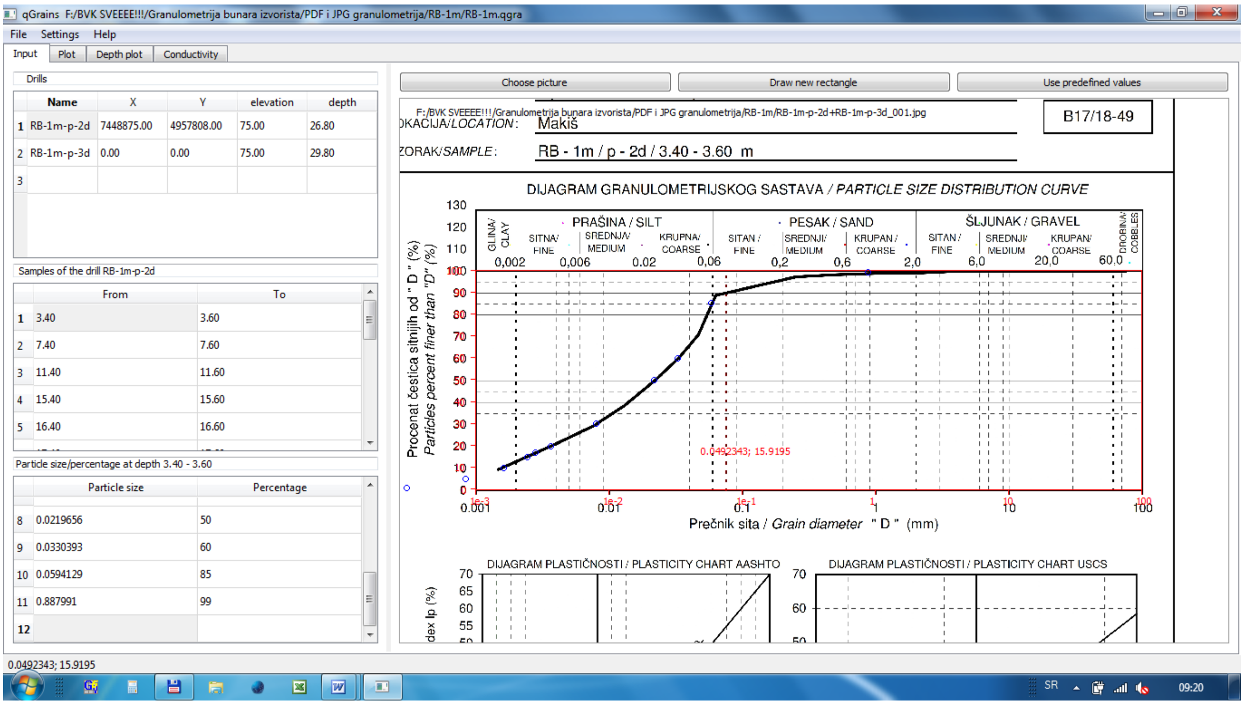
“Jaroslav Černi” Institute



qGrains, ver.*.*

SOFTWARE FOR HYDRAULIC CONDUCTIVITY ESTIMATION BASED ON GRAIN-SIZE COMPOSITION

Milan Dotlić, Milenko Pušić, Goran Jevtić, Milan Dimkić

Belgrade, 2018

PREFACE

In the hydrogeological exploration, determining the hydraulic conductivity of the porous medium is an unavoidable task. Hydraulic conductivity is the dominant parameter of the aquifer, which is involved in all groundwater flow computations. It is impossible to conduct these computations without knowing this parameter.

Estimation of the hydraulic head conductivity using one of the empirical formulas is mostly used manner. These formulas are based on the granulometric curves of sediment samples which are usually obtained from exploration drills. Every formula has an effective grain size of the material, which is obtained from granulometric curve. Results obtained in this way are limited by the relevance of the analyzed sample.

In practice, formulas for estimation of hydraulic conductivity for the same material can give results that can even vary for several orders of magnitude. It is obvious that empirical formulas do not have universal span, but each one corresponds to the specific conditions. Therefore, applying estimate requires caution and it is vital to obey authors' recommendation.

Software qGrains is based on the book of Vukovic M, Soro A (1992) Determination of hydraulic conductivity of porous media using grain-size composition. Water Resources Publications, Littleton, Colorado, USA, which is considered a classic studying material in this field. Software qGrains is developed for wider applications then the code described in this book. Besides estimation of the hydraulic conductivity, it allows complex analysis, interpretation and visualization of grain-size composition taken from drill samples in 1D, 2D and 3D environment.

The authors are: a mathematician and a software developer dr. Milan Dotlić, hydrogeologists prof. dr. Milenko Pušić and Goran Jevtić, and a civil engineer prof. dr. Milan Dimkić.

Authors would like to take this opportunity to express their gratitude to all the colleagues from the Institute Jaroslav Černi who tested this software in development phase and pointed out to mistakes and eagerly waited for its completion.

Contact e-mail:

milenko.pusic@jcerni.co.rs

milan.dotlic@jcerni.co.rs

Belgrade, January 2018

AUTHORS

INTRODUCTION

Software qGrains is intended for estimation of hydraulic conductivity based on grain-size analysis of samples taken from exploration drills. Number of samples, as well as number of drills in one file is not limited.

Results of the hydraulic conductivity estimations can be obtained using ten empirical formulas. These results can be interpreted in qGrains in vertical direction, for all or for chosen drills. It is possible to make profiles, choosing different drills or displays on the terrain map for different depth intervals or selected surfaces.

qGrains can be used for analyzing and displaying chosen percentage involvement on the granulometric curve, or the percentage involvement for chosen grain-size.

Using qGrains is it possible to make space classification, systematization and schematization of sediments based on chosen percentage involvement or chosen grain-size. This can be useful part of preparation for higher levels of hydrogeological interpretation, for example, making a hydrodynamic model.

User manual consist of two parts: practical, which represents a manual for qGrains use, and also a theoretical part.

QGRAINS

INTRODUCTORY NOTES

qGrains can be started using one of the following ways: 1) by clicking on the executable (.exe file), or 2) by clicking on the previously generated. qgra file if that is set in operating system. In this way main window is activated with splash screen Figure 1.

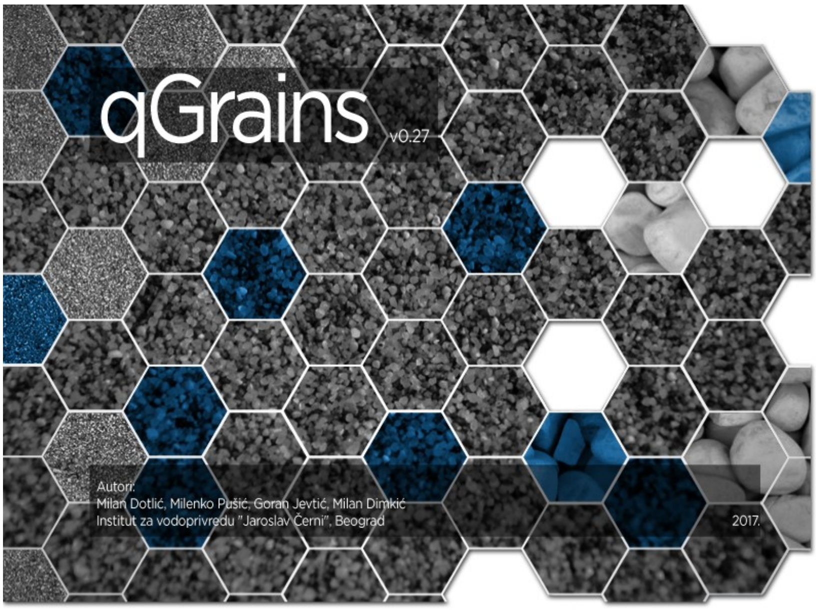


Figure 1. Splash screen of qGrains

Data can be input in qGrains manually by typing each grain size and percentage or by using pictures of granulometric curves.

If the data are input by using pictures, it is necessary to prepare pictures of granulometric curves in form of *.jpg* files before start using qGrains. These pictures can be scanned from previously printed reports. It is of utmost importance that axes are mutually perpendicular and without any rotation on the screen display.

qGrains saves files with extension. qgra, which is similar to Excel *.csv* format. This file can be imported into Excel if necessary, although this is not recommendable.

SOFTWARE STRUCTURE

Software *qGrains* is mainly formed of standard Windows application. Main window, Figure 2, consist of a title bar, a menu bar, tabs and a status bar.

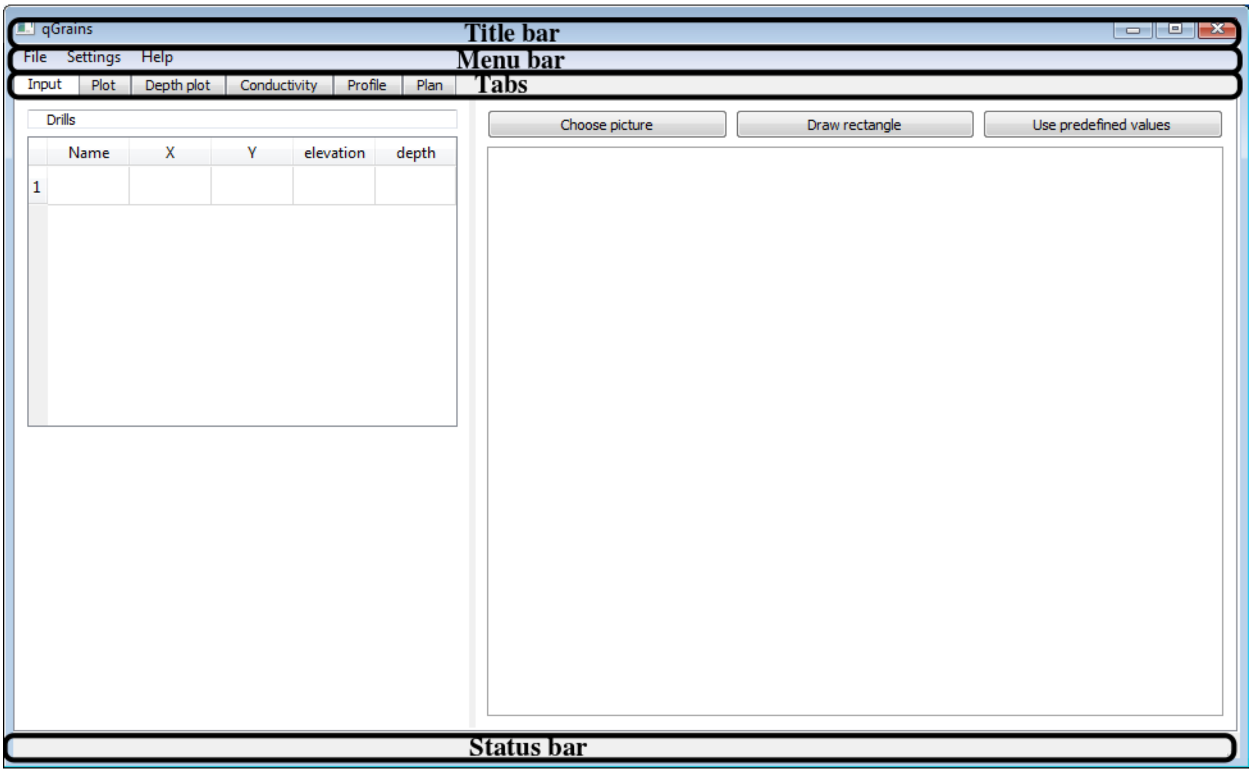


Figure 2. Main window of qGrains

A title bar displays the name of active file and options for minimization, maximization and closing application window.

A menu bar consists of submenus *File, Settings, and Help.*

Other tabs *Input, Plot, Depth plot, Conductivity, Profile, Plan* will be explained later in the text.

FILE

Menu *File,* Figure 3, consists of:

New – new file (shortcut Ctrl+N)

Open – loading old file (shortcut Ctrl+O)

Open from csv – loading a specific form of Rockworks model

Add – adding new drills on the existing ones

Save – save file (shortcut Ctrl+S)

Save As – save file with a different name

Quit – quit qGrains

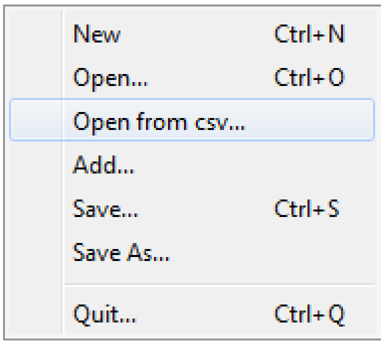


Figure 3. File menu

Option *Open from csv* gives possibility of loading csv file generated from Rockworks. In Excel file, which is an output of Rockworks, there is sheet *Interval* and this sheet should be saved as csv file. It is essential that this sheet has columns: Bore, Type, Depth1, Depth2, X-Top, Y-Top, Z-Top, X-Base, Y-Base, Z-Base.

Note: Loading this type of file does not set elevation and depth for drills. It is necessary to set those parameters manually.

Option *Add* allow us to combine several. qgra files.

SETTINGS

Menu *Settings*, Figure 4, has options *Tolerance* i *Parameters.*

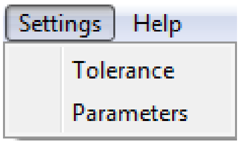


Figure 4. Settings menu

By clicking the option *Tolerance*, a window opens, Figure 5, in which tolerance can be set. This number represents tolerance for percentage involvement, which will be explained in more details later in this text.

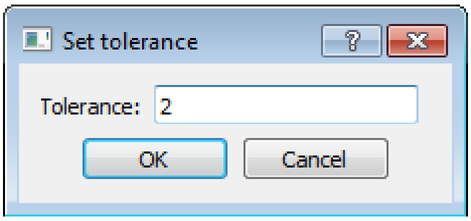


Figure 5. Tolerance

By clicking the option *Parameters*, a window opens, Figure 6, which sets temperature value, as well as Terzaghi and Zunker coefficients which are used for of hydraulic conductivity estimation.

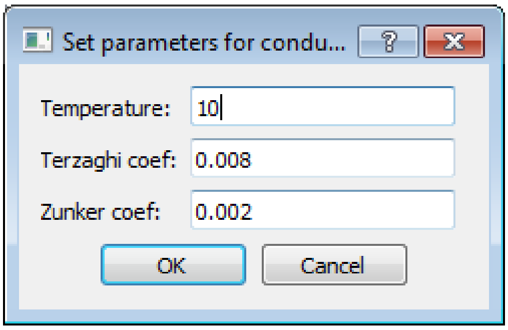
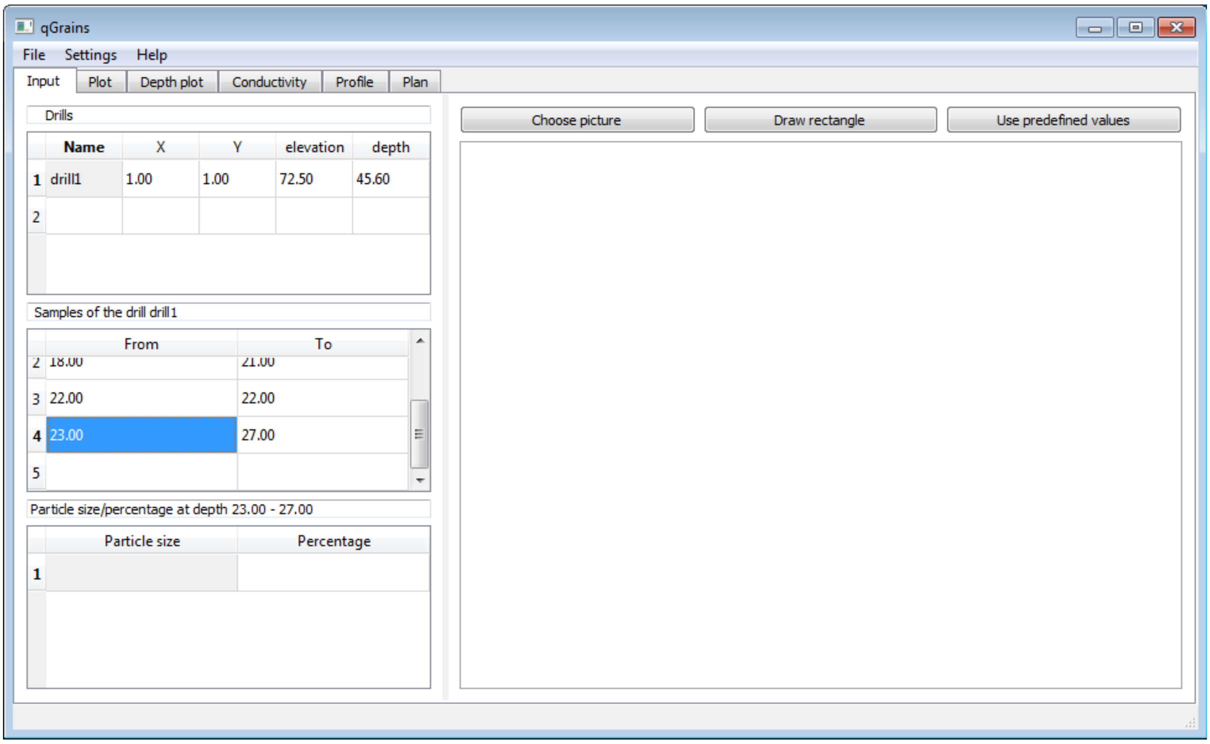


Figure 6. Parameters

INPUT TAB

Input tab serves for inputting data related to drills and samples. Visually, this tab is divided in two parts, Figure 7: on the left side there are tables for data input, and on the right side there is graphical part that serves for data digitalization from pictures.



Slika 7. Input tab

The upper table on the left side is for inputting drills data: name of the drill, x position, y position, elevation (meters above sea level), and drill depth. Click on specific drill in upper table activates corresponding table in the middle, which handles input data of sample depth. In this table, for every sample, we set depth of the sample (lower and higher depth). If the sample is in one point, then we should enter the same value in column *From* and *To*. This table does not allow overlapping of the samples (for example it is impossible to enter samples 2-4 and 3-5) and it is always automatically sorted. Click on specific sample in this table activates lower table, which handles input data of grain size and percentage fraction. These values can be entered manually, copying from Excel or through digitalization.

In the tables, there is always an empty row in the end which serves for inputting new data. We can always change data in tables.

Note: Data in all three tables on *Input* tab can be copied from Excel. If the copied section does not have enough data (it is mandatory to have 5 columns for upper table and two columns for other two tables) or if the data are incorrect (for example, text, instead of numbers) *qGrains* will post a warning.

On the right side of this tab there is an interface for digitalization of grain-size distribution curves from scanned documents. In this part contains buttons *Choose picture, Draw rectangle, Use predefined values* and area for graphical display. Right click on graphical display activates menu, Figure 8, with options *Set bounds, Properties, Predefined values*, which will be explained later in text.

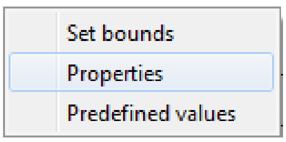


Figure 8. Menu obtained with right click on graphical display on the Input tab

Click on button *Choose picture* opens dialog for choosing scanned document with granulometric curves. After choosing picture in *.jpg* file format, it appears in the part for graphical display, Figure 9. In upper left corner of the graphical display, there is a written path to the selected picture as a reminder. On graphical display it is possible to use drag and zoom.

Next step in digitalization is drawing a rectangle over a rectangle on the picture where graph is shown. This is done by clicking button *Draw rectangle,* and then clicking onto bottom left corner of the rectangle at the picture and finally clicking onto upper right corner of the rectangle at the picture. When the first point is clicked, a button *Draw rectangle* changes its name into *First point is clicked*. When the second point is clicked, the button is again labeled as *Draw rectangle.* Greater precision in setting rectangle can be achieved by zooming the picture.

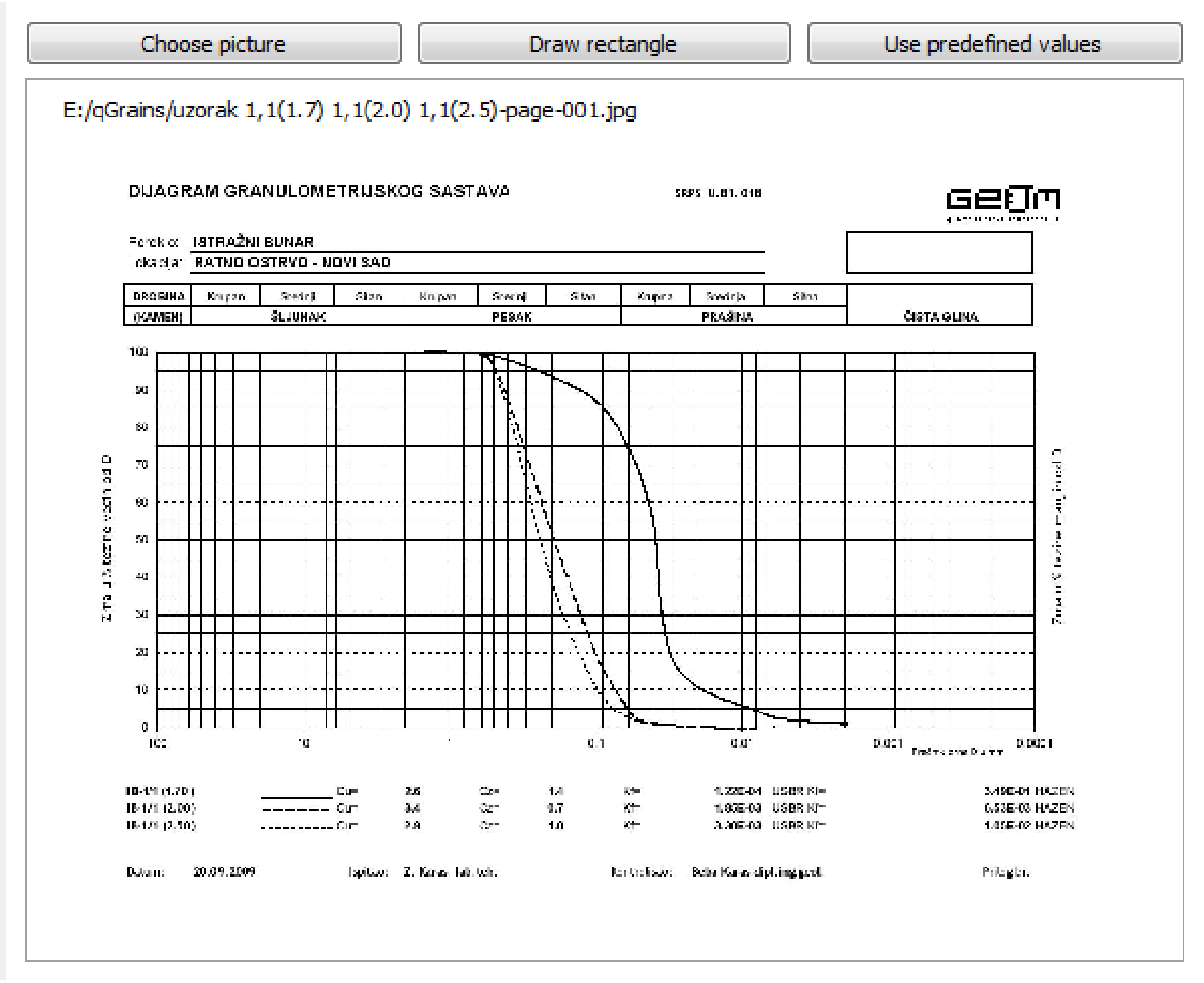


Figure 9. Loaded picture on graphical display

If we are not satisfied with matching of the drawn rectangle and rectangle on the picture, then we can repeat previous actions and draw a different rectangle.

After drawing a rectangle, we have to match values on the *x*-axis of drawn rectangle with values on the scanned picture. Right clicking on the graphical display and choosing *Set bounds* activates dialog on which we set left and right boundary values on the *x*-axis.

By choosing a sample from the middle table on the left and double click onto granulometric curve on graphical display, the clicked point is automatically entered into lower table on the left. If the sample is not selected, double click on graphical display does not cause an action. All points (with coordinates grain size and percentage) from the selected sample are drawn on graphical display. Mouse hovering on graphical display when the rectangle is drawn shows referent values in the status bar and also by the cursor. If we have more pictures with granulometric curves, we must repeat this procedure.

Note: Software does not save the scanned pictures. This is only a help for inputting data into tables.

Note: It is impossible to enter a point that has higher percentage involvement and smaller grain size than any previously defined point.

Click on button *Use predefined values* activates predefined values in order on y-axis, which also changes the label of this button into *Predefined value* - „value“. At the beginning, predefined values are 1, 5, 10, 15, 17, 20, 30, 50, 60, 85 and 99, but they can be easily changed, added or removed by choosing an option *Set predefined values,* which can be found in menu that is obtained by right click on graphic display. Choosing this option activates a dialog, Figure 10. In the first line of this dialog, we input new predefined values, which appears in the list below. Click on some value and *Delete* button on keyboard removes value from the list.

Note: Predefined point can be skipped by clicking on the graphical display while holding CTRL button on the keyboard.

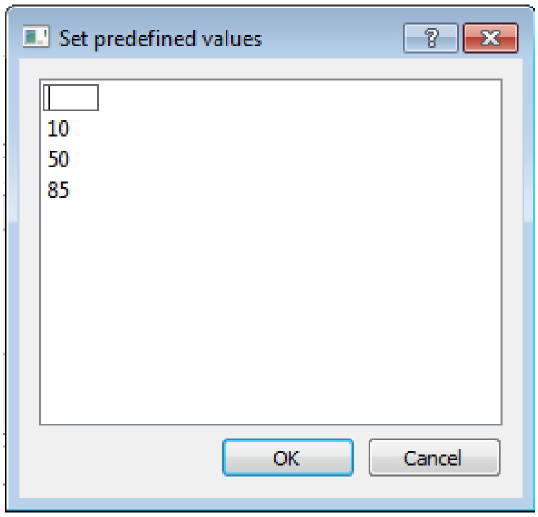


Figure 10. Dialog for adding and removing predefined values

Click on the option *Properties* which is found in the menu that is obtained by right clicking on the graphical display activates a dialog, Figure 11. In this dialog we can change color of the temporary rectangle, color of the rectangle, point color, line width and point radius.

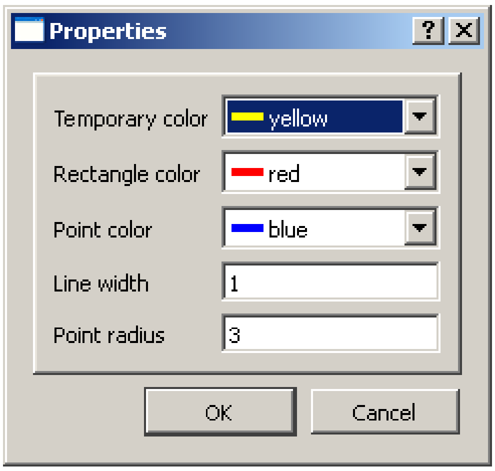


Figure 11. Dialog for setting options of the graphical display

PLOT TAB

Tab *Plot* is used for plotting granulometric curves which are input in the Input tab. Similarly, as in Input tab, this tab is visually divided on left side with tables and right side with graphical display, Figure 12.

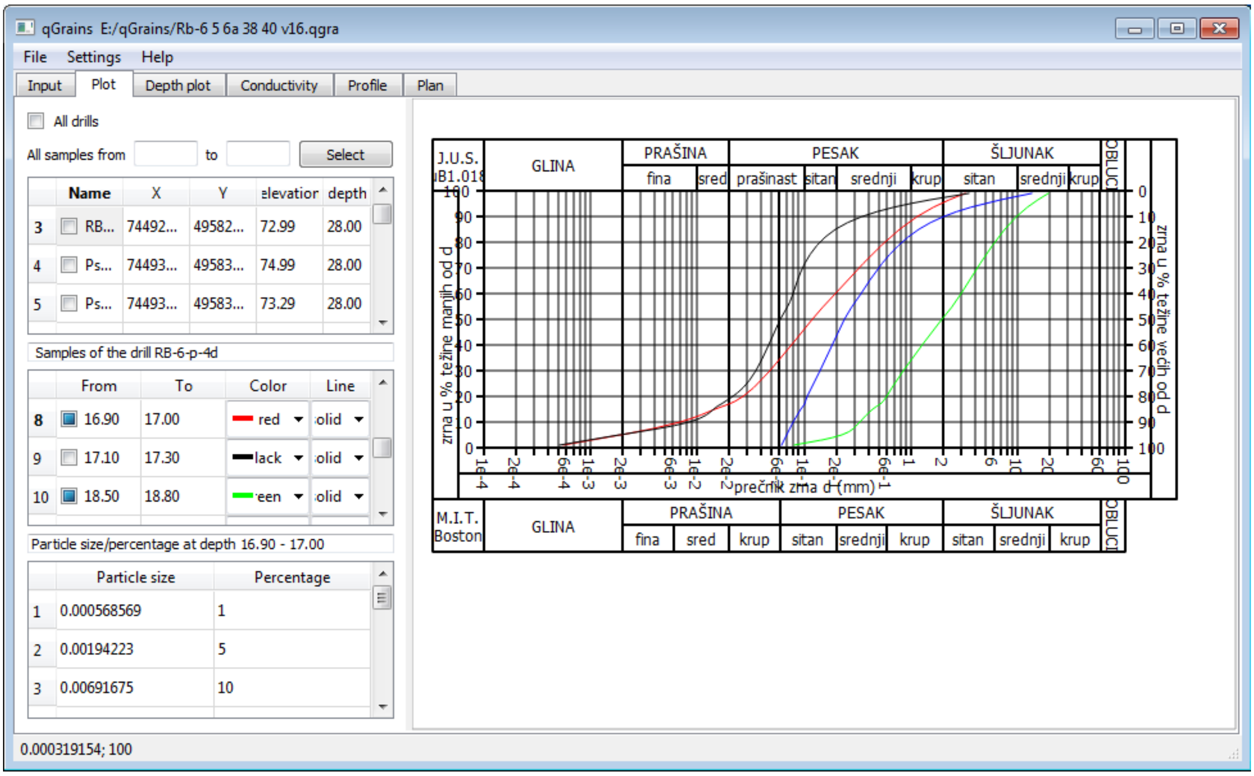


Figure 12. Plot tab

On the left side of this tab, there are options for selecting (*All drills, All samples from*), and also tables similar to those on the Input tab with additional check boxes. As on the Input tab, click on the drill in the table with drills activates table with samples in the middle, and click on the sample activates table with grain size and percentage. By checking a specific sample, its granulometric curve is shown in the graphical display. For every sample we can choose color and line type of its granulometric curve. By checking a specific drill, all its samples are checked. By checking box *All drills*, all drills are checked, while unchecking all drills are unchecked. By writing values in fields *From* and *To* and clicking on button *Select*, all samples in all drills whose depths are in selected interval are checked. Data in tables with drills and samples cannot be changed on this tab, but only on the Input tab.

Graphical display on right side has a painted frame, a form that is usually used for showing granulometric curves.

Note: Lithological classification according to grain size has two scales JUS (old Jugoslav standard) and MIT standard.

On graphical display, it is possible to use drag and zoom. The status bar shows values on the x and y axis when hoovering mouse over a graphical display. Right click on the graphical display activates a menu, Figure 13.

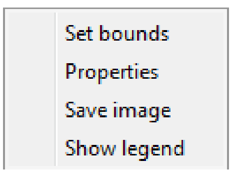


Figure 13. Menu obtained with right click onto graphical display on Plot tab

A click on option *Set bounds* activates dialog in which x-span and the look of the frame are set.

A click on properties activates dialog in which we set: title, color, line width of the frame, thin line width inside the frame, ratio height and width of the frame, font size, width of the granulometric curve, snap size and language (only Serbian and English are optional for now).

A click on *Save image* activates window for saving picture that is currently active on graphical display.

A click on *Show legend (Hide legend)* shows (or hide) legend.

A click on a certain sample which is checked in table, makes its granulometric curve line bold on graphical display. Similarly, if we click on a certain granulometric curve on graphical display, its line is bolded, and a sample of that granulometric curve is selected in tables on the left side.

Note that a click on the drill name in the table shows its sample table, while checking a drill (box in front of drill name) does not show sample table for that drill.

DEPTH PLOT TAB

Depth plot tab has two vertically aligned tabs: *Depth vs d* i *Depth vs %, Figure* 14.

Tab *Depth vs d* is used for plotting graph of depth (or elevation) relative to grain size. Tab *Depth vs %* serves for plotting graph of depth (or elevation) relative to percentage. Similarly, as on the previous tabs, both tab *Depth vs d* and *Depth vs %* are visually divided onto left side with tables and right side with graphical display.

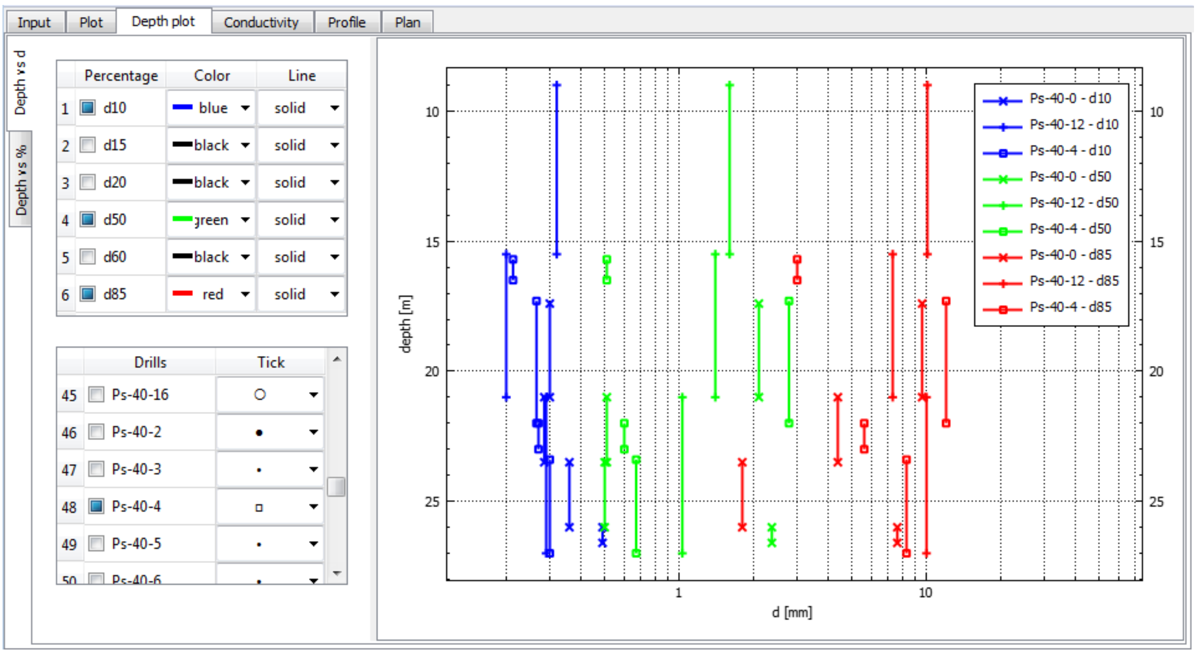


Figure 14. Depth plot tab

Depth vs d tab

On the left side of this tab, there is a table for choosing percentage and table for choosing drills. In the table for percentage choosing, beside the checkbox, we can choose color and line type for a certain percentage involvement. If the sample is in a certain range, it will be shown on graphical display as vertical line which goes *from* - *to* of specified depth.

We should be careful with this graph, because sometimes resulting graph may seem absurd. Let us examine an example.

Percentage in points on *Input* tab does not have to be integer numbers, but they have to be “near” the wanted percentage. With tolerance (menu *Settings -> Tolerance*) we set the term “near”. For example, if we have points (grain size, percentage) in the 3-5m sample:

(0.1, 8.2%),

(0.2,10.2%),

(0.3, 12.1%)

and tolerance 2, then for d_{10} plot will have two vertical lines, one at x=0.1mm from y=3m to y=5m, and the other one at x=0.2mm from y=3m to y=5m, Figure 15. Third point would not be plotted because it is not “near” enough for d_{10} (10%± tolerance).

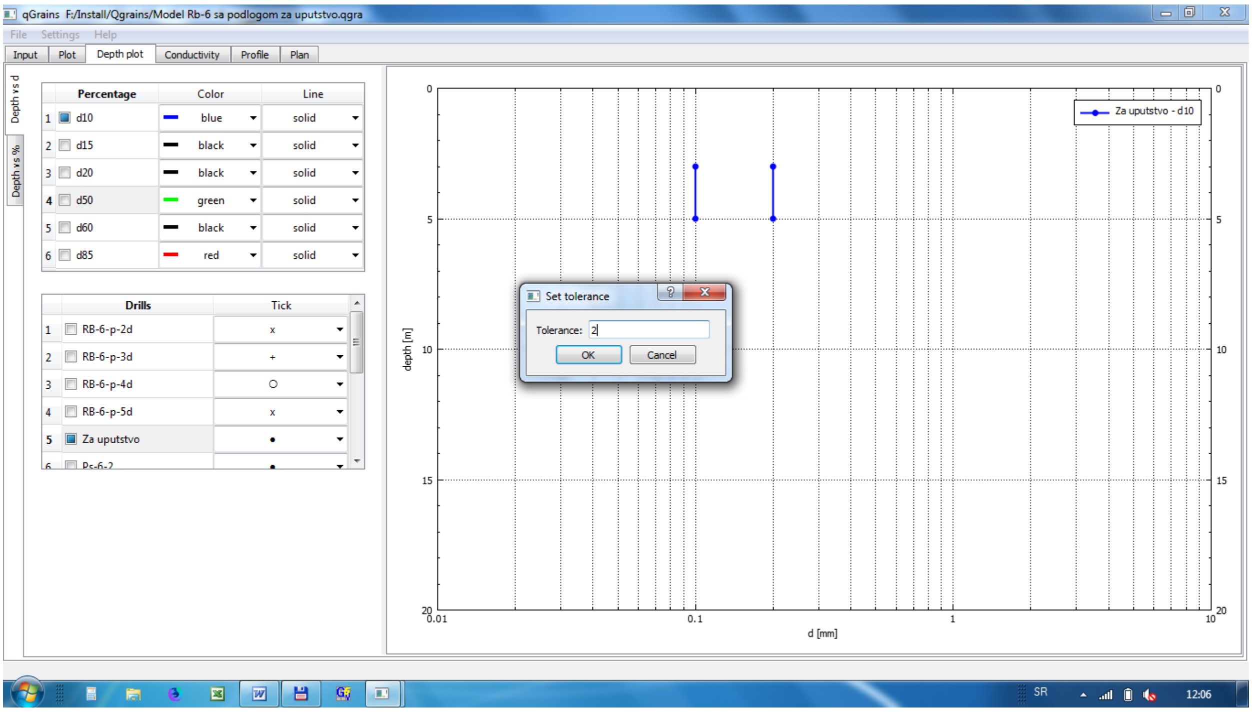


Figure 15. Example of inadequate tolerance (tolerance = 2)

By lowering the tolerance, for example tolerance = 1, we obtain one representative line for d_{10} in interval from 3 m to 5 m, as in Figure 16.

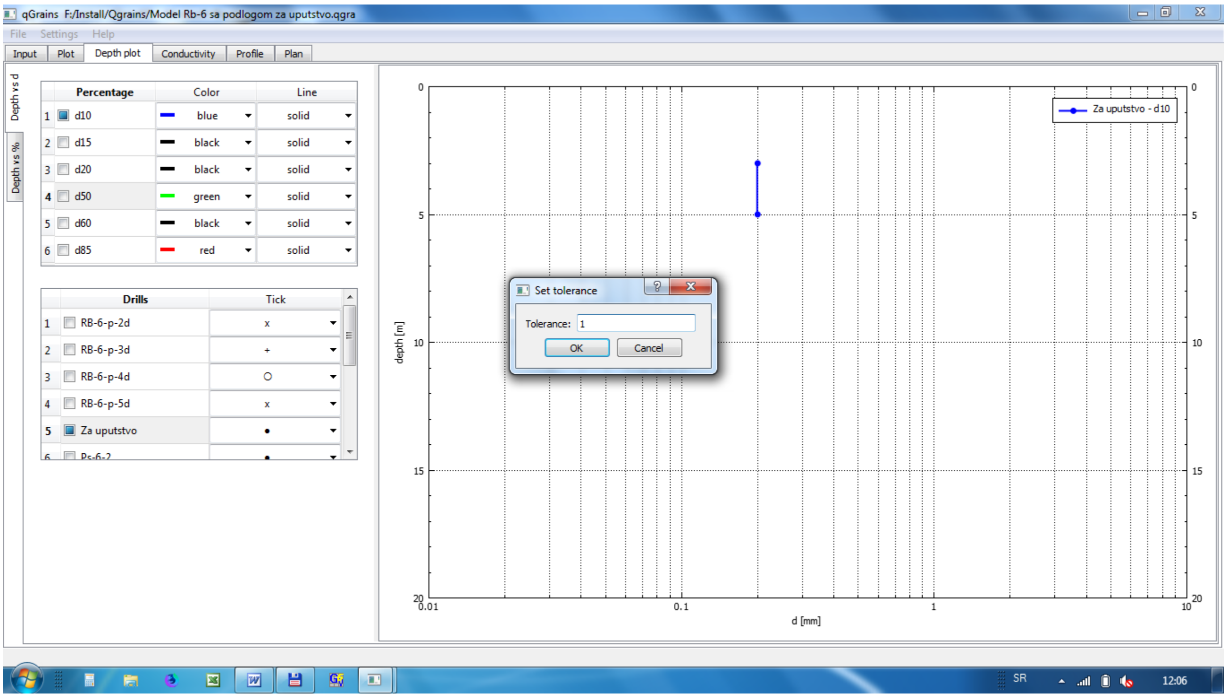


Figure 16. Plot for tolerance = 1

The lower table serves for choosing drills for which graphs of selected percentage will be plotted. Here, we can also set ending points tick.

Note: All samples from chosen drills are always presented.

On the graphical display we can use drag and zoom. Coordinates are shown in status bar as we hoover the mouse over the graphical display. Right click on the graphical display activates menu, Figure 17.

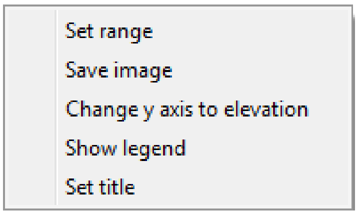


Figure 17. Menu obtained with right click on graphical display on *Depth vs d* tab

Option *Set range* activates dialog for setting range which is shown. Option *Save image* save *.jpg* image of what is currently on the graphical display. Option *Change y axis to elevation* (*Change y axis to depth*) changes y axis show to elevation (depth). Option *Hide/Show legend* hides or shows legend. Option *Set title* is used for setting a title.

Depth vs % tab

The upper table on the left side is for choosing grain size. There is always one empty row in this table in which we can enter new grain size (in the range *from-to*). In this table, beside check box for choosing which grain size should be shown, we can also choose color and line type. The lower table serves for choosing drills which are going to be shown on the graphical display and also a type of ending points.

Let us examine following example:

Let us have one sample on the depth from 3 to 5 m with points (grain size, percentage):

(0.15, 8.2%),

(0.30, 20%),

(0.50, 85%).

If the upper table shows grain size from 0.15 mm to 0.3 mm, on the plot we will have vertical line at x=20% - 8.2% = 11.8%, and y from 3 m to 5 m, Figure 18.

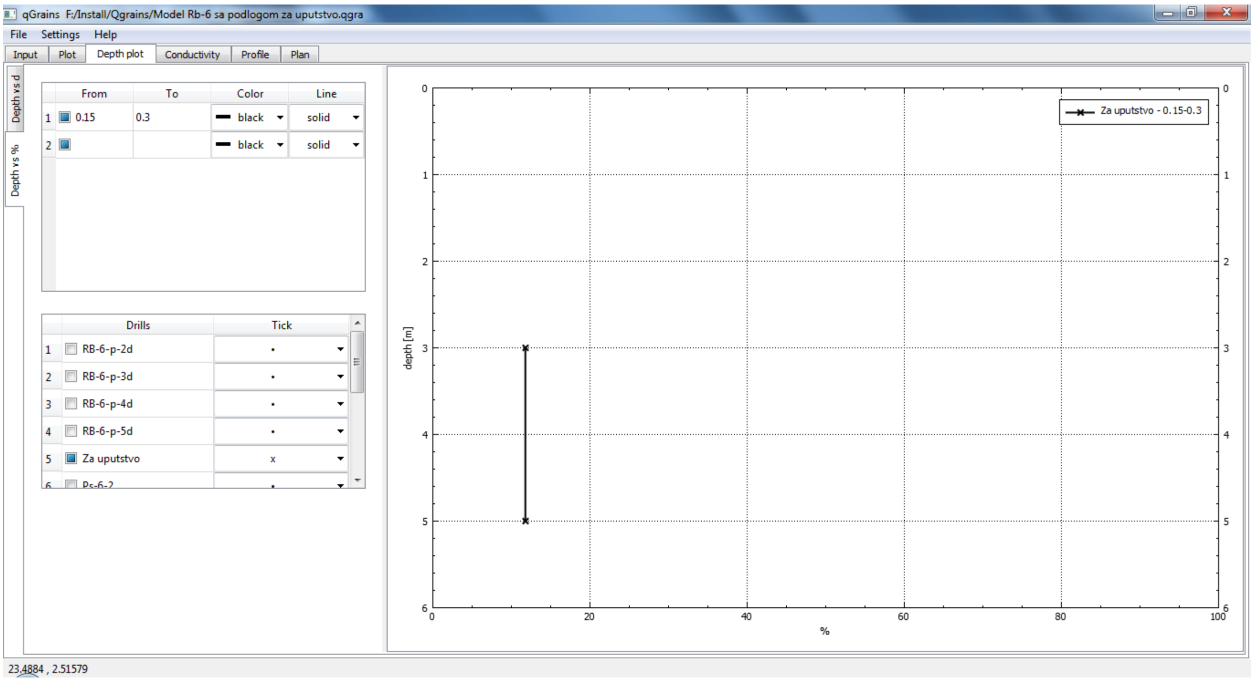


Figure 18. ***Depth vs %*** **tab**

If we choose to show grain size from 0.1 mm to 0.3 mm, plot will consist of one vertical line at

x=20% - 0% = 20%,

and y from 3 m to 5 m of depth, minus 0% in previous expression because the smallest inputted point has grain size 0.15mm. We consider the first point that is less or equal, and if there is none such point, we consider zero.

If the upper table shows grain size from 0.15 mm to 0.4 mm, on the plot we will have one vertical line at

x=52.5% - 8.2% = 44.5%,

and y from 3 m to 5 m of depth, Figure 19. As we don't have percentage for grain size 0.4 mm, with linear interpolation from the closest points we have the value of 52.5%.

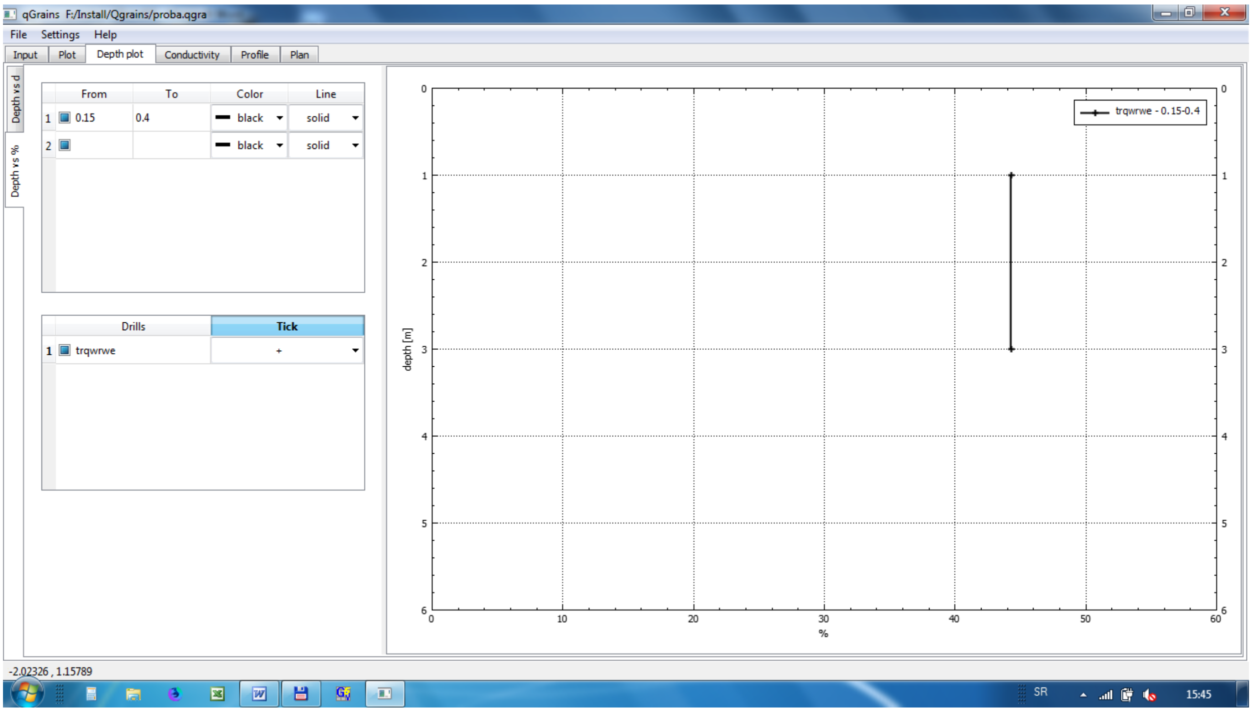


Figure 19. ***Depth vs %*** **tab**

Right click on graphical display activates same menu as on tab *Depth vs d.*

CONDUCTIVITY TAB

This tab, Figure 20, is used for estimation of porosity, coefficient of uniformity, and hydraulic conductivity. Hydraulic conductivity is estimated using ten formulas.

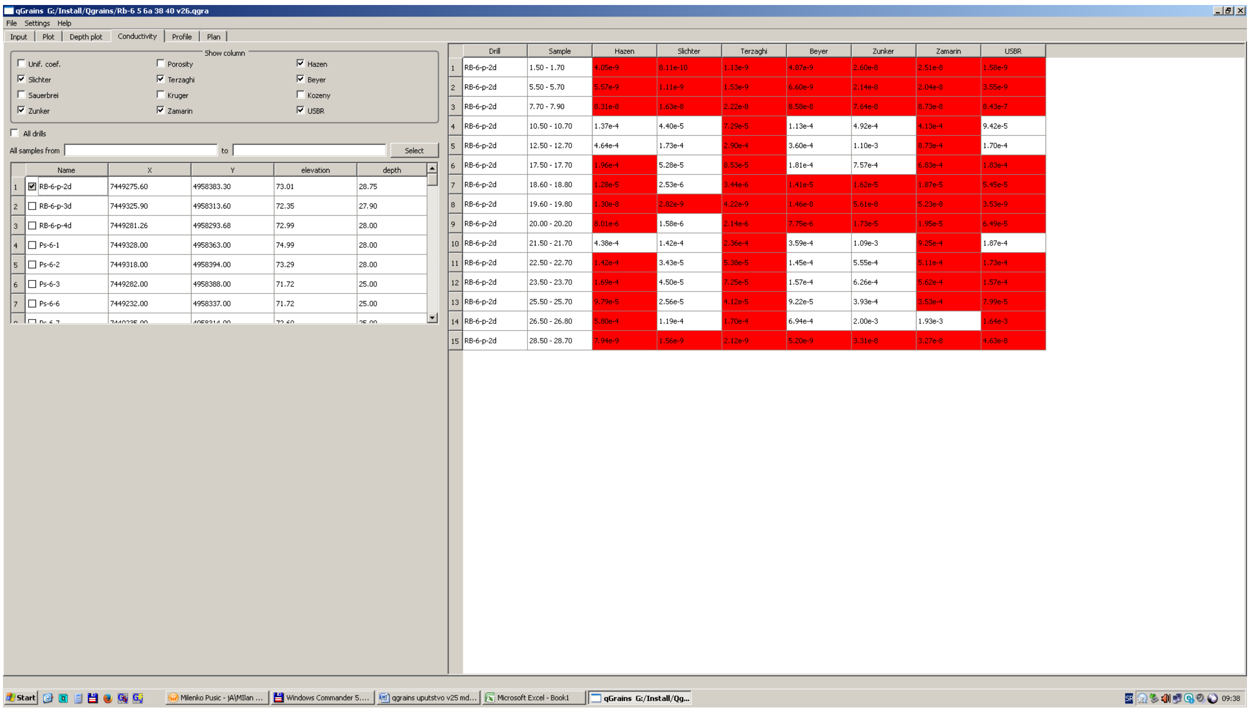


Figure 20. ***Conductivity*** **tab**

On the left side of this tab, in frame *Show column*, there are checkboxes for checking which column will be shown on the right table. Below this frame, there are tables for choosing which drills and/or samples will be shown for chosen columns, similarly to Plot tab.

Cells which are marked with red are those for which author of the formula does not recommend the use of his formula, based on the granulometric sample.

The results are shown in the table on the right side. Right click on this table gives option *export to csv.* This option saves data of this table in *.csv* file, suitable for use in Excel.

Note: In *.csv* file we have hydraulic conductivity obtained by all authors, regardless of their selection in qGrains.

Considering that *.csv* file does not contain information about the cell color, option *export to csv,* gives two *.csv* files: one with hydraulic conductivity, and other one with information about the cell color (1 if the color is red, 0 otherwise). Those two files can easily be merged in Excel.

PROFILE TAB

This tab, Figure 25, is used for graphical representation of the given input and obtained results of the material parameters along chosen profiles, and also for defining boundary contact surfaces between schematized layers and its visualization.

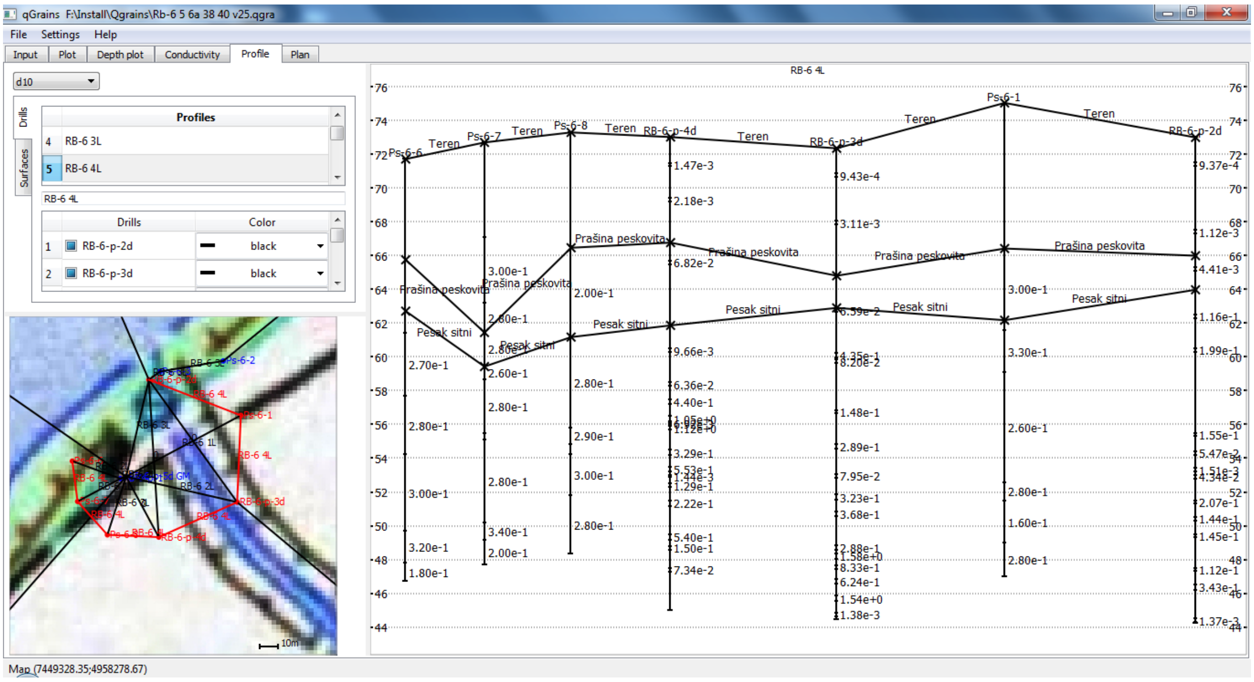


Figure 25. ***Profile* tab**

Profile consists of: combo box for choosing material parameter which will be presented, vertical tab for choosing profile and drills (*Drills* tab), vertical tab for Choosing surfaces (*Surface* tab), map and graphical display.

In the combo box for choosing material parameter which will be presented, we can choose among the following: *d_{10}, d_{15}, d_{20}, d_{50}, d_{60}, d_{85}, Unif. coef, Porosity, Hazen, Slichter, Terzaghi, Beyer, Sauerbrei, Kruger, Kozeny, Zunker, Zamarin, USBR, Grain size.* If we select *Grain size*, two fields appear for entering an interval of a grain size. In this case, the obtained value is same as on the tab *Depth vs %.*

Tab *Drills* has table for displaying profiles and table for choosing drills. Table with profiles always has empty last row in which we enter new profile. Profile is defined by drills checking order, where last checked drill is always added to the end of polygonal chain of profile. On this tab is also part for choosing drills, where all drills are listed with checkbox and combo box for choosing color of that drill.

On the *Surfaces* tab, all surface names are listed, where last row is always empty so we could enter a new surface.

On the map, drills are shown with respect to their coordinates that are entered on the *Input* tab. Right click on the map opens a menu, Figure 26, with options: *Image properties, Save image, Objects properties, Set range, Distance tool.*

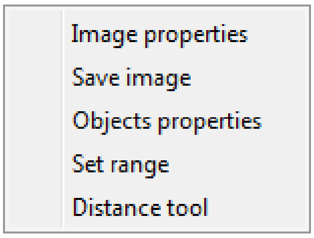


Figure 26. Menu that opens with right click on the map

Click on the *Image properties* activates a dialog on Figure 27.

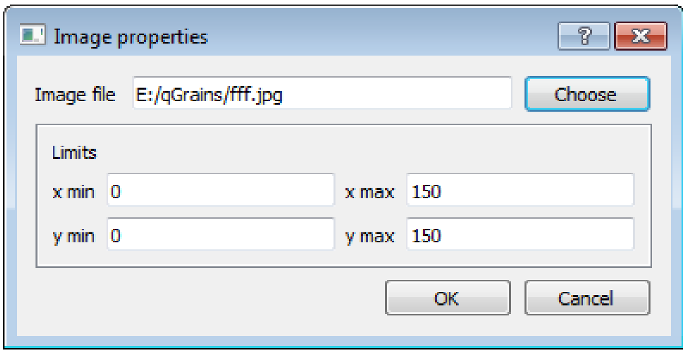


Figure 27. Dialog *Image properties*

In the field *Image file,* we are inputting location of the file where we have *.jpg* picture of the map. This also can be done by clicking *Choose* button and choosing a desired file. In fields *x min* and *y min* we are entering coordinates of the map lower left point, and in fields *x max* and *y max* we are entering coordinates of the map upper right point.

Click on the *Save image* saves current picture of the map.

Click on the *Objects properties* activates dialog on Figure 28.

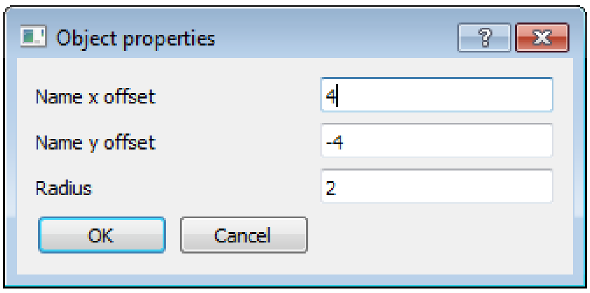


Figure 28. *Object properties* dialog

In this dialogue we can adjust offset for the drill name and radius of the drill circle.

Click onto *Set range* opens dialog in which we are adjusting range which is presented.

Click on *Distance tool* activates a distance tool.

By double clicking inside the drill circle on the map, that drill is checked (or unchecked) in the table. Checked drills on the map are marked with red color, and unchecked are marked with blue. By hoovering a mouse over map writes in status bar *Map(x,y)*, where instead of x and y we have values of coordinates on the map. Inactive profiles are marked with black color and active profile is makred with red color. Note that only one profile can be active.

On the graphical display, drills in profile and values of the selected material parameter are presented, Figure 29. Also, on the graphical display, chosen surfaces are also presented. Value of the selected material parameter is of grey color if *d effective* is contradicting a grain size recommended for using the formula.

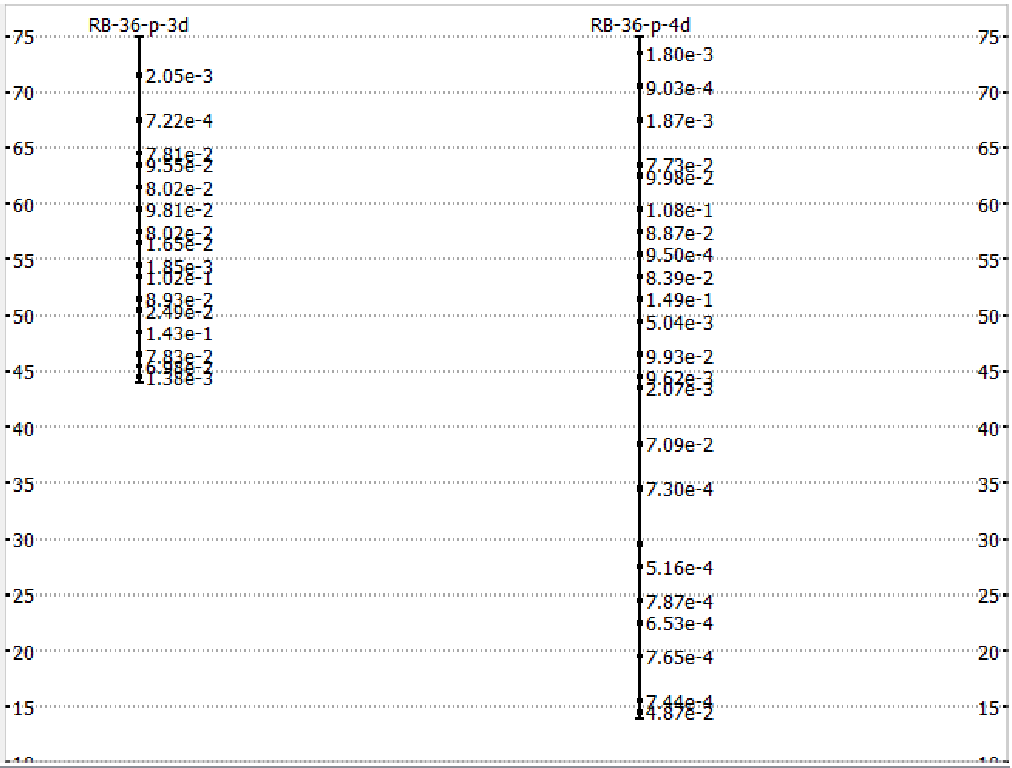


Figure 29. Example of drills on graphical display

Parameter values are given for every sample. Graphical display represents profile by the polygonal chain, whose crowns are chosen drills. On the map, we can use drag and zoom. Also, there is possibility to use zooming along only one of the axes, by holding *Ctrl* button on the keyboard, and using a mouse wheel we can zoom over x axis, and by holding *Shift* on the keyboard and mouse wheel we can zoom over y axis.

Right click onto graphical display activates the menu, as in Figure 30.

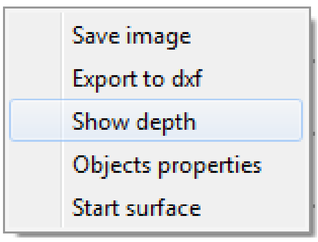


Figure 30. Menu that is obtained by right clicking on graphical display on *Profile* tab

Click on *Save image* saves picture that is currently on graphical display.

Click on *Export to dxf* saves picture in *dxf* format.

Click on *Show depth (Hide depth)* shows (hides) on the left side of the drill mean value of sample depth.

Click on *Objects properties* activates dialog on Figure 31, where we can adjust size of the ticks and font size. Also, on this dialog we set total number of division on the y axis.

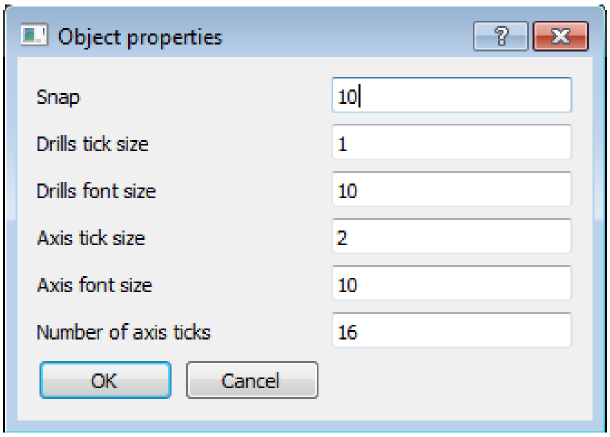


Figure 31. *Objects properties* dialog

Click on *Start surface* starts new surface. Points of the new surface are imposed by double clicking on graphical display. Points are inputted on the chosen order on each of the drills which is selected for presenting in the profile. On *Surface* tab, the name of the surface is automatically shown (at first as ordinal number) and can be changed in any moment.

On *Surfaces* tab, there we can check (or uncheck) any surface. When some surface is checked, it will be shown on the graphical display. If we select some surface on *Surfaces* tab, it is marked in pink color on the graphical display. Similarly, if we click on graphical display on some surface, it becomes selected in *Surfaces* tab.

Surface can easily be removed form table using the following procedure. Select surface that is to be deleted and press *Delete* button on the keyboard. When a surface is selected, it is also possible to move points that are forming it. We can add points to any surface in the following manner. Select a desired surface and then right click on graphical display. On the obtained menu (same as on Figure 30 with one more option *Add point to selected surface*), click on the additional option starts adding of new points.

Right click on table in *Surfaces* tab gives option *Export to csv.* This option saves all surfaces in *.csv* file. The first line of this file denotes surface name, and then in the following lines are coordinates of drills and defined height of the surfaces.

PLAN TAB

This tab, Figure 32, is used for graphical displays of the terrain map of the material parameters for different depth intervals or selected surfaces. It contains a section for choosing section or interval, a section for choosing material parameter, a section for choosing calculation domain for isolines, and a map.

On the map, we have shown drills, name of the drills and calculated values. Map is connected with map on the *Profile* tab. We can use drag and zoom on the map.

On the combo box *By* we can pick different type of the section: *elevation, depth, surface* i *thickness.*

If *elevation*, or *depth*, is selected, then two fields appear for values *From* and *To* and one more combo box for choosing parameter that is presented. For *depth,* samples whose depth is between *From* and *To* are presented. For *elevation,* samples whose heights are between *From* and *To* are presented.

For example, if we select *depth* and set values from 15 m to 20 m, and have samples on one drill with depths 14 - 16, 17 - 19 i 19.5 - 20, samples 17-19 i 19.5-20 will be presented. When there are more values in the selected range, we calculate their arithmetic mean and that is presented on the map. The value and the name of the drill are marked with:

- black color, if in that drill there is no sample in selected range,

- green color, if in that drill there is only one sample in selected range,

- red color, if in that drill there are more than one sample in selected range. Value is obtained as arithmetic mean of values of all samples that are in the range.

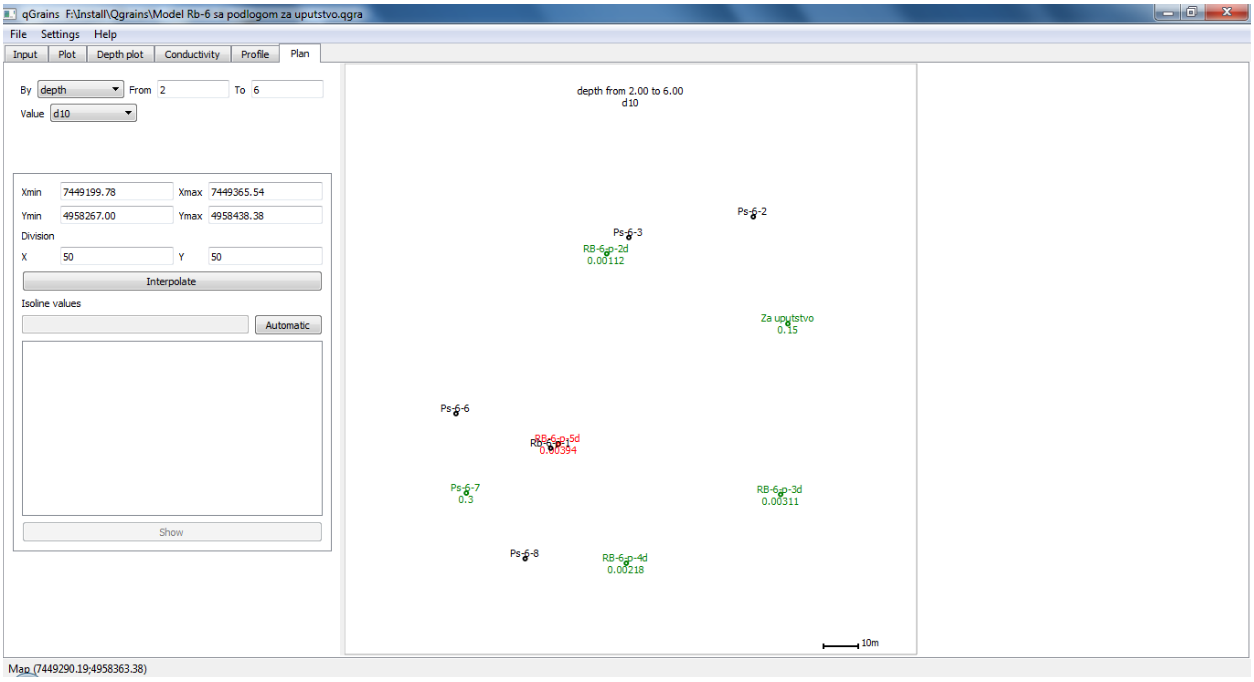


Figure 32. *Plan* tab

If *surface* is selected in *By* combo box then there is an additional combo box where we can choose one of surfaces previously defined on *Profile* tab. The heights of the surfaces by the drills are presented on the map. A drill name is marked in black color if surface does not have a value in that drill. Drill name and value are marked in green color if the surface has a value in that drill.

If *thickness* is selected, then two more combo boxes appear and we can choose surface previously defined on *Profile* tab in both. Values that represent differences between heights of surfaces in the drills are presented on the map.

Whenever we change selection in *By* combo box, map display changes.

In the part for calculation of isolines, it is necessary to input rectangle coordinates (*Xmin, Xmax, Ymin, Ymax*) in which isolines will be calculated, and also division of this rectangle (*Division X* i *Division Y*). After this we have to click on *Interpolate* button in order to interpolate values in the complete domain.

When values are interpolated, we can input values of the isolines and then present them by clicking *Show* button. A value of an isoline can be input in the field, and after clicking *Enter* on keyboard, the value is presented in the list below. There is also another way, and that is by clicking onto *Automatic* button, where we are inputting number of all isolines values in dialog which appears, and they are uniformly distributed between minimal and maximal value which are obtained from interpolation.

Right click on the map activates the menu as in Figure 33.

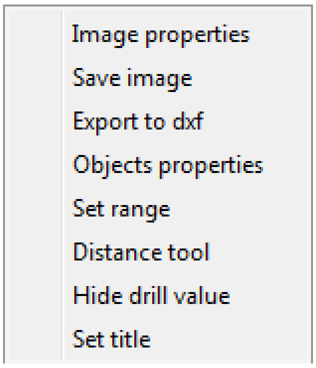


Figure 33. Menu that is obtained by right clicking on the map on Plan tab

Click on *Image properties* activates dialog as in Figure 27, and has the same purpose as on the *Profile* tab. Click on *Save image* saves current image of the map.

Click on *Export to dxf* saves picture in *.dxf* format.

Click on *Objects properties* activates dialog as in Figure 34, where we can adjust drill radius size on the map, a color of the isolines and also label incidence.

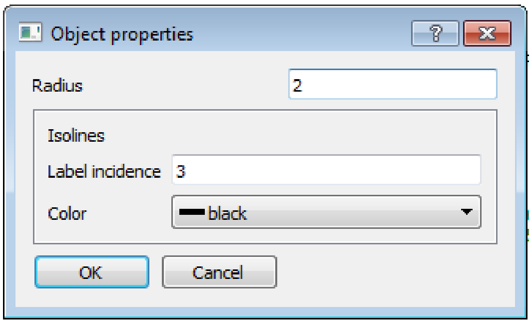


Figure 34. *Objects properties* dialog on *Plan* tab

Click on *Set range* activates dialog for setting domain for showing on the map.

Click on *Distance tool* activates distance tool.

Click on *Show/Hide drill value* shows (hides) values in drills.

Click on *Set title* sets title on the map. Beside the title, there are also selected settings presented on the map.

THEORY

Hydraulic conductivity is the fundamental parameter for groundwater flow computation. This parameter depends on porous medium but also on fluid (water). It represents the ease with which fluid can move through pore spaces. This definition of hydraulic conductivity was obtained from Darcy's law, which was defined by Henry Darcy. Darcy's law can be expressed

$$Q = \omega \cdot K \cdot I \tag{1}$$

or

$$v = K \cdot I = \frac{Q}{\omega} \tag{2}$$

where is:

Q – total discharge, volume of fluid (groundwater) which in one-time unit flows through cross section of the column [L^3T^{-1}];

ω – area of cross section, [L^2];

K – hydraulic conductivity, [LT^{-1}];

I – decline in hydraulic head, i.e. difference between hydraulic heads [-];

v – Darcy velocity, which can also be seen as ratio of a discharge and an area of cross section, [LT^{-1}].

In the previous equation, hydraulic conductivity includes filtration properties of porous medium (size, shape, grain distribution, porosity, etc.) but also fluid properties (above all viscosity).

Groundwater moves through system of pores, therefore Darcy velocity is not real velocity of fluid, but rather fictive quantity. Averaged fluid velocity is a ratio of Darcy velocity and porosity.

From the equation (2), we can see that fluid velocity is directly proportional to hydraulic conductivity; therefore error in estimation of hydraulic conductivity directly impacts the velocity and discharge precision. In nature, hydraulic conductivity of medium is non-uniformly distributed in space, which emphasizes the significance of good estimation of hydraulic conductivity.

In practice, there are a lot of methods for hydraulic conductivity estimation. Which one will be used depends on available data, research goal, natural conditions and others limiting factors.

Methods that use empirical formulas and data of grains size distribution curves for hydraulic head estimation are advantageous because they are easy and fast to use. Main flaw of these methods is relevance of analyzed sample in whole space volume, as well as limitations of use based on other conditions.

Based on laminar flow of groundwater, schematized with system of pipes with different radius, hydraulic conductivity can be seen as (Vukovic, Soro, 1991,1992):

$$K = \frac{g}{\nu} \cdot C \cdot \varphi(n) \cdot d_{ef}^2 \tag{3}$$

where is:

g – gravitation, [LT^{-2}],

v – kinematic viscosity coefficient, [L^2T^{-1}].

C – non-dimensional coefficient, which depends on a number of parameters of porous medium (grain distribution, grain shape, petrography compound, heterogeneity, etc.),

$\varphi(n)$ – function that defines relation between real and schematized porous medium, depending on porosity and degree of compaction,

n – porosity, [-].

d_{ef} - effective radius of grains in porous medium, [L].

For calculation of water kinematic viscosity using temperature, we are using following term:

$$\nu = 3.0277 \cdot 10^{-14} \cdot t^4 - 8.731 \cdot 10^{-12} \cdot t^3 + \\ + 9.7155 \cdot 10^{-10} \cdot t^2 - 5.5088 \cdot 10^{-8} \cdot t + 1.7766 \cdot 10^{-6} \quad (4)$$

Results of a number of papers from different authors show that there is a relation between a coefficient of uniformity (η), which is obtained from granulometric curve, and porosity (*n*), Figure 35:

$$n = f(\eta) \quad (5)$$

where is:

$$\eta = \frac{d_{60}}{d_{10}} \quad (6)$$

η – uniformity coefficient, [-].

d_{60} – grain size for 60% on granulometric curve, [L],

d_{10} – grain size for 10% on granulometric curve, [L].

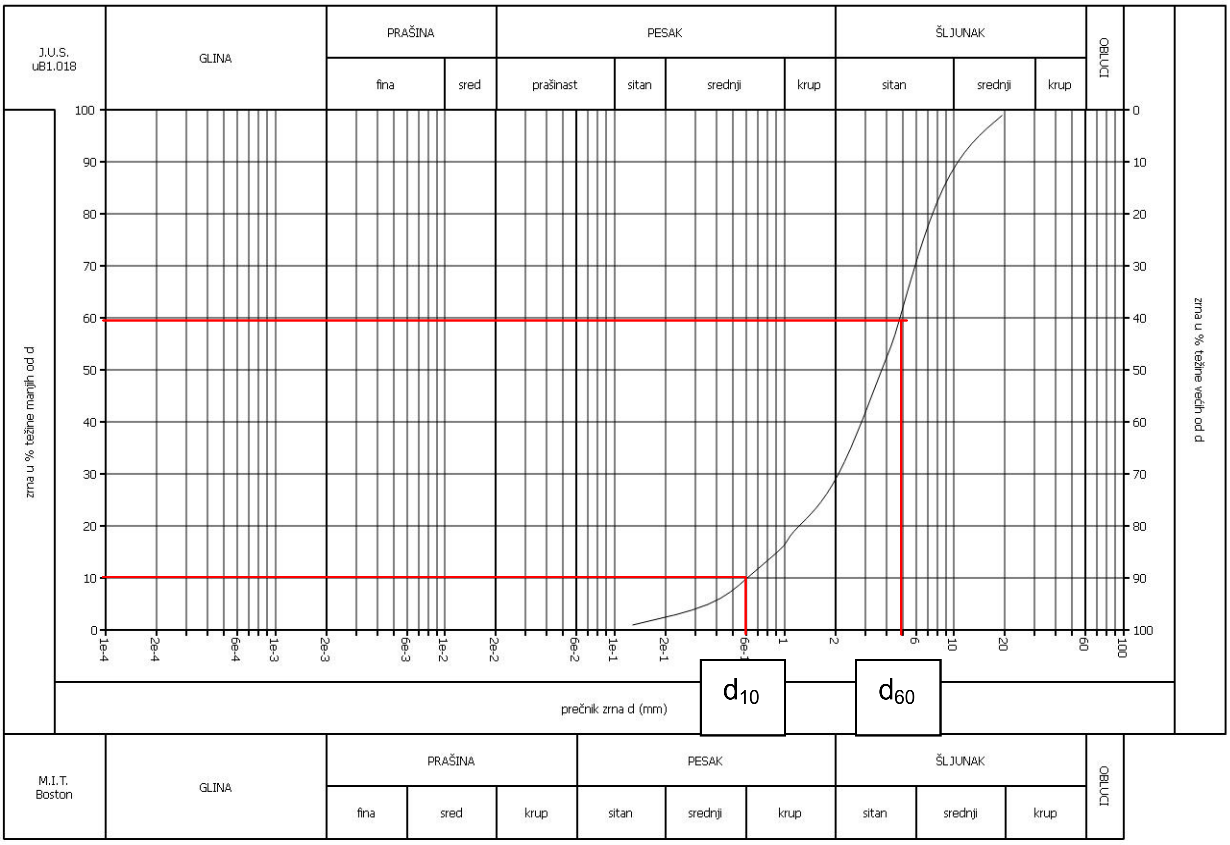


Figure 35. Granulometric curve and grains with 10% and 60% percentage

As uniformity gets higher, the porosity declines. In practice, results of experimental findings of V.S. Istomina[1)] are often used. These results are given in form where porosity depends on uniformity coefficient, Figure 36. Experiments were performed with natural send, coarse send, and gravel.

1) В. С. Истомина. 1957. Фильтрационная устойчивость грунтов, Гос. изд-во лит-ры по строительствы и архитектуре, стр. 295

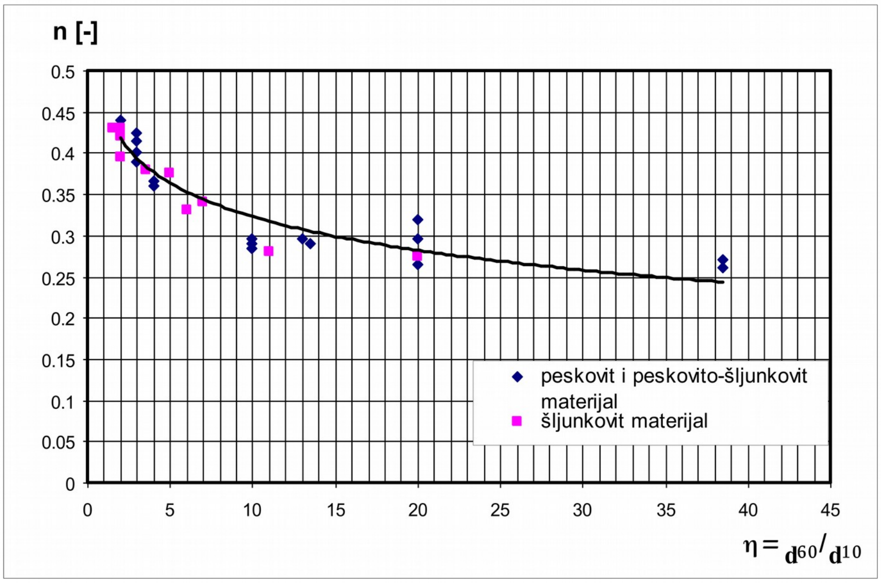


Figure 36. Dependence of porosity (*n*) on uniformity coefficient (*η*) (Istomina, 1957)

Based on Figure 2, we have a formula for estimation of porosity using an uniformity coefficient:

$$n = 0.255\left(1 + 0.83^{\eta}\right) \quad (7)$$

From equation (3) we can deduce that hydraulic conductivity is proportional to the square of effective grain radius. When the porous medium consists of equal-sized grains, grain radius is also effective radius.

In practice porous medium is composed of various sized grains, therefore there are different ways to define effective radius of grain size. Sizes which relate to 10%, 17% or 20% involvement on granulometric curve of porous medium often used are (Vuković, Soro, 1991, 1992).

Note that in all formulas effective radius is expressed in mm, and hydraulic conductivity in m/s.

EMPIRICAL FORMULAS FOR HYDRAULIC CONDUCTIVITY ESTIMATION

Empirical formulas for hydraulic head estimation are mainly derived from laboratory experiments with sandy samples. Their application is mainly limited with a grain size. Some formulas are limited by the size of uniformity coefficients (Hazen, Bejer, Kriger, USBR). Constants given here are taken as recommendation from authors, or as median representative values.

Formulas used in qGrains are given in Table 1. Although, in original form these formulas are of dimensional, non-homogeneous and specific character, here we transformed them in form that allows comparison, all in accordance to the equation (3). All formulas are taken from ((Vukovic, Soro, 1991, 1992). Area of implementation is given in the last column of Table 1.

Table 1. Formulas for hydraulic conductivity estimation

	Author	Formula	Area of implementation
1	Hazen	$K = 6 \cdot 10^{-4} \cdot \frac{g}{\nu} \cdot [1 + 10(n - 0.26)] \cdot d_{10}^2$	0.1 mm < d_{10} < 3 mm $\eta = \frac{d_{60}}{d_{10}} < 5$
2	Slichter	$K = 0.01 \cdot \frac{g}{\nu} \cdot n^{3.287} \cdot d_{10}^2$	0.01 mm < d_{10} < 5 mm
3	Terzaghi	$K = 0.008 \cdot \frac{g}{\nu} \cdot \left(\frac{n - 0.13}{\sqrt[3]{1 - n}} \right)^2 \cdot d_{10}^2$	1 mm < d < 2 mm
4	Beyer	$K = 6 \cdot 10^{-4} \cdot \frac{g}{\nu} \cdot \log \frac{500}{\eta} \cdot d_{10}^2$	0.06 mm < d_{10} < 0.6 mm 1 < η < 20
5	Sauerbrei	$K = 0.00375 \cdot \frac{g}{\nu} \cdot \frac{n^3}{(1 - n)^2} \cdot d_{17}^2$	d_{17} < 0.5 mm
6	Kruger	$K = 4.35 \cdot 10^{-5} \cdot \frac{g}{\nu} \cdot \frac{n}{(1 - n)^2} \cdot d_{ef}^2$	0.2 mm < d < 1 mm $\eta > 5$
7	Kozeny	$K = 0.0083 \cdot \frac{g}{\nu} \cdot \frac{n^3}{(1 - n)^2} \cdot d_{ef}^2$	1 mm < d < 2 mm
8	Zunker	$K = 0.002 \cdot \frac{g}{\nu} \cdot \left(\frac{n}{1 - n} \right)^2 \cdot d_{ef}^2$	0.1 mm < d < 1 mm
9	Zamarin	$K = 0.0082 \cdot \frac{g}{\nu} \cdot \frac{n^3}{(1 - n)^2} \cdot (1.275 - 1.5 \cdot n) \cdot d_{ef}^2$	1 mm < d < 2 mm
10	USBR	$K = 4.8 \cdot 10^{-4} \cdot \frac{g}{\nu} \cdot d_{20}^{2.3}$	0.2 mm < d < 1 mm $\eta < 5$

BIBLIOGRAPHY

Istomina, V.S. (1957). Filtration Stability of Soils (in Russian). Gostroizdat, Moscow-Leningrad

Vukovic, M., Soro, A., 1985, Analiza empirijskih formula za određivanje koeficijenta filtracije preko podataka o granulometrijskom sastavu, Vode Vojvodine, Novi Sad

Vukovic, M., Soro, A., 1991, Određivanje koeficijenta filtracije preko podataka o granulometrijskom sastavu, posebna izdanja, Institut za vodoprivredu "Jaroslav Černi", Beograd, 42 pp

Vukovic, M., Soro, A., 1992, Determination of Hydraulic Conductivity of Porous Media from Grain-Size Composition, first ed., Water Resources Publications, LLC, Littleton, CO, 83 pp

Table of contents