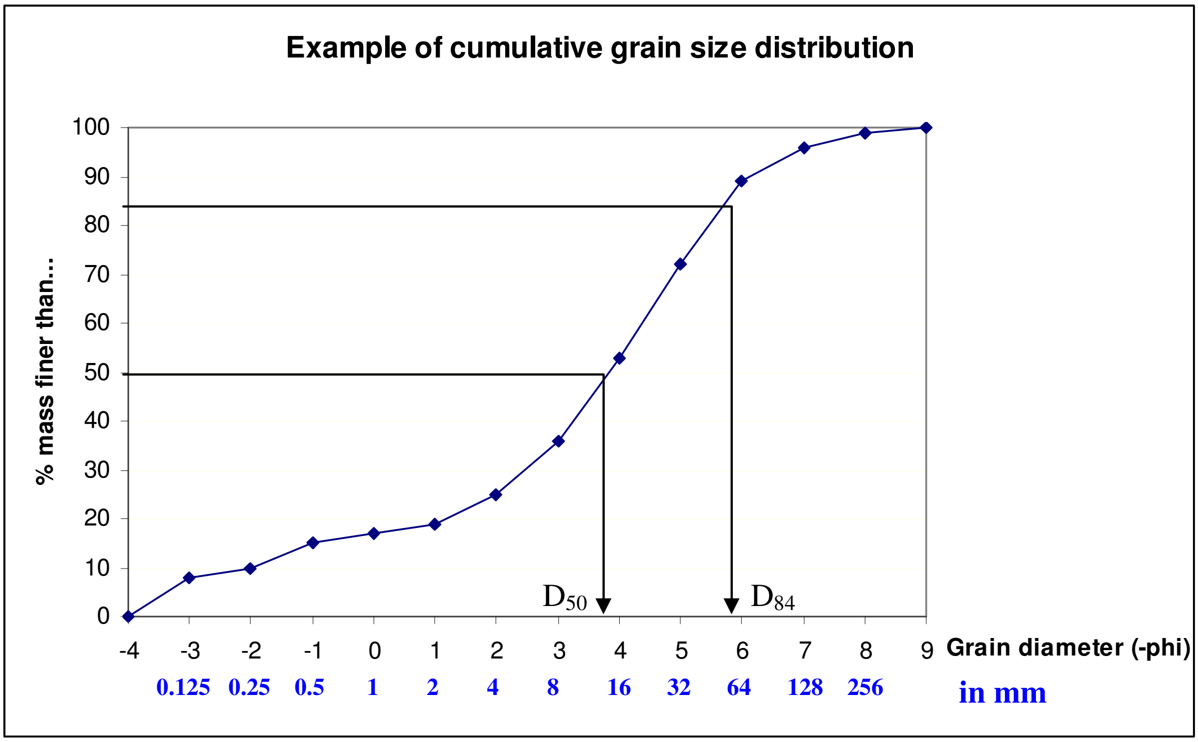
Determining grain-size distributions using photographic methods (surface) or sieving methods (sub-surface)

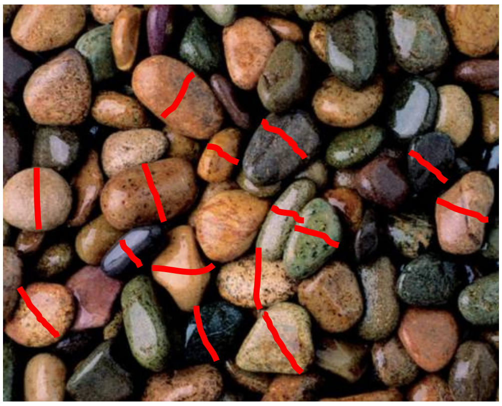
Firstly: there is a very detailed free book that explains very thoroughly how to carry out "Sampling Surface and Subsurface Particle-Size Distributions in Wadable Gravel- and Cobble-Bed Streams for Analyses in Sediment Transport, Hydraulics, and Streambed Monitoring" by Bunte and Abt (2001): http://www.fs.fed.us/rm/pubs/rmrs_gtr074.html

The methods described below are for the determination of cumulative grain size distributions (see figure below). Note that the grain size on the x-axis is usually expressed in *–phi* scale, where the equivalent particle size in *mm* is equal to 2^{-phi}. This allows both coarse and fine grain sizes to be equally visible on the diagram.



Scientists typically use the D_{50} and D_{84} as representative grain sizes for sediment: D_{50} is the median grain size and D_{84} the 84th percentile used to represent the coarse fraction (50% and 84% of the sediment is finer than D_{50} and D_{84}, respectively). These are the grain sizes that are commonly used for comparison between sediment (e.g., is sediment getting coarser or finer downstream a river?).
A diameter of –phi = 3.9 is equivalent to $2^{3.9} = 14.9$ mm.
A diameter of 14.9 mm is equivalent to –phi = ln(14.9)/ln(2) = 3.9.

Scientists will also commonly use the intermediate axis of a pebble as the "grain size" (knowing that pebbles have three perpendicular axes: short, intermediate and long). On a gravel bar, pebbles tend to lie with their short axis perpendicular to the surface, thus exposing their section that contains the intermediate and long axes. Consequently, on a picture of the surface of a gravel bar, the longest visible axis will be the longest pebble axis and the shorter visible axis perpendicular to this axis will be the pebble's intermediate axis (see red lines on some of the pebbles to the right).

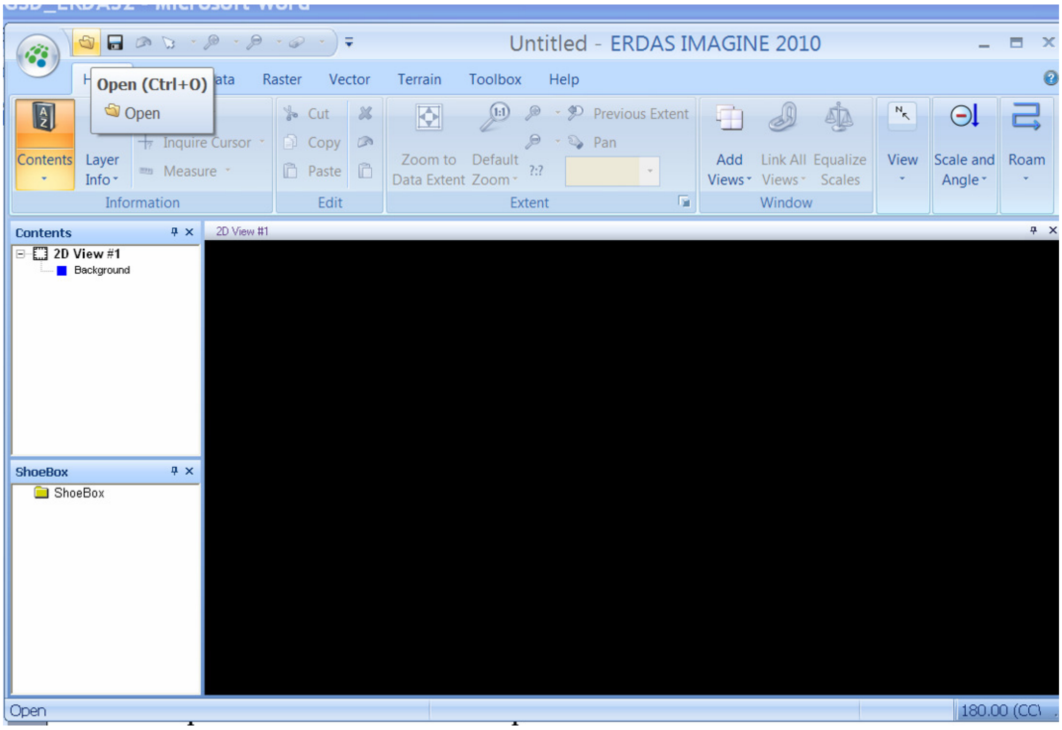


Obtaining a cumulative grain size distribution (GSD) from pictures using Erdas Imagine

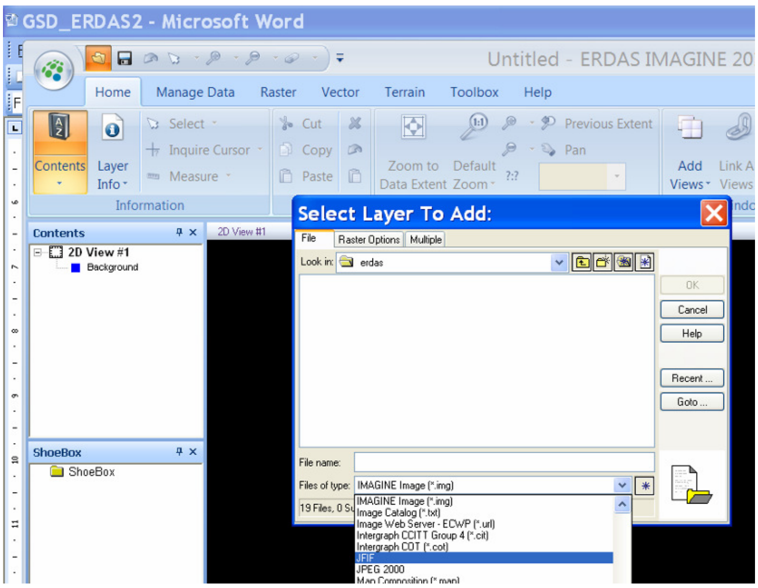
Pictures of the surface of a gravel bar (or any other object of which you want to determine GSD) must be taken perpendicular to the surface. A scale (e.g., an object you know the size of) must be placed in the middle of the picture. Below, the different steps to proceed are described.

Download the file "gridfinal.aoi".

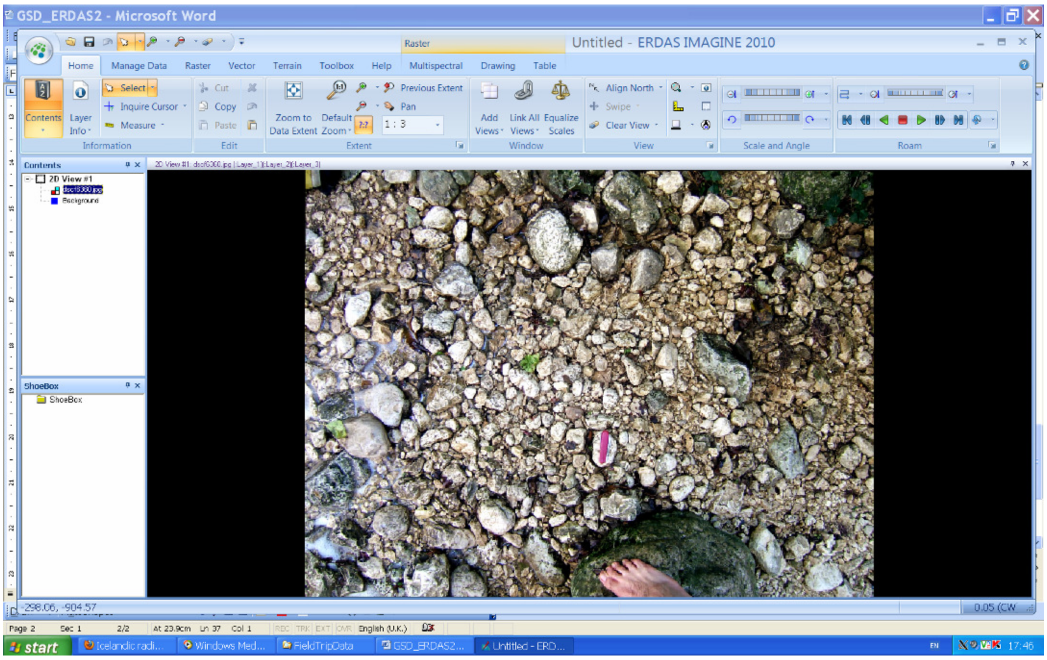
Open Erdas Imagine 2010: a window opens and you can open one of your pictures using the "open file" icon:



Navigate to the folder where the pictures are placed and select the format "JFIF" from the scroll down menu (this will display JPG images):



Your pictures should appear in the list of files. *If they don't, make sure that there are no spaces, multiple dots and/or special characters in the file and folder names.* Double click on the picture you want to use. It will be displayed in the window (see next page).

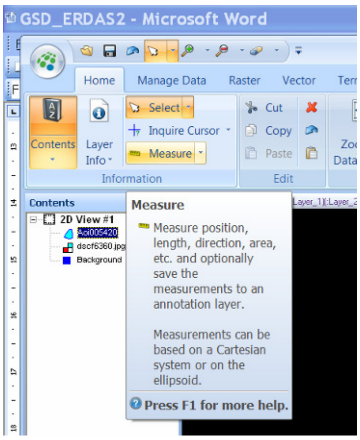


You can zoom in and out using the buttons in the “Extent” and “Scale and Angle” panels at the top (feel free to explore what the different buttons do).

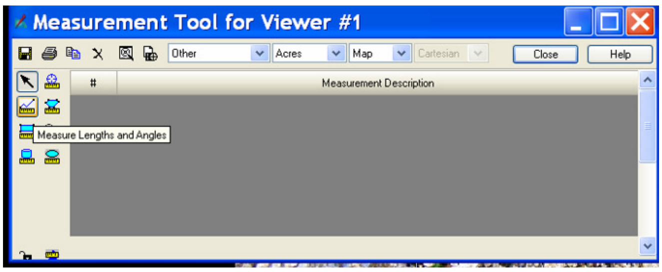
Use the “open file” button again and select “AOI” instead of JFIF in the scroll down menu. Navigate to the folder where the file “gridfinal.aoi” is located and double click on it. A grid will appear on top of the picture. The grid contains 100 line intersections (the intersections on the external boundaries of the grid will not be used). The grid can be moved with the mouse. It can also be resized by clicking on one of the corners of the grid, holding the button and moving the mouse. *WARNING: you need to make sure that the grid remains square. To do so, hold the “uppercase” key while you resize your grid.*

Resize the grid and move it to the zone of interest in the picture, that is, the zone which you think is representative of the sediment on the gravel bar:

You can now start measuring. You will measure the intermediate axis of the pebble found at each of the grid intersection. To do so, click on the “Measure” button in the menu (see below).



A “Measurement tool” window will appear:

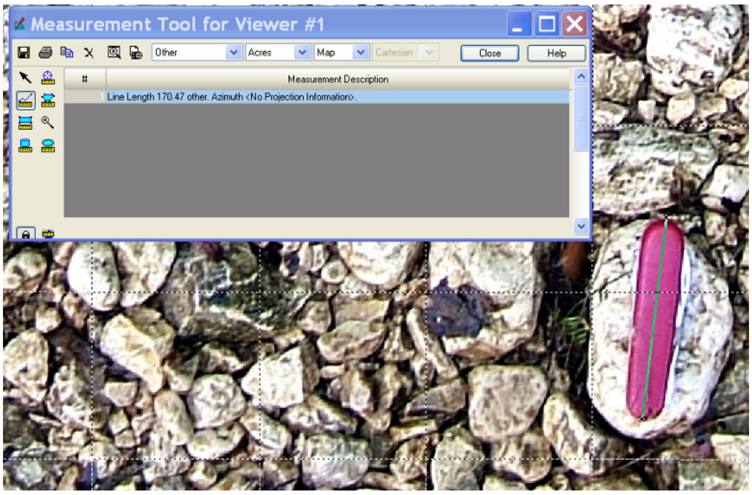


Click on the “measure lengths and angles” button (the ruler with the line) and then on the “lock” button at the bottom left (if you don’t do that, you will have to click on the measurement button after each measurement). You are now ready to measure!

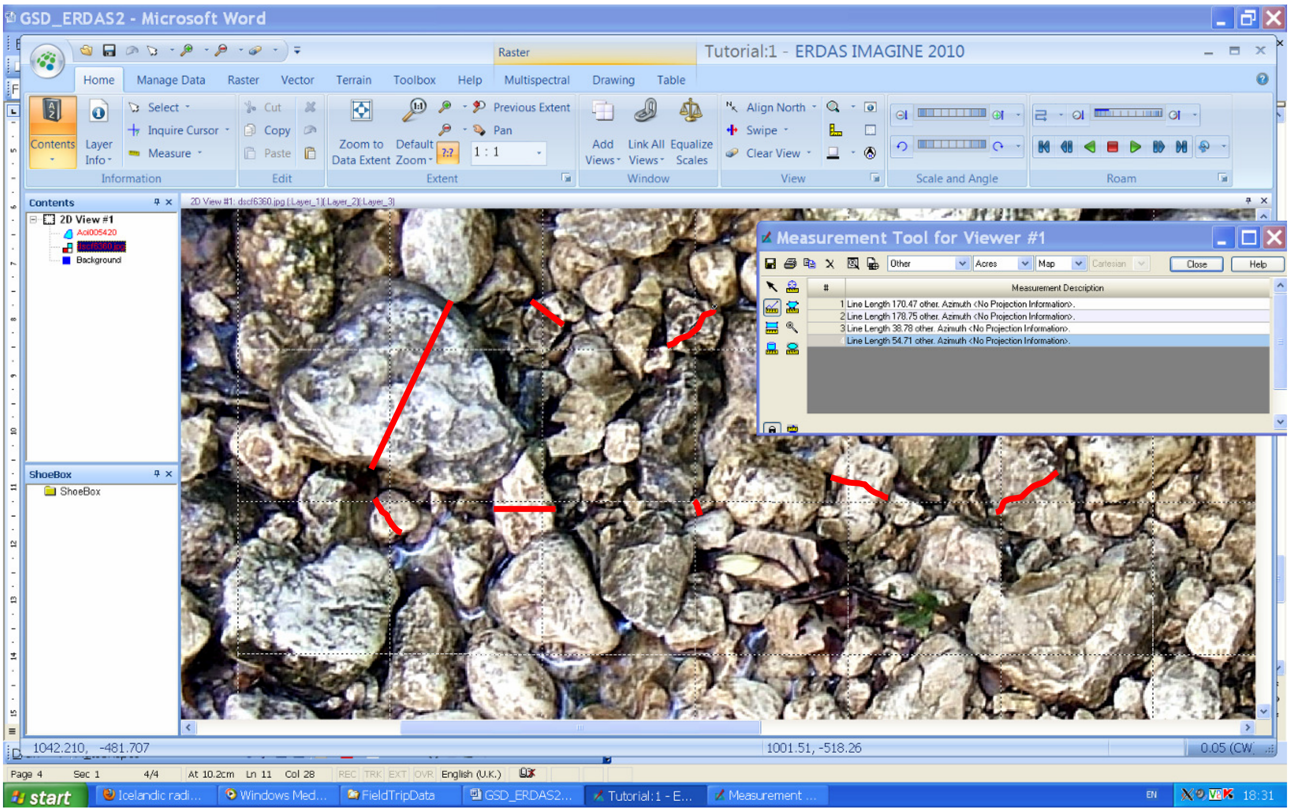
You can zoom in and out while you are making your measurements. This allows you to focus on the zone of interest and make accurate measurements.

IMPORTANT: the first thing you MUST measure is your scale on the picture. DON'T FORGET TO DO SO!

Zoom where your scale is, click once on one extremity of the scale and double-click on the other extremity. A measurement will appear in the "Measurement tool" window.



You can now measure the pebbles at the intersections of the grid. To do so, proceed in the same way: click at the extremity of the axis you want to measure and double-click at the other extremity (see below, I have highlighted the axes in red).



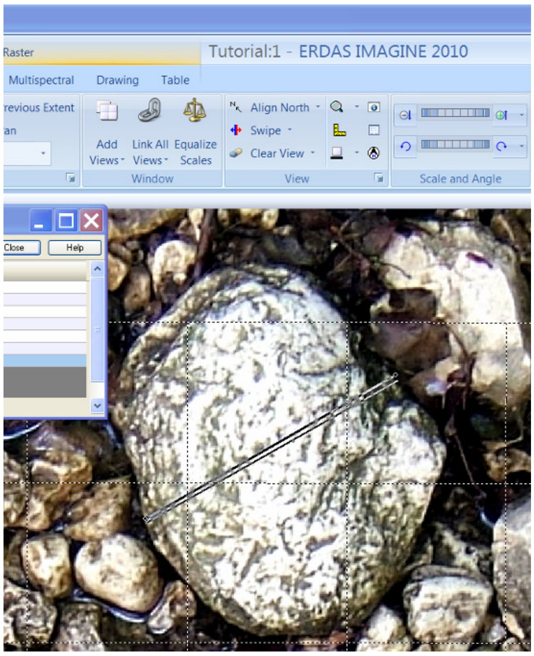
The table will progressively get populated.

A few remarks:

- I haven't found a way of getting rid of an erroneous measurement. If you do one, just write it down on a piece of paper. You will remove it later when you import the table in Excel.
- If you don't double-click rapidly enough, the measurement tool will still be activated. Just double-click again at the same place.
- I usually proceed along lines: I measure the pebble at the top left, then proceed towards the right until I reach the end of the grid. There, I go to the line below and proceed towards the left. And so on…

- If a grid intersection is on vegetation, in a hole or on a pebble that is substantially buried, skip that point.

- Sometimes, pebbles are partially buried. You will have to use your judgement to imagine where the pebble will end. For example, the image to the right shows an example where I tried to forecast where the pebble would end, based on the shape of the other pebbles on the gravel bar. The forecast outline of the pebble is shown in red. If you think that the measurement will be too inaccurate, skip the point.
- If an intersection is on sand or mud, you will need to record a very small grain size at this point: if you can't see the grains because they are too small, click somewhere and then double-click very close to where you clicked, so that a very small axis measurement will appear in the table.

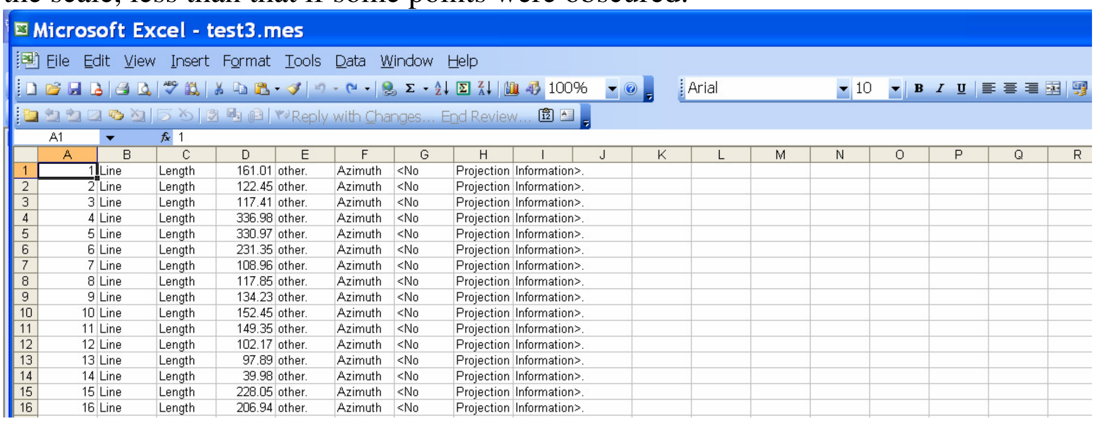


- Ideally, the grid will be sized so that no pebble has more than one grid intersections on it. However, this can be difficult for mountain rivers where pebbles can be very large and gravel bars very small. If it happens, a pebble which has n intersections on it will be measured n times. The pebble to the right has two intersections on it: I measured it twice (see the two measurement lines – I did not superimpose them completely so that you can see them). *This procedure has been recommended by Kellerhals and Bray (1971, uploaded on WebCT), see also Attal and Lavé (2006) for description of sampling methods. This procedure has been criticised by Bunte and Abt (2001, page 156; book freely available, see beginning of the handout). In the absence of a satisfying alternative method, we will stick to that.*

Note also on the image to the right the button in the "Scale and Angle" at the top right that can be used to zoom in and out while you are doing the measurements.

It will probably take you ~1 hour to do your first picture but your performance will improve with time! I can do a picture in 5 minutes now.
When you are finished, save the table by clicking on the floppy icon at the top left of the measurement tool window. This will create a *.mes* file that you can open with Excel.

Open Excel. Open file → select "all files" and open your *whatever.mes* file. In the import option, select "delimited" and "space" as delimiter. You will obtain a table with 9 columns (most of which contain useless information for our purpose) and 101 rows if you have measured 100 pebbles and the scale, less than that if some points were obscured:



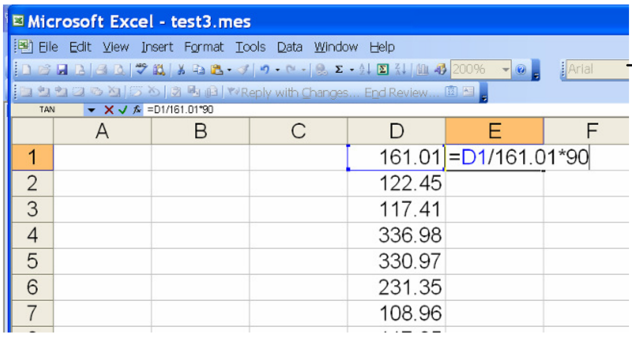
	A	B	C	D	E	F	G	H	I
1	1	Line	Length	161.01	other.	Azimuth	<No	Projection	Information>.
2	2	Line	Length	122.45	other.	Azimuth	<No	Projection	Information>.
3	3	Line	Length	117.41	other.	Azimuth	<No	Projection	Information>.
4	4	Line	Length	336.98	other.	Azimuth	<No	Projection	Information>.
5	5	Line	Length	330.97	other.	Azimuth	<No	Projection	Information>.
6	6	Line	Length	231.35	other.	Azimuth	<No	Projection	Information>.
7	7	Line	Length	108.96	other.	Azimuth	<No	Projection	Information>.
8	8	Line	Length	117.85	other.	Azimuth	<No	Projection	Information>.
9	9	Line	Length	134.23	other.	Azimuth	<No	Projection	Information>.
10	10	Line	Length	152.45	other.	Azimuth	<No	Projection	Information>.
11	11	Line	Length	149.35	other.	Azimuth	<No	Projection	Information>.
12	12	Line	Length	102.17	other.	Azimuth	<No	Projection	Information>.
13	13	Line	Length	97.89	other.	Azimuth	<No	Projection	Information>.
14	14	Line	Length	39.98	other.	Azimuth	<No	Projection	Information>.
15	15	Line	Length	228.05	other.	Azimuth	<No	Projection	Information>.
16	16	Line	Length	206.94	other.	Azimuth	<No	Projection	Information>.

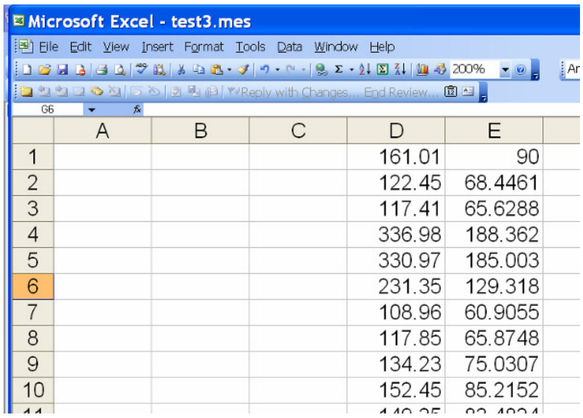
Delete all the columns except the one that contains the measurements (col. D) and save the Excel file. Now, you will have to perform a series of operation to create your GSD.
Note: Kellerhals and Bray (1971) showed with their model of voidless cube that GSD by number obtained by the method we use here (grid) can be directly comparable to GSD by mass obtained by sieving methods. This means that in theory, if some sediment is completely homogeneous, the GSD by number obtained with the grid should be the same than the GSD that would be obtained by sieving the sediment and determining the GSD by mass. In other words:

- *the median grain size D_{50} obtained by the grid method should be determined by number: D_{50} will be the size for which the number of pebbles that are larger is the same than the number of pebbles that are smaller (e.g., if you have measured 80 pebbles, D_{50} will be the size for which 40 pebbles are larger and 40 pebbles are smaller).*
- *the median grain size D_{50} obtained by the sieving method should be determined by mass: D_{50} will be the size for which the mass of pebbles that are larger is the same than the mass of pebbles that are smaller (e.g., if you have sieved 80 kg of sediment, D_{50} will be the size for which 40 kg of sediment grains are larger and 40 kg of sediment grains are smaller).*

Note that Bunte and Abt (2001) also discuss work that suggests that the voidless cube model may not be a good representation of river sediment (p. 227-230).

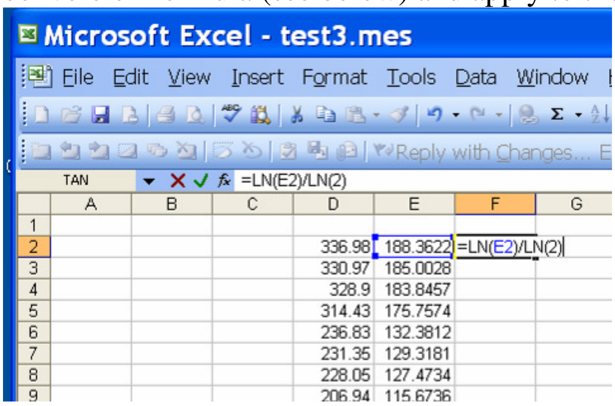
Step 1: scale the measurements. We know the size of the scale (in my case, the pen knife is 90 mm long). In the table, the size of the scale (first row) is 161.01 (see previous figure). We thus need to apply a conversion factor to all measurements that will turn 161.01 into 90. In the column next to the measurement, type the conversion formula and apply it to the whole column (see below; note that you will probably have a value different from 161.01 and your scale may not measure 90 mm, please adapt accordingly).

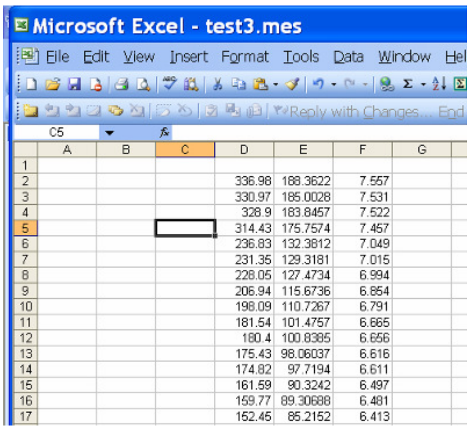




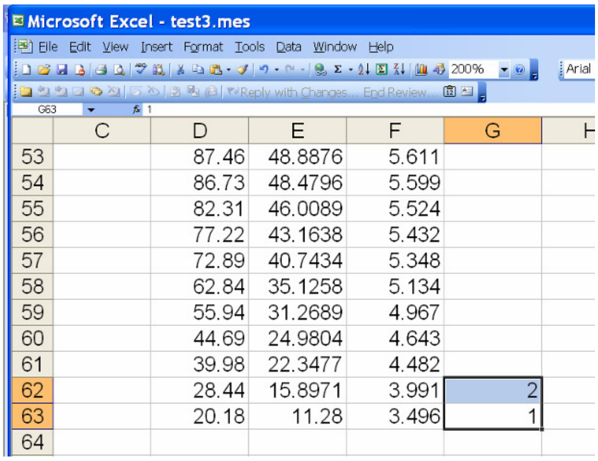
The measurements in column E are now in mm. The first row can be removed and the measurements can be sorted by descending value ("data" → "sort"). We now have a list of pebble sizes ordered with the largest pebble at the top and the smaller at the bottom.

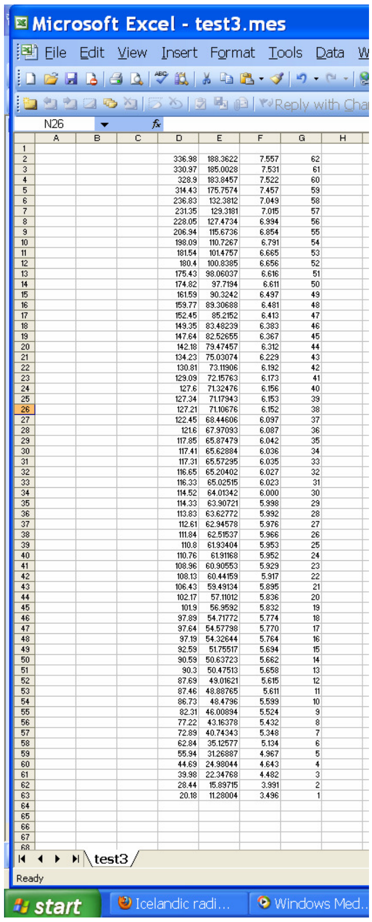
We can transform the size in mm into a size in –phi scale: in the next column (F), type the conversion formula (see below) and apply to the whole column.





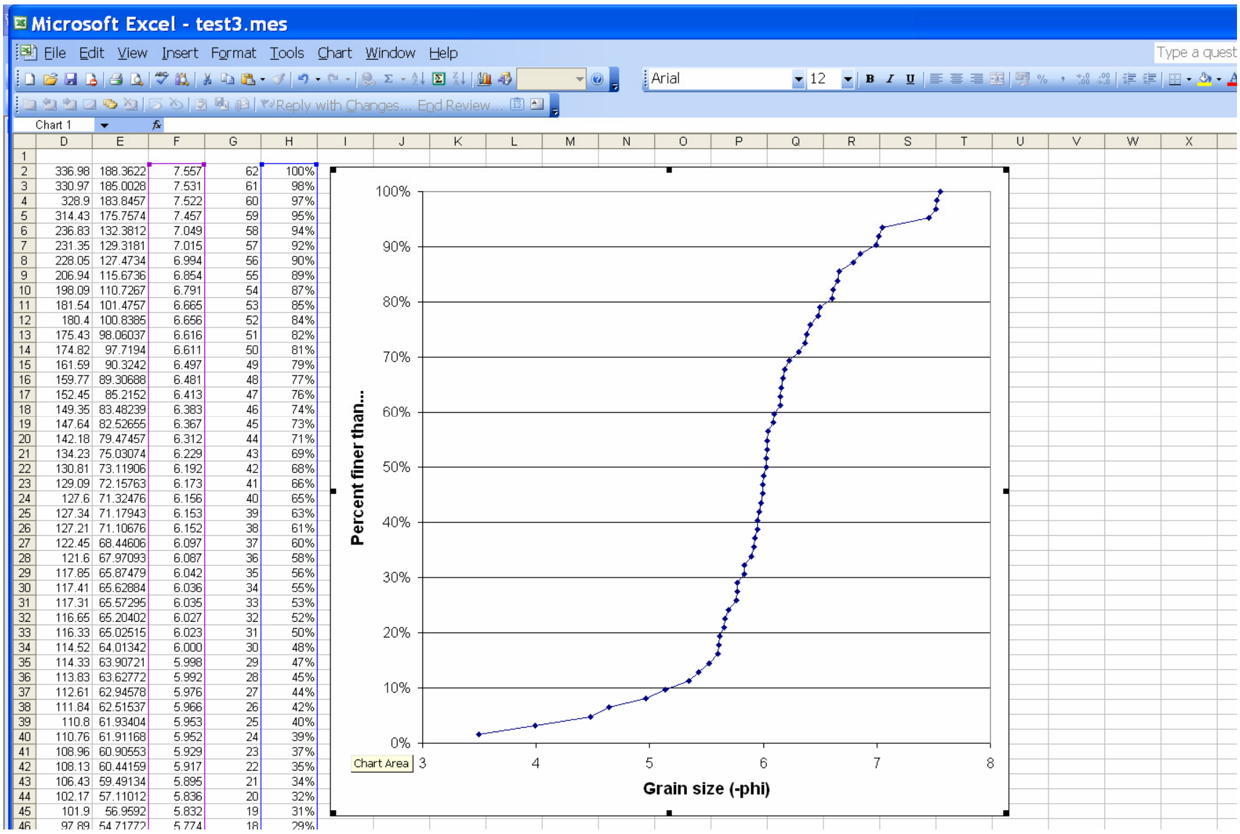
Now, we need to create the cumulative % by number. We need to include the cumulative number of pebbles. To do so, start at the bottom of the list and write “1” in the last row in column G. Write “2” above, select the two cells, click on the little square at the bottom right of the selection, hold and drag to the top of the list. This should fill the column G with ascending consecutive numbers:





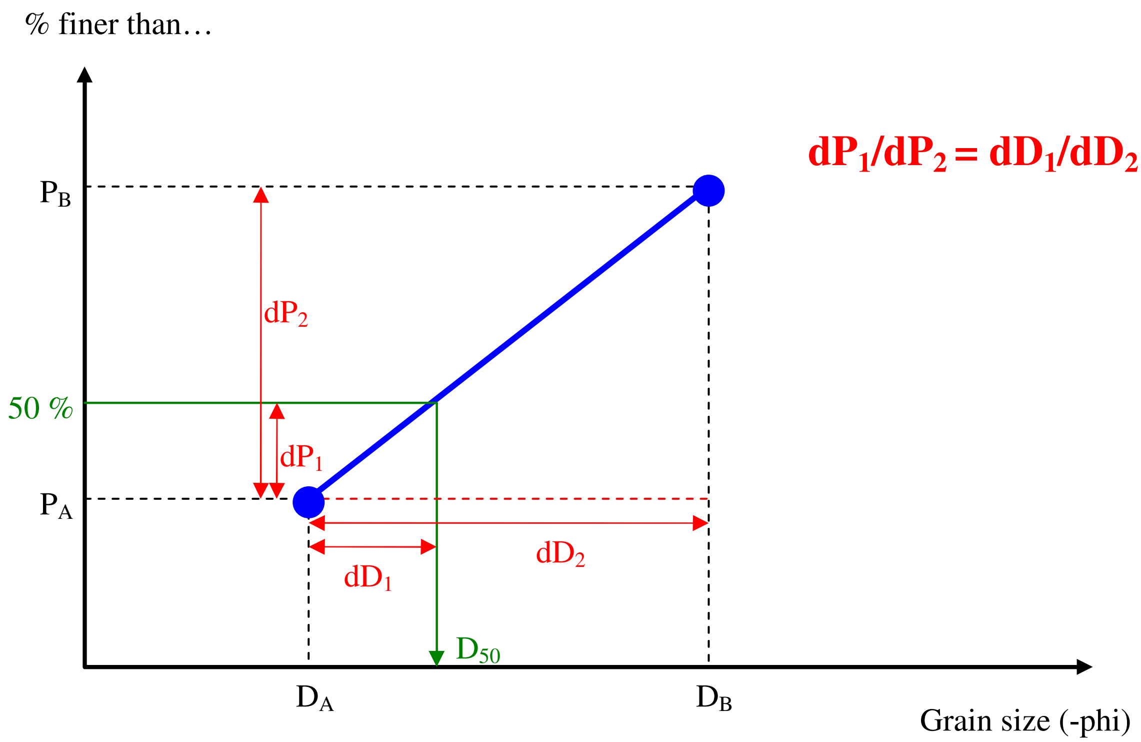
Note that in my case, I have only 62 measurements because many intersections had vegetation or buried pebbles. We now need to transform the cumulative numbers into cumulative %. We know that 100 % of the pebbles are smaller than the pebble at the top of the list. We thus need to apply a conversion factor that will turn 62 (in this case) into 1 (= 100 %). In column H, divide the number in column G by 62 and format column H into % (using the “%” button in the menu at the top).

Your cumulative GSD is *column H = f (column F)*! Create the diagram using these two columns.
I will put one of these files on WebCT as an example.



The GSD from different sites along the river can be put in the same figure for comparison (the coarser the sediment, the further to the right the curve will be).
The representative grain sizes (e.g., D_{50}, D_{84}) can be determined graphically (see first figure of handout) or using the data in the table. In this case for example, we can see that D_{50} = 65.0 mm (-phi = 6.023) and D_{84} = 100.8 mm (-phi = 6.66). To check that this makes sense, we can verify that the number of pebbles smaller than D_{50} is the same than the number of pebbles larger than this size (here we have confirmation that 31 pebbles are smaller than 65 mm and 31 pebbles are larger than 65 mm).
The evolution of these representative grain sizes (e.g., D_{50}, D_{84}) along the river can be examined (downstream fining?).

Note that in some cases you will have to calculate D_{50} or D_{84}, for example if the number of pebbles is odd (so you may have a pebble at 49 % and another one at 51 %). If this is the case, you will have to determine the linear relationship between the two points above and below the percentage you are interested in and calculate the corresponding D_x. The calculation is as follow:



The equation can be rewritten as (note that "50 %" is "0.5" in the spreadsheet):

$(0.5 - P_A)/(P_B - P_A) = (D_{50} - D_A)/(D_B - D_A)$

$\rightarrow D_{50} = [(0.5 - P_A)*(D_B - D_A) /(P_B - P_A)] + D_A$

Example: we have two points: -phi=7.05 at 48.9% and -phi=7.3 at 56.8%.
$D_{50} = [(0.5-0.489)*(7.3-7.05)/(0.568-0.489)]+7.05 = 7.085$ in -phi, that is $D_{50} = 2^{7.085} = 135.8$ mm.

If you want to calculate D_{84}, proceed as above but replace 0.5 by 0.84. To make sure that you have made the calculation right, check that the D_x you have calculated is comprised between D_A and D_B.

Obtaining a cumulative grain size distribution from a volumetric sample (sieving)

In this case, you will need to look at the cumulative mass of sediment (see Kellerhals and Bray, 1971, and discussion page 6).

You have sieved the sediment using sieves of mesh 10, 20 and 40 mm (-phi = 3.3, 4.3 and 5.3, respectively) and have weighed independently large pebbles. We thus know the total mass of sediment and the mass of the following fractions: < 10 mm, 10-20 mm and 20-40 mm. We also have the mass of a series of pebbles that didn't go through the 40 mm sieve but were not particularly large (<< 80 mm).

We need to determine the size of the pebbles that we weighed independently. To do so, we will make a very crude assumption and assume that the pebbles are spheres of density 2650 kg/m^3 (typical of rock constituting the crust of the Earth, e.g., granite, limestone; the density would be higher if the rocks were basalt, lower if they were porous sandstones).
The volume of a sphere is $\pi D^3/6$ where D is the diameter (in meters).
The mass of a sphere of diameter D is thus

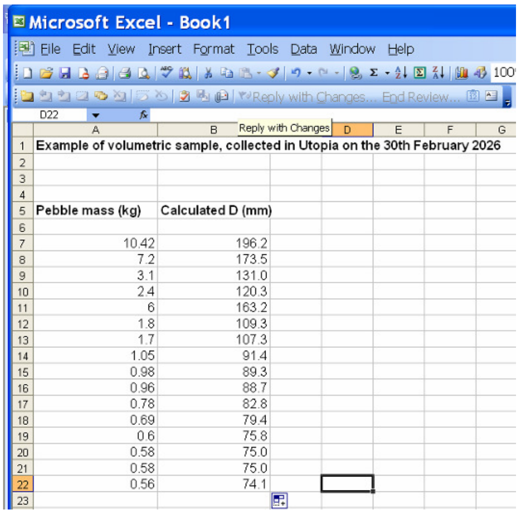
$$\mathbf{M = 2650*(\pi D^3/6).}$$

The diameter of a pebble of mass M, assuming that the pebble is spherical, is thus

$$\mathbf{D = [6M/2650\pi]^{1/3}.}$$

Note that if you use the mass in kg, D will be in meters. The result will need to be multiplied by 1000 to be in mm.

In the Excel spreadsheet where the measurements have been recorded, order the pebbles weighted independently by ascending mass and calculate their size using the formula above:



Example of volumetric sample, collected in Utopia on the 30th February 2026

Row	Pebble mass (kg)	Calculated D (mm)
7	10.42	196.2
8	7.2	173.5
9	3.1	131.0
10	2.4	120.3
11	6	163.2
12	1.8	109.3
13	1.7	107.3
14	1.05	91.4
15	0.98	89.3
16	0.96	88.7
17	0.78	82.8
18	0.69	79.4
19	0.6	75.8
20	0.58	75.0
21	0.58	75.0
22	0.56	74.1

At that point, you will create a new fraction 40-80 mm, the mass of which will be the mass of the particles that didn't pass through the 40 mm sieve PLUS the mass of the pebbles weighted independently that are smaller than 80 mm, that is, the pebbles in row 18-22 in the table to the left.

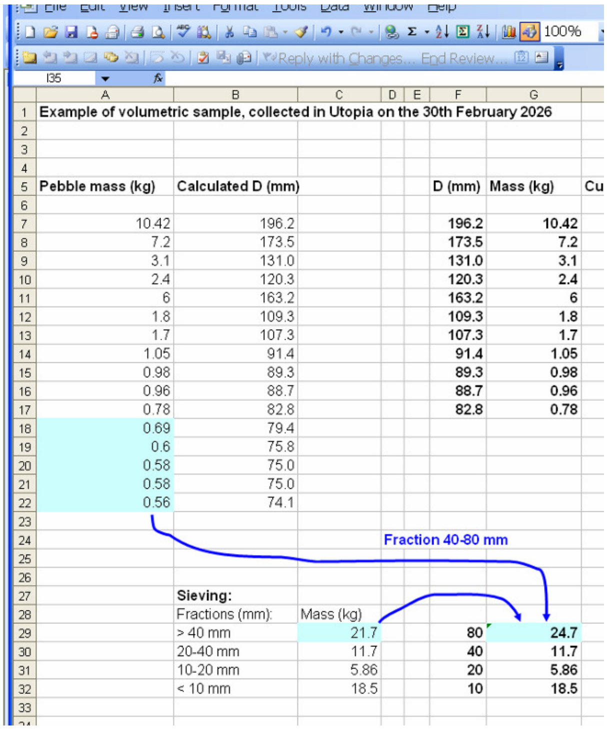
We now have the mass of:
- individual pebbles larger than 80 mm (rows 7-17),
- fraction 40-80 mm,
- fraction 20-40 mm,
- fraction 10-20 mm,
- fraction < 10 mm.

We want to have these data in two columns:
- diameter (for the fractions, we will use the upper limit value, i.e., 20 mm for the 10-20 mm fraction, because we will look at the "% mass finer" than a given diameter, this will become clear).
- mass.

You want to reorganise the data to obtain something like that (see to the right):

In column H, you can now calculate the **cumulative mass**, beginning at the bottom of the table.
In H32, you will have the mass of sediment finer than 10 mm = 18.5 kg.
In H31, you will have the mass of sediment finer than 20 mm = 18.5 + 5.86 kg.
In H30, you will have the mass of sediment finer than 40 mm = 18.5 + 5.86 + 11.7 kg.
And so on…

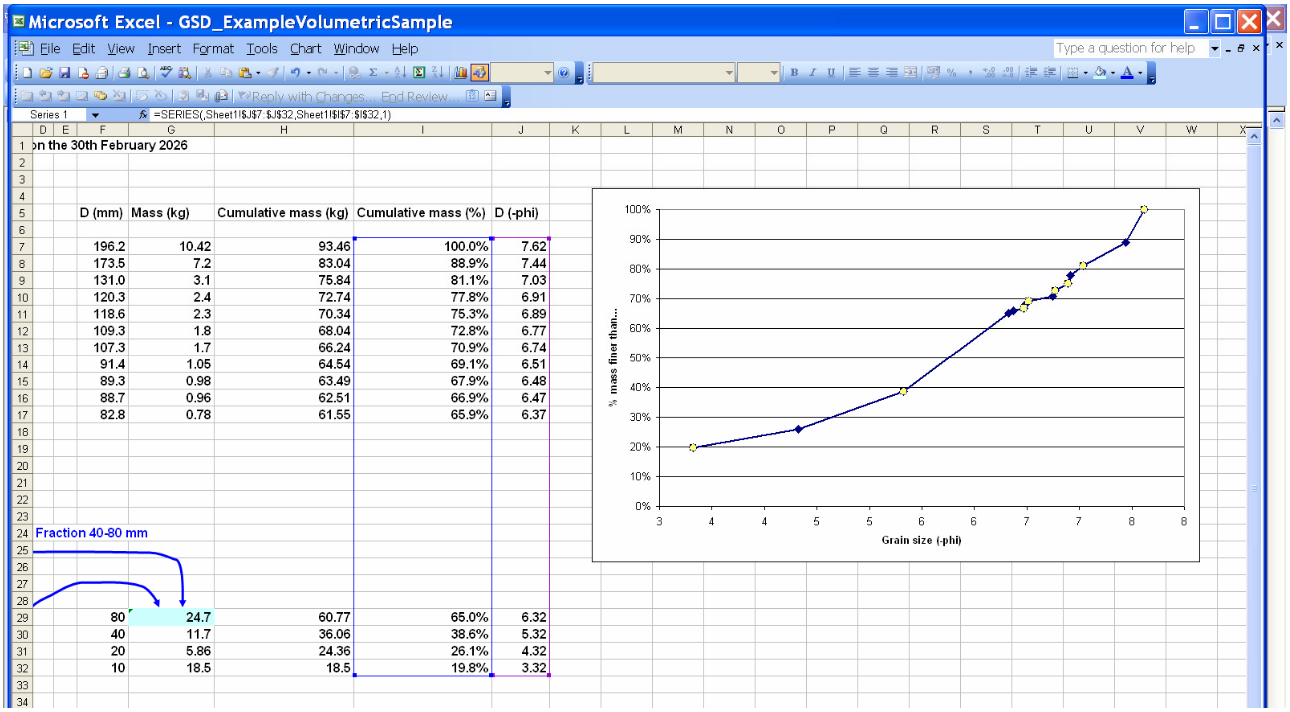
In column I, you can calculate the % of the total mass that the cumulative mass represents by dividing the cumulative mass in column H by the total mass of sediment (which will be in H7 here).



Example of volumetric sample, collected in Utopia on the 30th February 2026

Row	A	B	C	F	G
5	Pebble mass (kg)	Calculated D (mm)		D (mm)	Mass (kg)
7	10.42	196.2		196.2	10.42
8	7.2	173.5		173.5	7.2
9	3.1	131.0		131.0	3.1
10	2.4	120.3		120.3	2.4
11	6	163.2		163.2	6
12	1.8	109.3		109.3	1.8
13	1.7	107.3		107.3	1.7
14	1.05	91.4		91.4	1.05
15	0.98	89.3		89.3	0.98
16	0.96	88.7		88.7	0.96
17	0.78	82.8		82.8	0.78
18	0.69	79.4			
19	0.6	75.8			
20	0.58	75.0			
21	0.58	75.0			
22	0.56	74.1			
24			Fraction 40-80 mm		
27		Sieving:			
28		Fractions (mm):	Mass (kg)		
29		> 40 mm	21.7	80	24.7
30		20-40 mm	11.7	40	11.7
31		10-20 mm	5.86	20	5.86
32		< 10 mm	18.5	10	18.5

Finally, you can convert the pebble diameter in *–phi* scale in column J using the formula "= ln(diameter in mm)/ln(2)". The result is shown below. The cumulative GSD is *column I = f(column J).*



Row	F	G	H	I	J
5	D (mm)	Mass (kg)	Cumulative mass (kg)	Cumulative mass (%)	D (-phi)
7	196.2	10.42	93.46	100.0%	7.62
8	173.5	7.2	83.04	88.9%	7.44
9	131.0	3.1	75.84	81.1%	7.03
10	120.3	2.4	72.74	77.8%	6.91
11	118.6	2.3	70.34	75.3%	6.89
12	109.3	1.8	68.04	72.8%	6.77
13	107.3	1.7	66.24	70.9%	6.74
14	91.4	1.05	64.54	69.1%	6.51
15	89.3	0.98	63.49	67.9%	6.48
16	88.7	0.96	62.51	66.9%	6.47
17	82.8	0.78	61.55	65.9%	6.37
24	Fraction 40-80 mm				
29	80	24.7	60.77	65.0%	6.32
30	40	11.7	36.06	38.6%	5.32
31	20	5.86	24.36	26.1%	4.32
32	10	18.5	18.5	19.8%	3.32

See page 8 for a description of further analysis and determination of representative grain sizes.

Mikaël Attal, November 2011