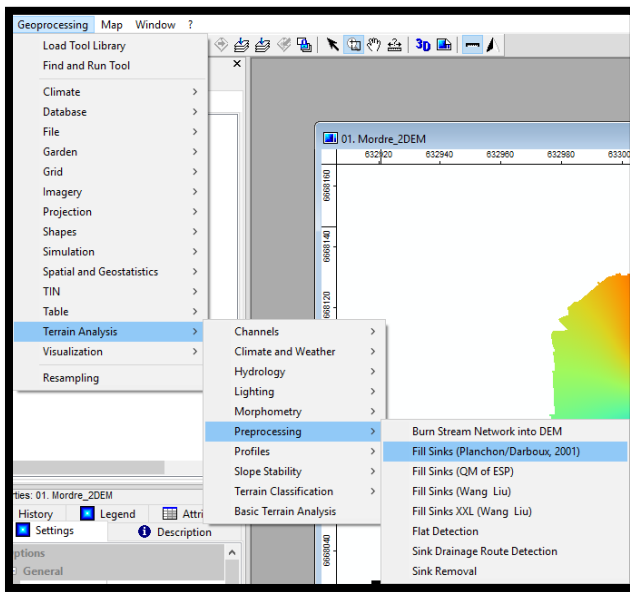


Figure 65, Geoprocessing → terrain Analysis → Pre-processing → Fill Sinks (Planchon/Darboux, 2001)

A new menu will appear as shown in figure 66. Here the original DEM should be selected as the grid to process.

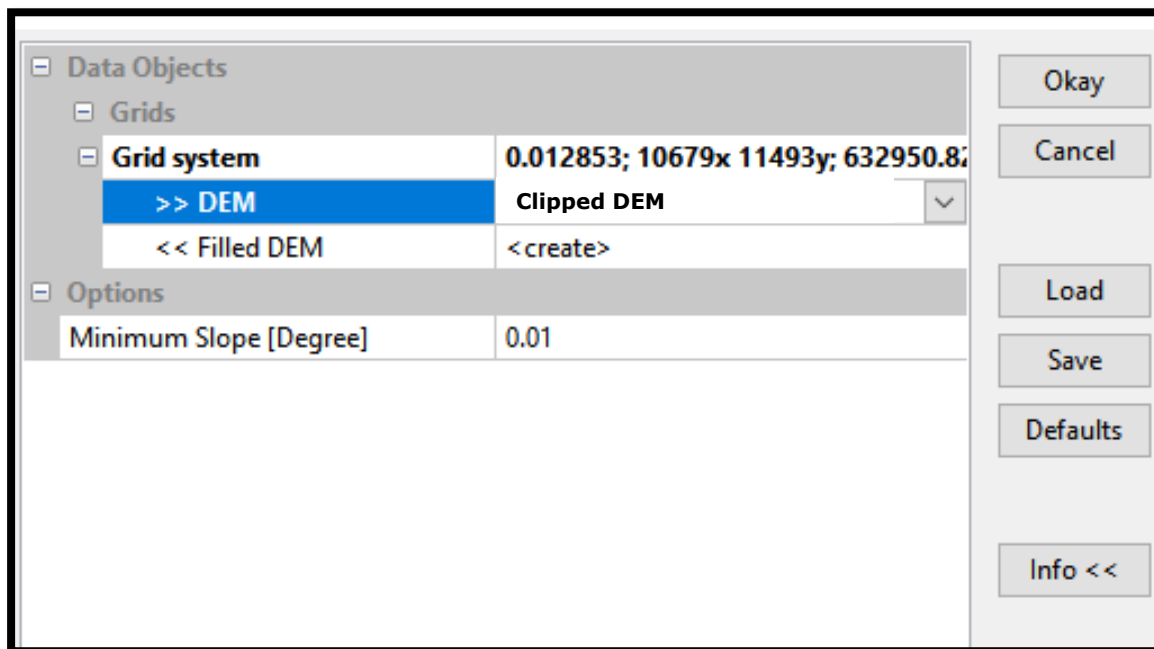


Figure 66, In this menu the clipped DEM from paragraph 4.5.2 should be added.

After the clipped DEM has been added, click on "okay".

The filling of the sinks in this DEM may take some time because it is a complex algorithm. This algorithm fills the little holes in the DEM, this way these holes will

not come up in the volume calculation of the rill. The rill itself will not get filled because the rill is not a hole but a crevice.

### II.5.5 Downslope area function

This function marks the lowest point of slopes in the area. With this function, a grid can be created marking the lowest point in the area where all the water accumulates. In this case it is a rill of the area. To make this grid, go to Geoprocessing → Terrain Analysis → Hydrology → Flow Accumulation → Downslope Area [interactive]. The following menu will appear, as shown in figure 67.

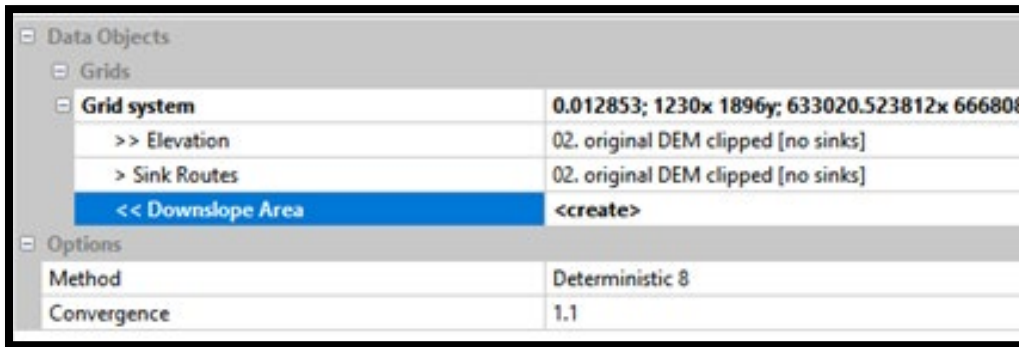


Figure 67, Select the correct grid system that contains the clipped DEM and select the clipped DEM in the Elevation row and Sink Routes Row.

Click okay when finished.

The interactive tool for downslope area is now activated. Choose the action cursor from the top toolbar in SAGA. Click at the starting point of the gully or rill to generate a line that follows the accumulation of water in the rill. Deactivate the tool by clicking on geoprocessing and unchecking the downslope area tool. The down slope area layer in the left side of the screen should look like figure 68.

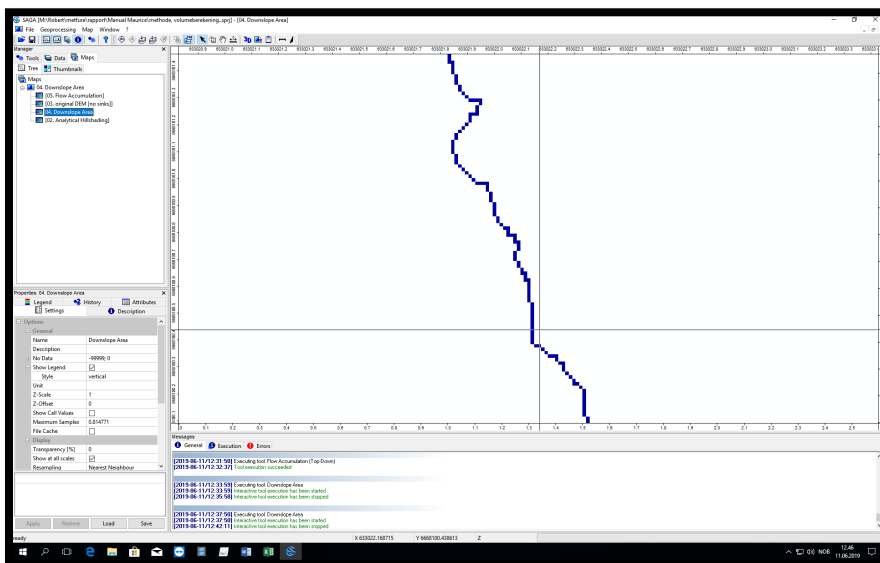


Figure 68, The line of the rill. Generated with the downslope area tool.

It is possible to compare the way the rill flows with the picture of the rill in the analytical hillshading layer. To do this, the parts of this layer with the value 0 should be considered as no data. In the left part of the screen, an overview with information about the current selected layer can be seen. (figure 69)

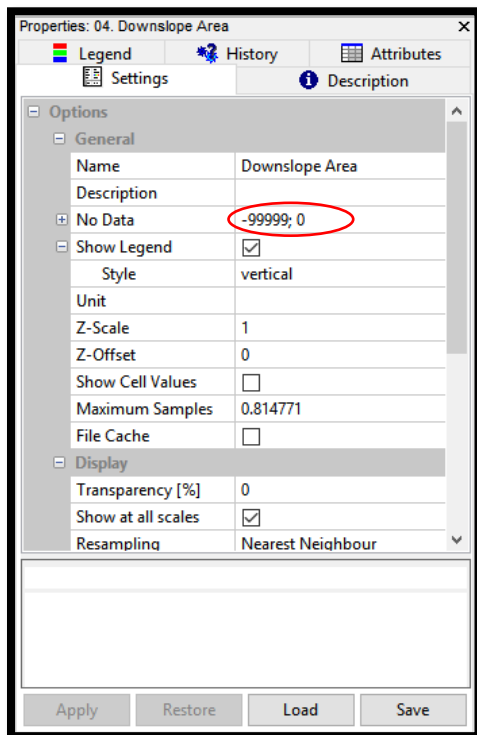


Figure 69, Menu with data on current selected layer. (Properties menu)

Within the circle in figure 69, the data is typed that should be considered as "no data". All the values outside of the line in figure 68 are 0 and should be considered as "no data". For this reason, type 0 as a no data value in this box as shown in figure 69. Everything except for the line of the rill will then proceed to be invisible. Making it ideal to lay it over the analytical hillshade, as shown in the example in figure 70.

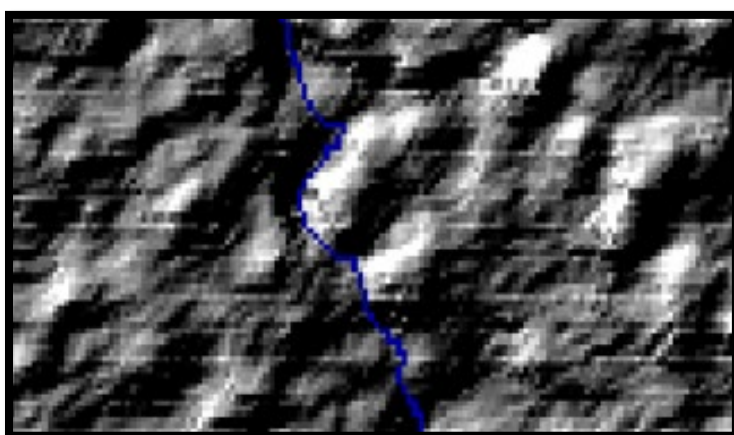


Figure 70, The downslope area line in as a new layer above the analytical hillshade layer.

### II.5.6 Converting the downslope area grid to a shape,

In this paragraph it is explained how to convert the grid layer, downslope area, to a shape. This requires multiple steps. First the grid layer will be converted to points, then the points will be converted to lines, the lines will then be used to make a buffer around the rill.

To start, go to Geoprocessing → shapes-Grid Tools → Vectorisation → Grid Values to Points. A new menu will appear as shown in figure 71.

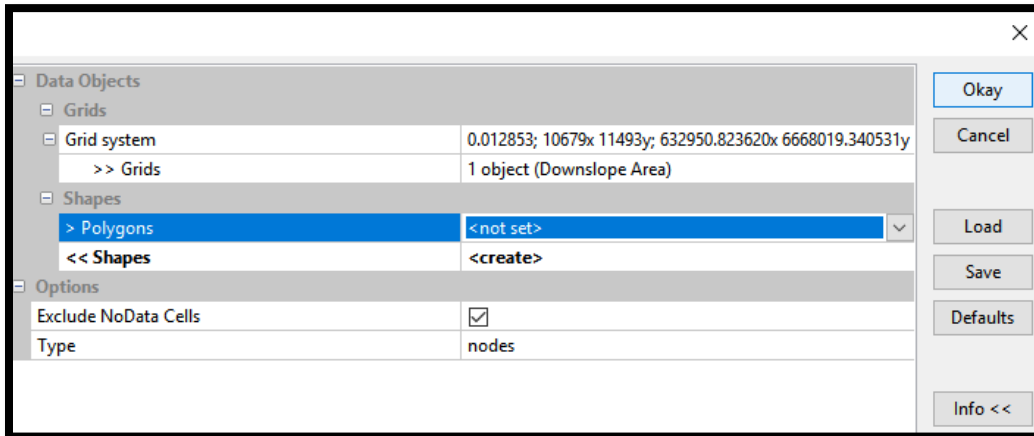


Figure 71, Creating points from grid values.

Select the downslope area grid from the right grid system in the top two rows of this menu. Since the values with 0 are marked as "no data", it is good to leave the checkbox near "Exclude NoData Cells" checked. When done, click okay.

Points with every value in every gridcell will now be made. The next step is the same as done before in II.3.3. The points will be converted to lines. Click on Geoprocessing → Shapes → conversion → convert points to lines. Select the points to convert into lines in the next menu and click on Okay when done. The points will be connected with lines as shown in the example In figure 72.

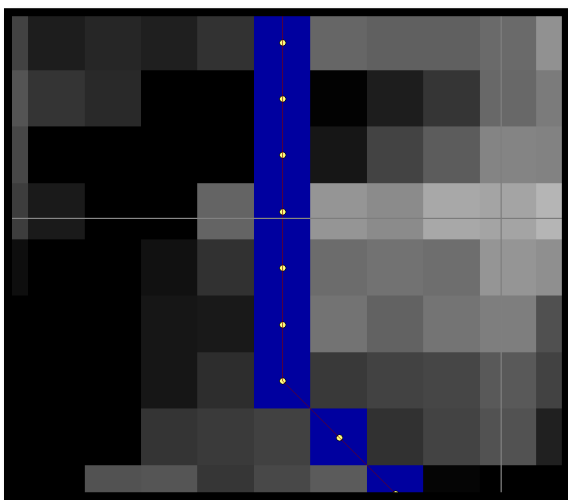


Figure 72, Points are now connected with lines.



The next step is to add a buffer of around 5 cm on this line since the rill in this case is 10 cm. If the rill is for example 30 cm wide, then add a buffer of 15 cm and so on.

Click Geoprocessing → Shapes → Tools → Shapes Buffer. The following menu will appear, as seen in figure 73.

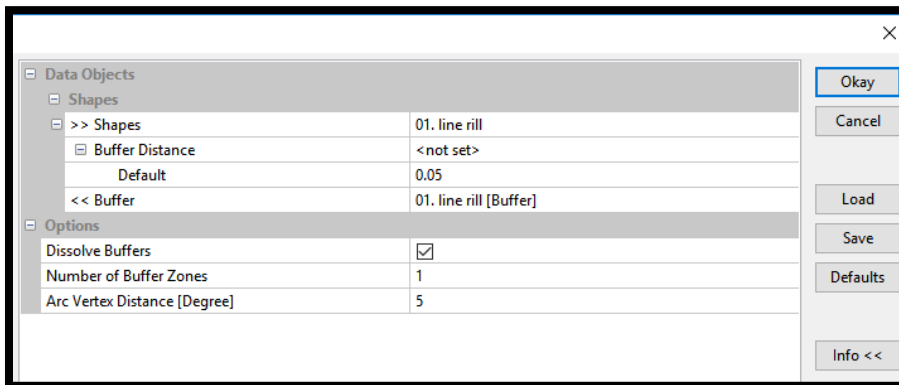


Figure 73, Select the line shape and add set the buffer distance to 0.05 metres.

Click okay when done. The buffer should look like figure 74.

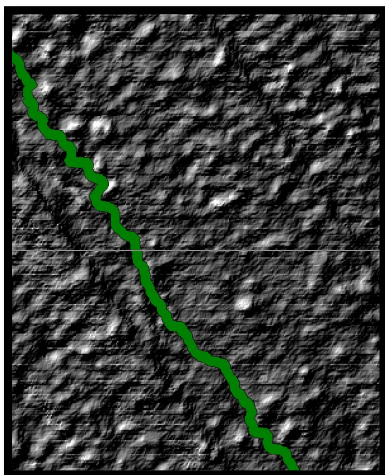


Figure 74, Buffer around the line. Marking the 10 cm wide rill.

Now, just like before, the DEM and resampled DEM are going to be clipped with the buffer shape. Go to Geoprocessing → Shapes-Grid Tools → Spatial Extend → Clip Grid with Polygon. The same menu as in figure 47 will appear.

2 clips will be made here. One clip using the buffer as the polygon to clip the:

- Second resampled clipped grid as shown in figure 62. (flattened Z values)
- Original clipped grid. (original Z values with depth of Rill)

The two clipped DEM's should look like figure 75.



Figure 75, Clipped DEM and the clipped Resampled DEM should both look like this.

This is the DEM and the Resampled DEM will be subtracted from each other in the next step.

### II.5.7 Calculation of the volume.

The DEM and Resampled DEM now need to be subtracted from each other. Go to Geoprocessing → Grid → Calculus → Grid difference. The menu in figure 76 will appear.

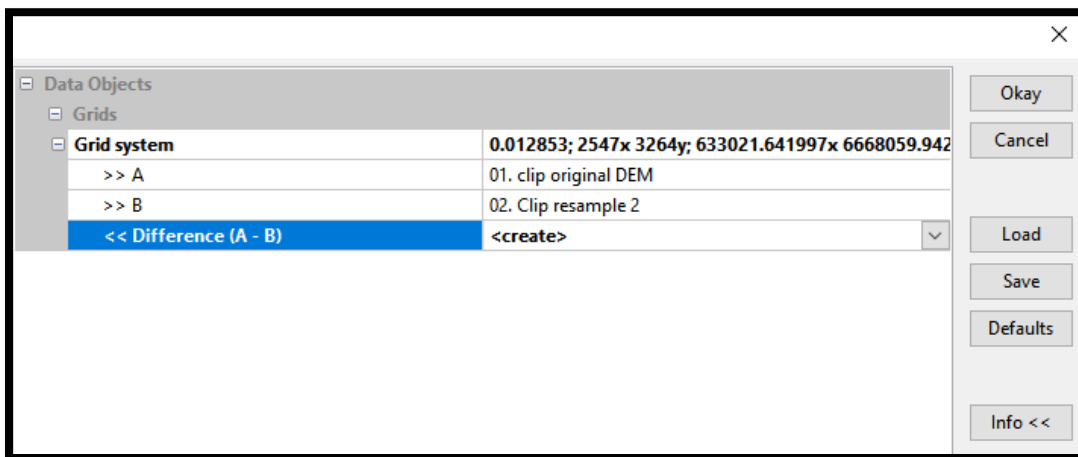


Figure 76, Select both clipped DEM's (clipped with the buffers), The original in A, and the resampled in B.

This will result in a new layer called: Grid-difference (A - B).

This layer is used in the last step.

The last step is to calculate the volume of the grid difference layer. This can be done via Geoprocessing → Grid → Calculus → Grid Volume.

This menu allows for the calculation of the volume of grids as seen in figure 77

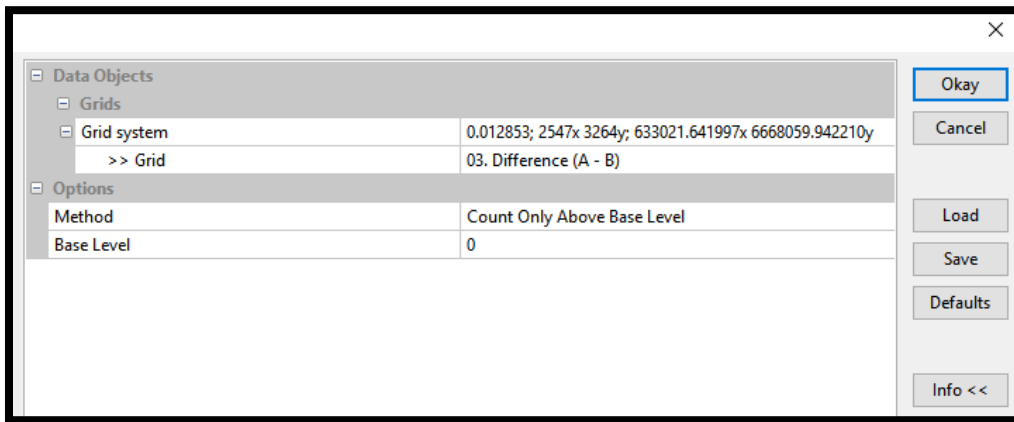


Figure 77, Grid volume calculation.

Add the difference (A – B) layer to the Grids the volume calculator should use.

The best method up until now is to count only below base level. The base level in this case will be 0 since this is the highest Z value, to be found in this layer now.

Click okay to start the calculation. The answer of the gully's volume will be given as a notification. (figure 78)

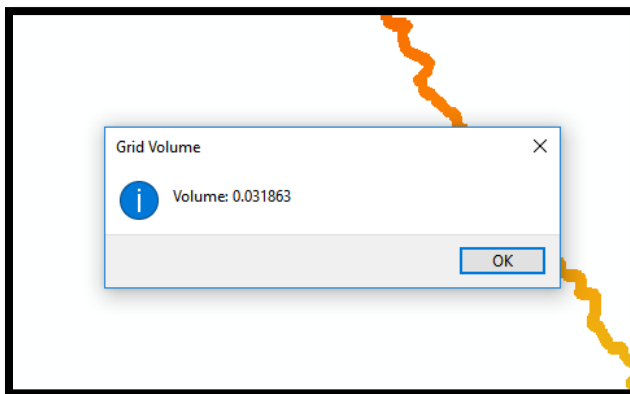


Figure 78, Apparently the gully's volume in this case is 0,031863 m<sup>3</sup>. This is a reliable calculation according to our estimations.)

This is how the volume of rills and gullies is calculated. Be sure to compare the answer with some estimations to check whether the answer is correct or not.

## II.6 Using LISEM to simulate ephemeral gully erosion

To simulate the catchment in an area, like Skuterud, one can utilise LISEM to simulate gully erosion in the area. In this paragraph it is explained how to make a simulation in LISEM of gully erosion. The area of Skuterud will be taken here as an Example.

Since rainfall is one of the main factors that cause gully erosion, this will be considered with the simulation. When LISEM is opened, the first screen will appear as seen in figure 79.

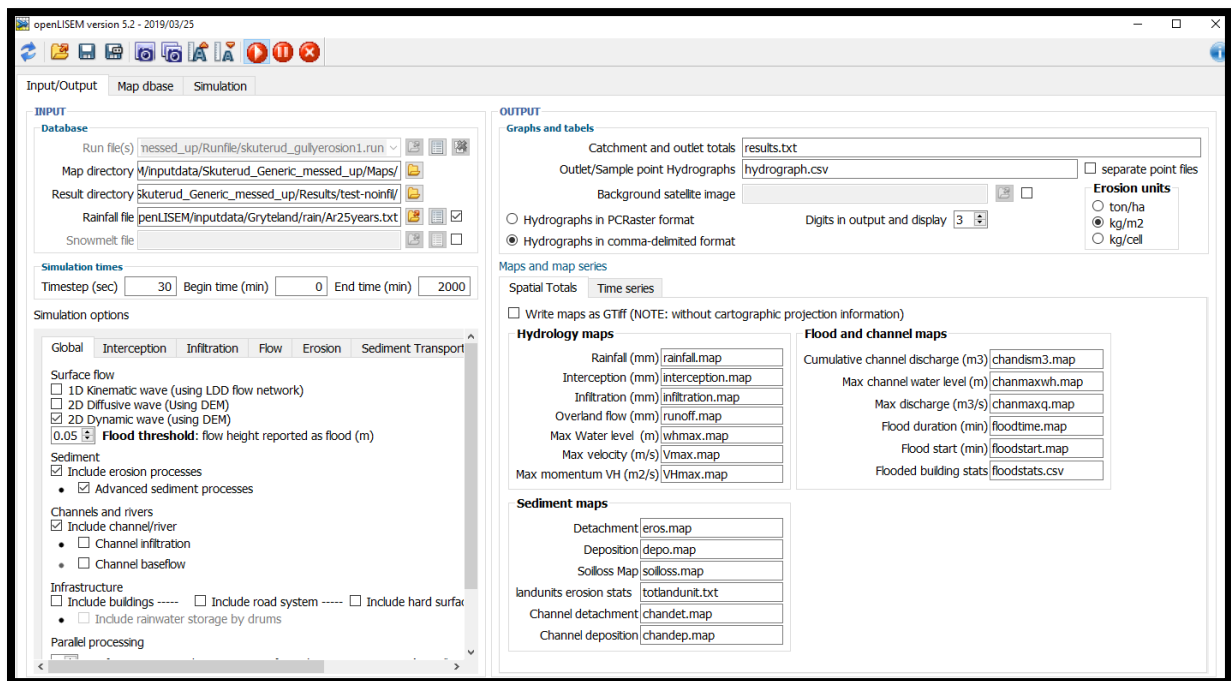


Figure 79, The first menu in LISEM.

Here, one can set the first settings for the simulation. These settings include:

- Which Run-file to use
- Which map package to use, (it needs a map-directory for that)
- Which rainfall file to use, (and if necessary, a snowmelt file)

The first step should be to obtain these files from the specific area that must be simulated. These files can be obtained within NIBIO.

Paragraph II.6.1 will explain how to run a basic simulation. Paragraph II.6.2 will explain how to modify map-files and txt-files to run a more realistic simulation of gully erosion.

## II.6.1 Running a basic simulation in LISEM

To run a basic simulation, LISEM needs a couple of files which contain the characteristics of the catchment in the area. These files are basically administrated in the following categories, as seen in figure 80.

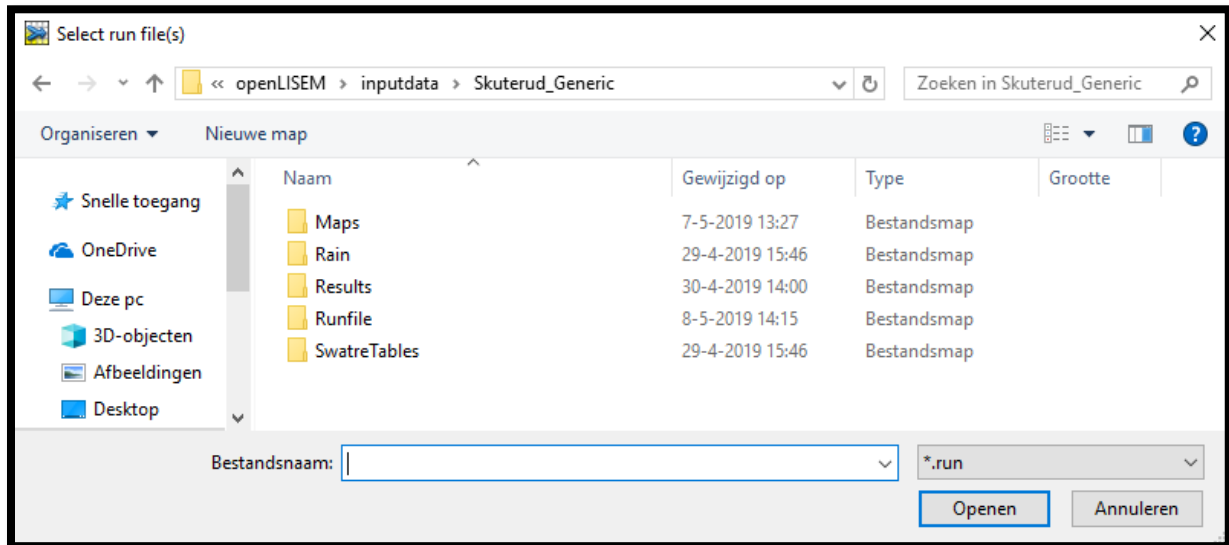


Figure 80, Recommended map structure for files to use in LISEM.

It is recommended that all the files of an area will be saved in this order to prevent confusion in LISEM. The first file to add in LISEM is the RUN-file. The RUN-file forms the backbone of the whole simulation made in LISEM since it contains a script that describes which map files and parameters should be used a certain time. To add a RUN-file to LISEM, simply click map icon, as shown in figure 81.

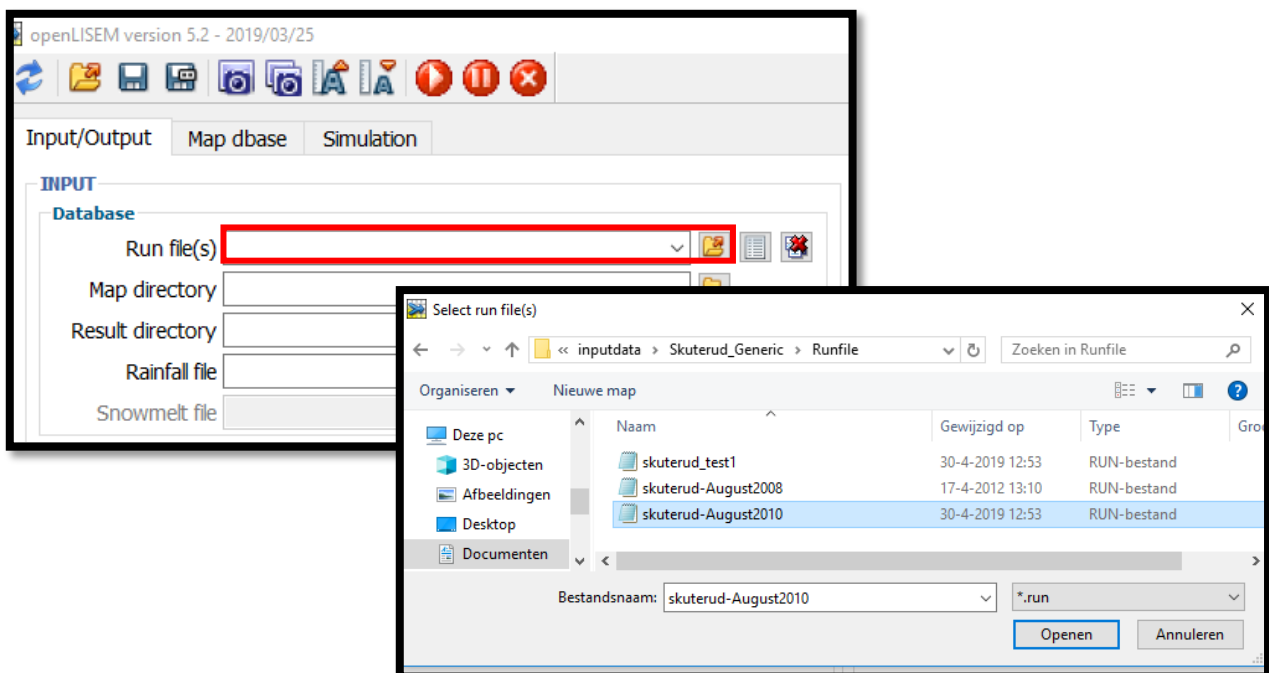


Figure 81, Click the map icon or type a file directory here to add a RUN-file.

After the run file has been added, the file directory should appear in the empty white row.

Now the maps can be added. This can be done by clicking the map icon or typing the directory as shown in figure 82.

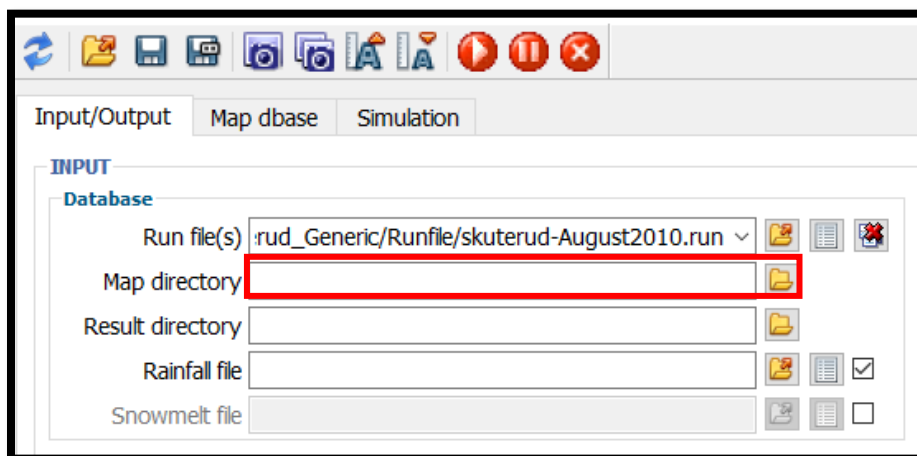


Figure 82, Click the map icon, or type a directory in the empty space next to it.

The map-files contain data on each characteristic of the area. Table 6 displays all of the files that should be in the map directory. The (map) files are the files one can adjust when certain characteristics of the area are not up to date. This can be done in a program called Nutshell. (more about this in paragraph II.6.2) For instance the ch.map contains data on the crop height of the area. During the winter, there are no crops and limited vegetation, so it is important to check if the value in ch.map is the right one.

Table 6, Overview of map files and other files necessary in directory (in case of Skuterud)

| Files           |                   |               |
|-----------------|-------------------|---------------|
| Aggrstab.map    | Hardsurf.map      | n.map         |
| Area.map        | Headout.map       | Outlet.map    |
| Barriers.map    | Id.map            | Outpoint.map  |
| Ch.map          | Inithead.001      | Per.map       |
| Ch.map.aux.xml  | Inithead.002      | Profile.inp   |
| Chancoh.map     | Inithead.003      | Profile.map   |
| Chandepth.map   | Inithead.004      | Roadwidth.map |
| Changrad.map    | Inithead.005      | rr.map        |
| Chanman.map     | Inithead.006      | Stonefrc.map  |
| Channeltest.map | Inithead.007      |               |
| Chanside.map    | Inithead.008      |               |
| Chanwidth.map   | Inithead.009      |               |
| Coh.map         | Inithead.010      |               |
| Cohadd.map      | Lai.map           |               |
| Crustfrc.map    | Idd.map           |               |
| D50.map         | Iddchan.map       |               |
| D90.map         | Iddchanscalar.map |               |
| Dem.map         | Iddchantest.map   |               |
| Grad.map        | MDS.map           |               |

These map files are used to simulate a catchment. This may seem a bit overwhelming, but the only a few files need to be modified in case of a more realistic simulation of the catchment (gully erosion) in Skuterud. However, all these files are necessary in LISEM to be able to run a simulation.

The next step is to set a result directory, as shown in figure 83.

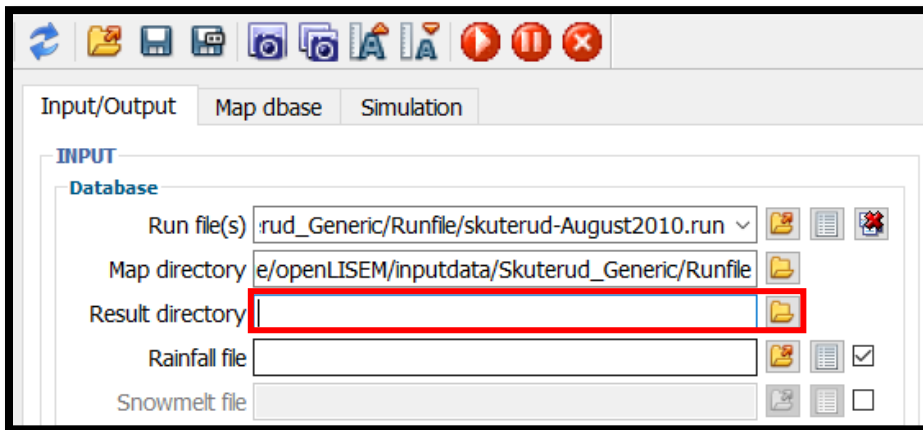


Figure 83, Type a directory to store the simulation's results or select one by clicking the map icon.

It is important to create a new result directory with each simulation! Otherwise the previous results will be overwritten. New maps can be created just by typing them in the result directory.

Now, a rainfall file should be added. More rain means more run off, and more run off means more ephemeral gully erosion on agricultural fields. The selection of the rainfall file is shown in figure 84.

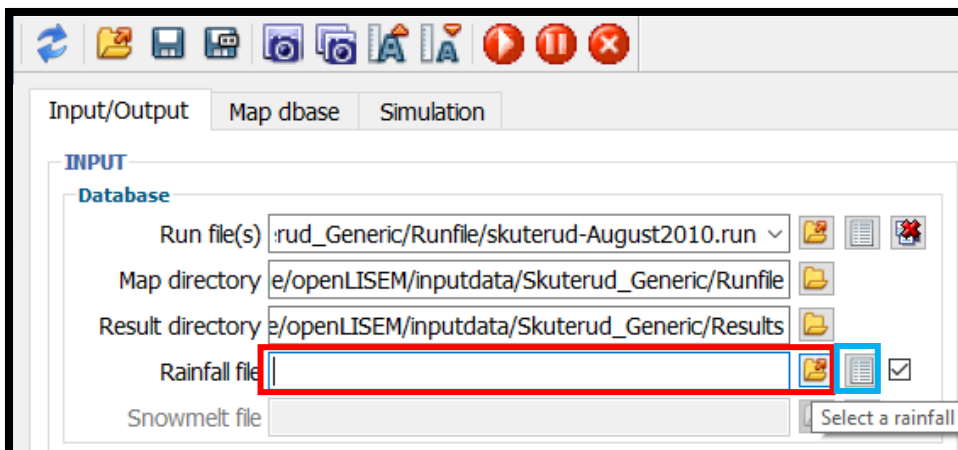
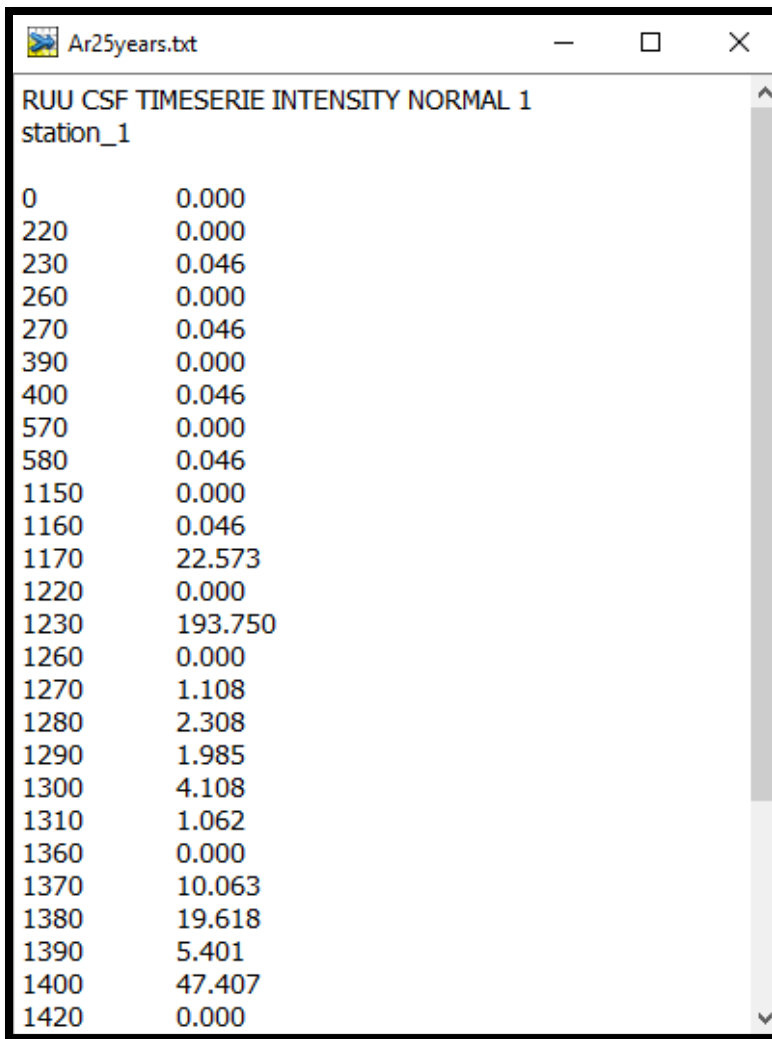


Figure 84, Select a rainfall file by clicking the map icon or by typing its directory.

Rainfall files are txt-files that contains data on the amount of rainfall at every timestep. Once the rainfall file's directory has been added to LISEM, one can click on the txt file icon (blue square in figure 84), to show how the rain will fall during the simulation. A text-table will appear with 2 columns as shown in figure 85.



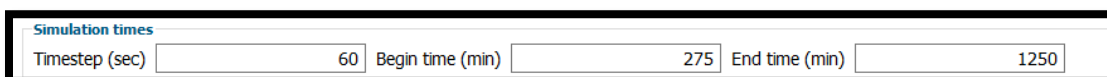


| timestep | amount of deposition |
|----------|----------------------|
| 0        | 0.000                |
| 220      | 0.000                |
| 230      | 0.046                |
| 260      | 0.000                |
| 270      | 0.046                |
| 390      | 0.000                |
| 400      | 0.046                |
| 570      | 0.000                |
| 580      | 0.046                |
| 1150     | 0.000                |
| 1160     | 0.046                |
| 1170     | 22.573               |
| 1220     | 0.000                |
| 1230     | 193.750              |
| 1260     | 0.000                |
| 1270     | 1.108                |
| 1280     | 2.308                |
| 1290     | 1.985                |
| 1300     | 4.108                |
| 1310     | 1.062                |
| 1360     | 0.000                |
| 1370     | 10.063               |
| 1380     | 19.618               |
| 1390     | 5.401                |
| 1400     | 47.407               |
| 1420     | 0.000                |

Figure 85, In the rainfall file, the left column shows the timestep and the right column shows the amount of deposition at the given timestep.

All time steps are given in seconds. Looking at this table will also come in handy when the simulation is already running to know when the rainfall in the simulation will start.

Setting the duration of the Simulation is also important. This can be set in the input/output tab under simulation times as shown in figure 86. Be sure to select the begin time and end time in correspondence with the rain file.



| Simulation times |    |                  |     |                |      |
|------------------|----|------------------|-----|----------------|------|
| Timestep (sec)   | 60 | Begin time (min) | 275 | End time (min) | 1250 |

Figure 86, Setting simulation times.

Once the time steps are taken care off, a couple of more factors can be checked. When calculating gully erosion, it is important to cross out the boxes for Sediment (Include erosion processes, Advanced sediment processes.) as shown in figure 87.

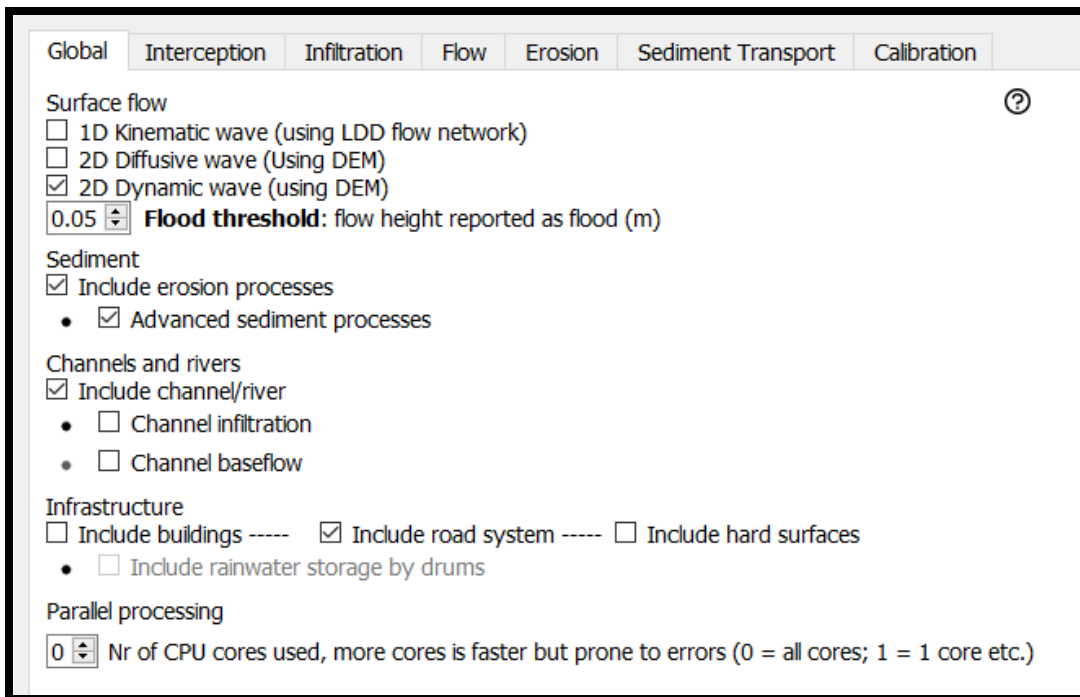


Figure 87, Global tab in the Input/output tab in LISEM.

It is also possible to include hard surfaces, road systems or buildings, provided the map-files are available in the map-file directory.

When it comes to simulating gully erosion, “infiltration” is one of the most important parameters that determines the development of gullies. When it comes to setting the infiltration parameters, SWATRE-tables are usually used. SWATRE-Tables are txt-files that contain information on the permeability of each type of soil. Which soil layers are in a specific point is mentioned in the profile.map file. SWATRE-tables are imported to LISEM, as shown in figure 88.

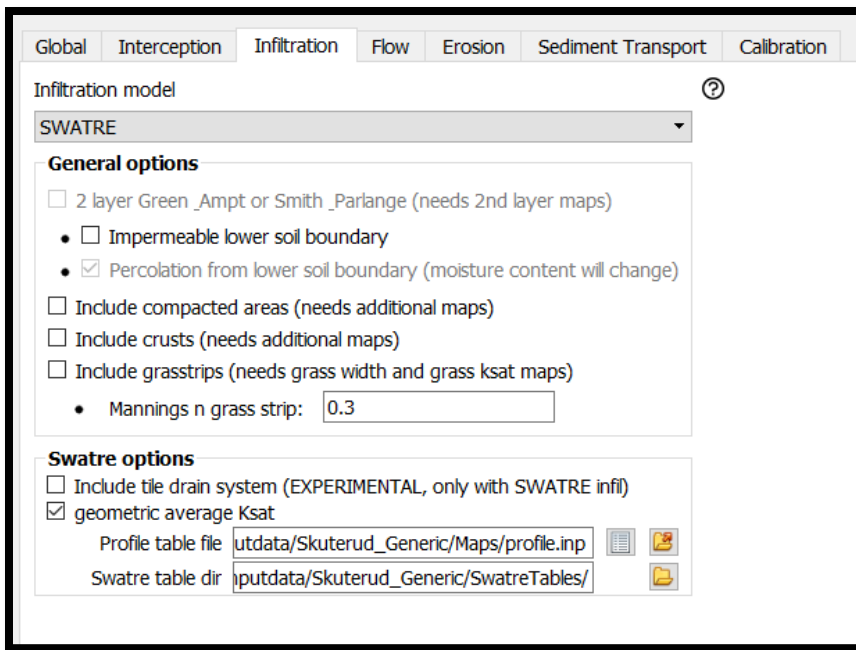


Figure 88, Set "SWATRE" as the method to quantify the amount of infiltration in the area.

After SWATRE is selected as the infiltration model, set the directory for LISEM so it can find the SWATRE-tables. This option can be found under "Swatre options".

On a side note, in some cases the infiltration is too high when looking at the simulations. This would call for some modifying of the permeability numbers in the SWATRE-tables. This can be easily done by opening the SWATRE-tables in Excel and lowering the permeability values (k). (this can be helpful when the soil is frozen, for instance.)

The simulation can now be run by clicking the play button in the toolbar on the top of the screen, if all necessary maps are imported to LISEM. (figure 89)

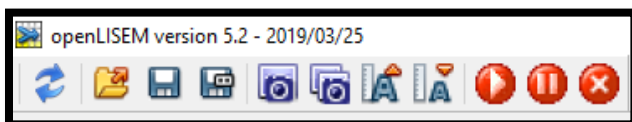


Figure 89, Toolbar on top of the screen in LISEM.

If not, all maps are there, LISEM will give an error notification, telling which file is missing. These files can be (re)created using Nutshell, or simply copying and pasting another map with the same values. For example, when an error appears that d90.map is missing, it is possible to convert the d50.map in nutshell to a d90.map and then save it as d90.map. This prevents errors and will not interfere with the simulation (if the values of the maps are supposed to be the same).

While running the simulation, it is possible to check in on the progress made via the simulation tab, as shown in figure 90.

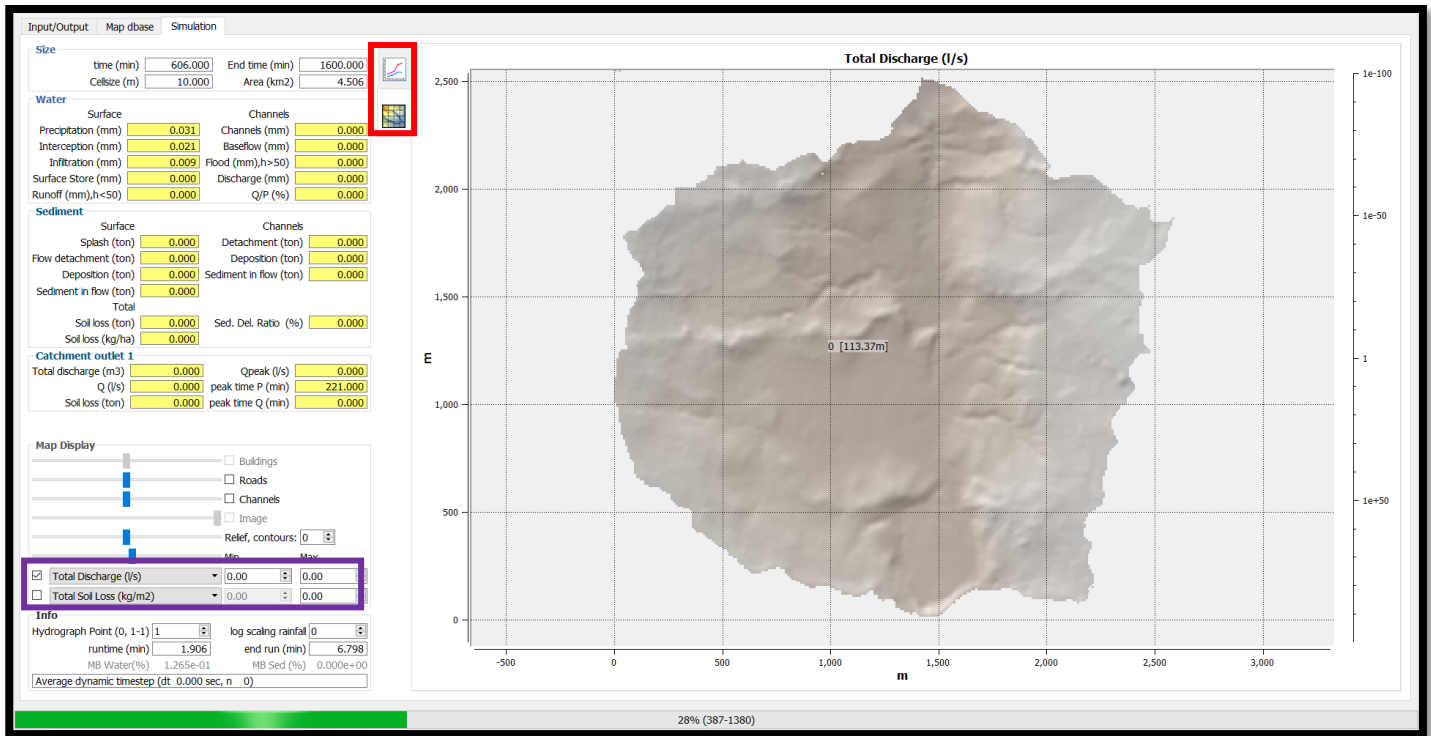


Figure 90, Simulation tab.

The simulation screen provides information about the catchment in Skuterud. The buttons in the red square are useful for toggling between a map view of the area (in this case Skuterud), Or a hydrograph of the area as shown in figure 91

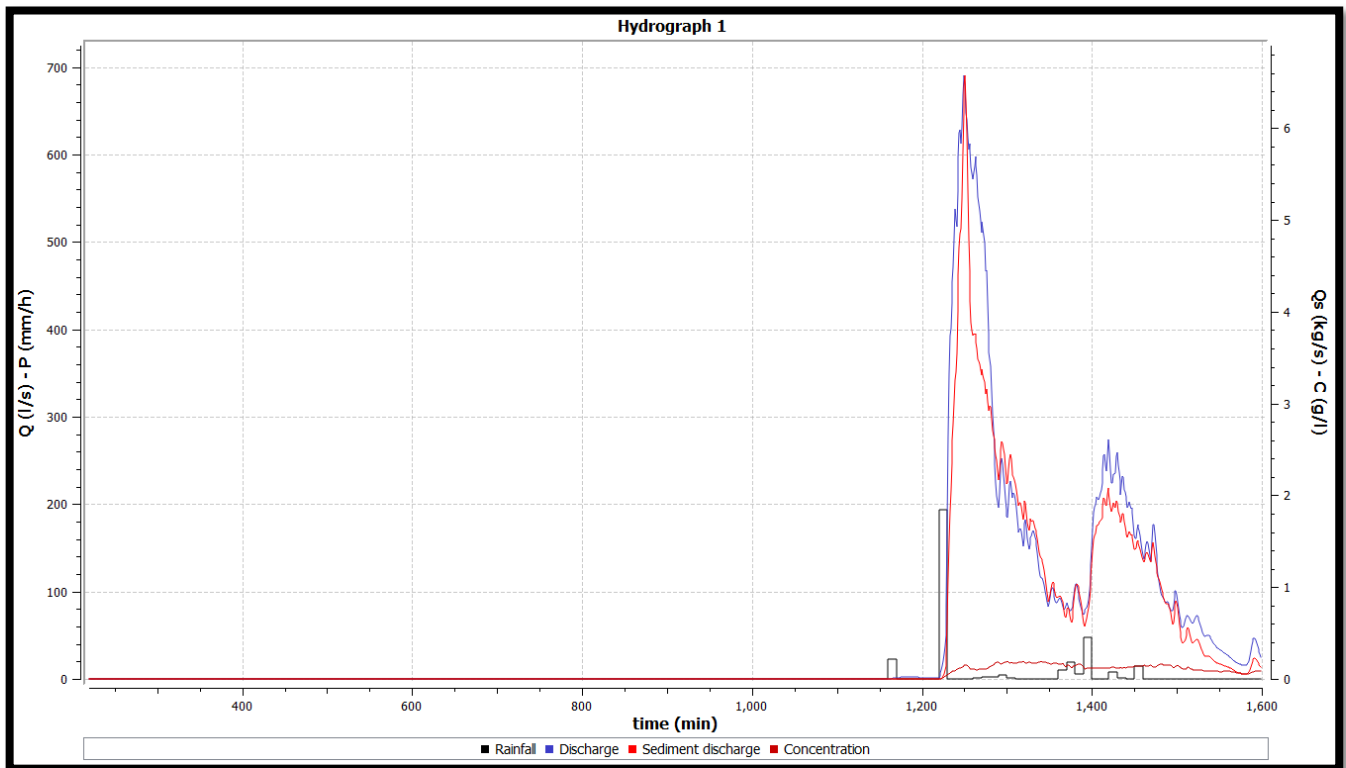


Figure 91, A hydrograph of Skuterud after some rainfall.

The hydrograph provides information on how much rainfall, discharge, sediment discharge and concentration there is spanning over the duration of the simulation.

The map provides information on how rainwater runs off in the area. The map can also show different data which is available by clicking the tabs in the purple square. (figure 90) The tabs contain the following information: (figure 92)

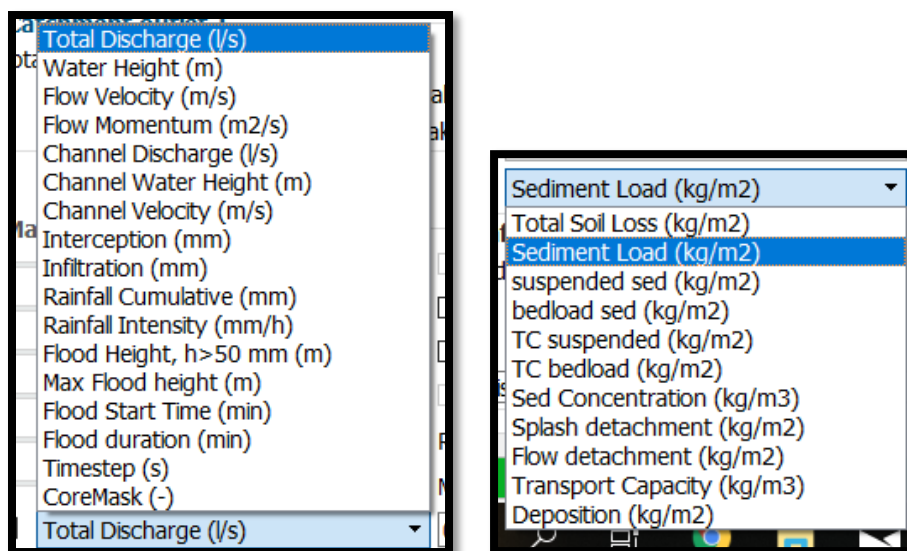


Figure 92 All of the information that can be shown in the map.

Keep in mind to always create a new result directory if there is need for another simulation with different parameters. This way the old results will not be overwritten. This is it when it comes to running a basic simulation of the catchment in an area.

### II.6.2. Modifying map files

To get a more realistic representation of the catchment in an area, it is necessary to modify the parameters in some maps. The files that should be changed according to the current situation are shown in table 7. The changes of the situation of the map parameters are related to the time of year.

Table 7, Overview of files that must be modified.

| file                 | specification  | Why it needs to be changed   | Range of values |
|----------------------|--|--|-----------------|
| <b>Ch.map</b>        | Crop height map  | The parameters in these maps need to be changed to match the winter situation of the area. So low crop height, a low leaf area index and a small percentage of vegetation covering the soil. | 0-30            |
| <b>Lai.map</b>       | Leaf area index map  |  | 0-12            |
| <b>Per.map</b>       | percentage of vegetation covering the soil                               |  | 0-1             |
| <b>SWATRE tables</b> | The SWATRE-tables contain permeability parameters (k) of each soil type. | The permeability of the soils should be lowered since the soil is frozen in the winter period (when most gully erosion occurs)   | -               |

To change the first attributes in ch.map, lai.map and per.map, one must use Nutshell. Nutshell makes it possible to change the values within the map-files. Once nutshell is opened, the first screen looks like figure 93.

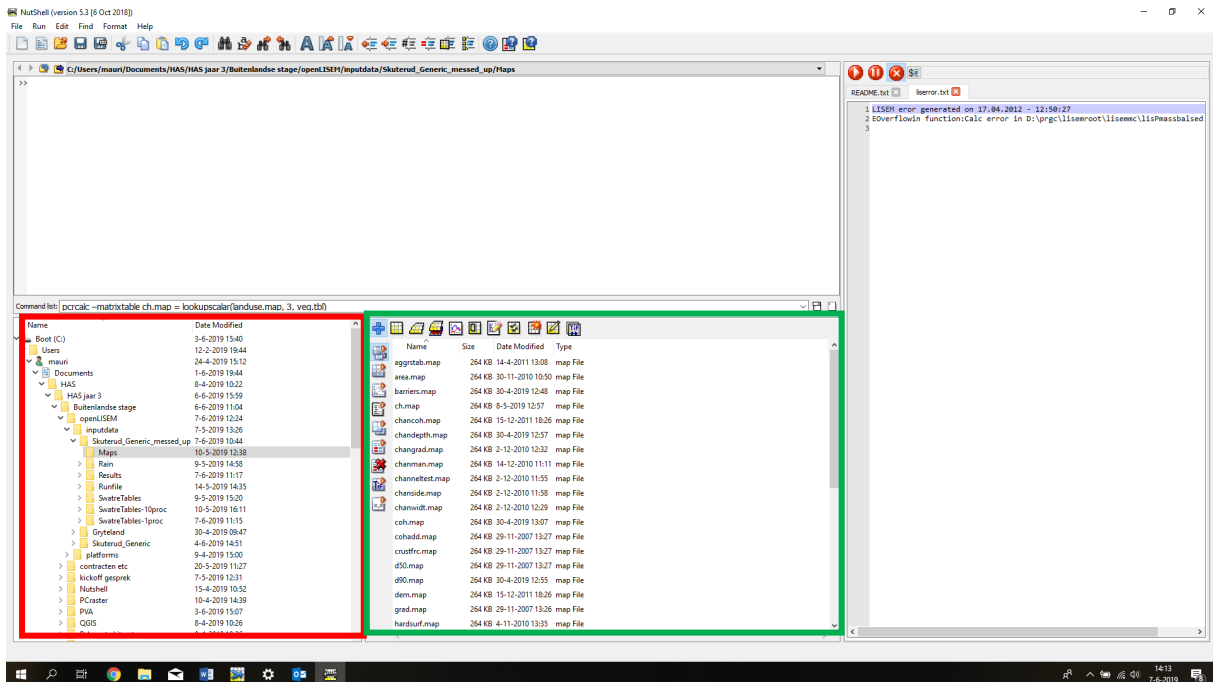


Figure 93, Base menu in Nutshell.

To modify the maps, the directory where the maps are saved should be selected first. This can be done within the red square in figure 94. By clicking the maps directory, the map-files should appear in the menu within the green square.

Now to start modifying a map's values. Click on a map that needs other values in the map list (green square) to select it. Double click, to open the map (the programme Aquila is needed to view these maps, so be sure to install it)

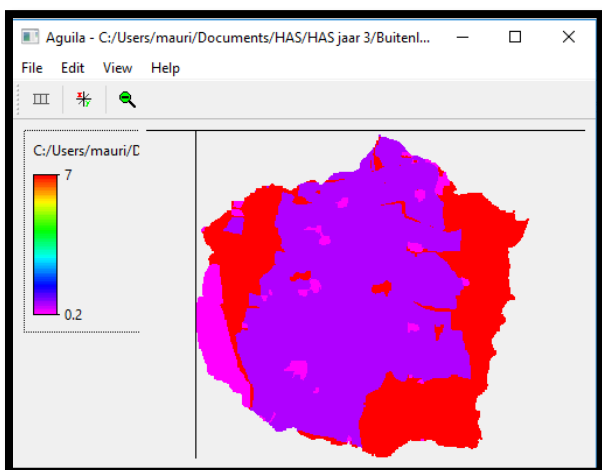


Figure 94, Ch.map of Skuterud. The values depict crop height in meters. (red is a forest)

Since most gully erosion appears during the winter period (when there is almost no vegetation), it is necessary to change the crop height in the agricultural fields to around 10 centimetres, max.

To change the values in the map, select ch.map in nutshell and click on the map edit icon, as shown in figure 95.

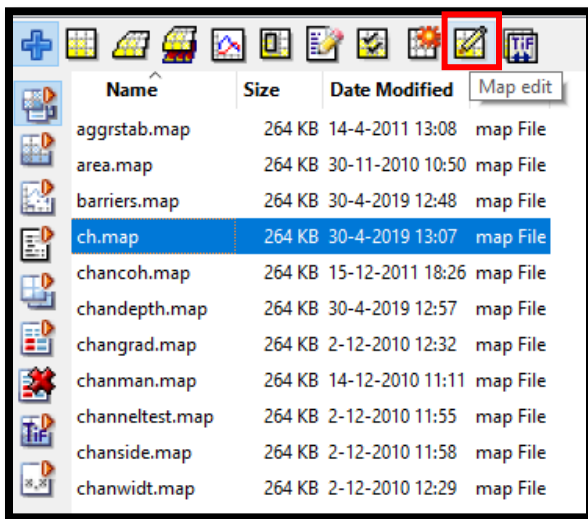


Figure 95, Select a map → map edit.

A new screen will appear in which it is possible to modify the map values. (figure 96)

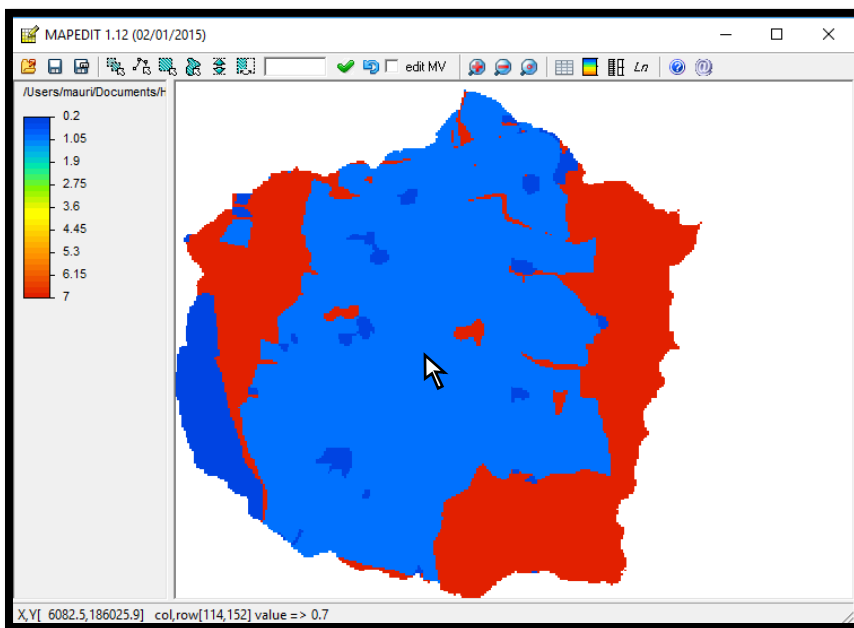


Figure 96, It is also possible to determine the value by looking at the colour in the legend.

While moving the cursor over the map, it is possible to see the current value of that certain part of the map. This value is shown at the bottom of the screen in figure 97.



In this case, the crop height at the place of the cursor is 0,7 meters high. This area is an agricultural field in Skuterud. During the winter, there are only some remains of the crops. For this reason, the crop height needs to be changed to 0,1 meters. To do this, click the "edit cells between two values" icon, as shown in figure 97. A small menu will appear that asks which values to select.

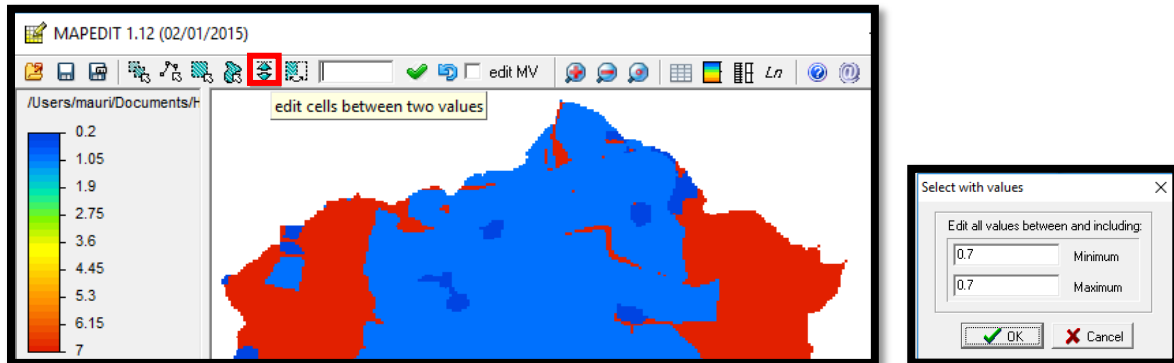


Figure 97, Editing cells between two values.

The values are put in the small menu as shown in figure 97. All cells with that value are now selected in the map and have changed colour. Now the selected cells can be modified, as shown in figure 98.

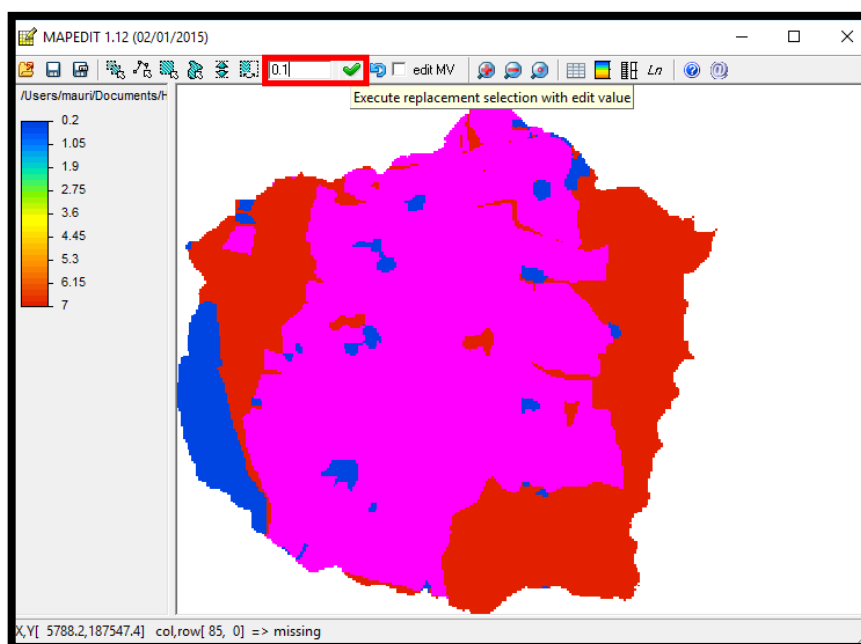


Figure 98, Type the new value of the selected cells in the area within the red square

After the new value is filled in, click on the "check" icon to finish the editing. It is now possible to either save the map under the same name, overwriting the last version or save it under a different name. Just click the save icon on the top left part of the screen to finish up.

Now the value is modified. Repeat these steps if the modification of other values in other maps is deemed necessary. All the maps have the same PCraster layout, so it all works the same way.

## Attachment III: Research design, field measurements vs drone measurements

This attachment describes the way the conventional measurements and drone measurements were taken in the field.

5 conventional measurements were taken in the field but due to some complications with the conventional measurements, only conventional measurement 2, 4 and 5 were able to be compared to the drone images.

Every conventional measurement is marked with two paper markers in the field. these markers help to elaborate the coordinates of the profile. As seen in figure 99



Figure 99, The red line between the markers will form a cross section of the profile

The same gully was measured on an altitude of 20 metres with the drone. The profiles are numbered to retain a good overview. The numbering of the profiles is given in a schematic in figure 100.

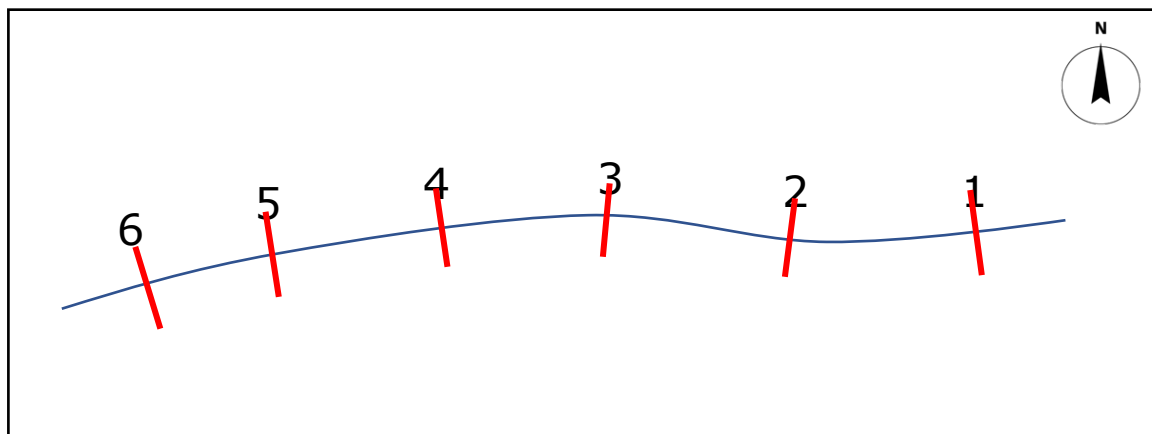


Figure 100,, Schematic representation of a rill in with drone measurements 1 till 6 in Skuterud

Six measurements with the drones were made. Only drone measurement 6, 5 and 2 were compared to conventional measurements in the end to check the drone's accuracy. Drone measurement 6 was compared with conventional measurement 5. Drone measurement 5 was compared with conventional measurement 4 and Drone measurement 2 was compared with conventional measurement 2.

As the rill continues to the east, the rill becomes more and more flat according to the field measurements. The digital cross sections were made of these profiles using the drone imagery. The cross sections of the conventional measurements have been detrended, as well as the cross sections of the profiles that are made in SAGA. A detailed explanation of this process is given in paragraph II.4.

Due to irregularities with the drone measurements, not all profiles compared because it was hard to make out which drone profile matched each conventional measured profile. Another thing that caused confusion is that 5 conventional measurements were done in the field, while 6 sites were marked with markers. For this reason, only the drone profiles that matched the conventional measurements are shown. (Of which there are 3 of in chapter 5)