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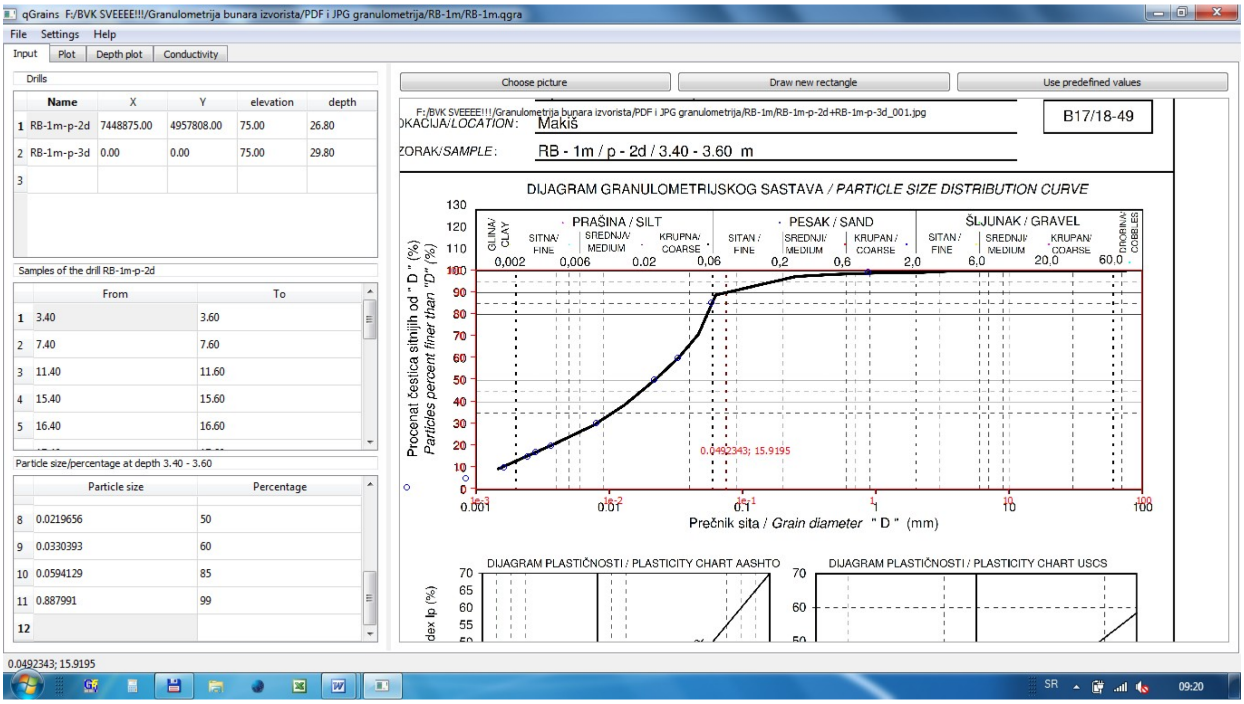

qGrains, ver.*.*

SOFTWARE FOR HYDRAULIC CONDUCTIVITY ESTIMATION FROM GRANULOMETRY

Milan Dotlić, Milenko Pušić, Goran Jevtić, Milan Dimkić

Belgrade, 2018.

PREFACE

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

Estimation of the hydraulic head conductivity using one of the empirical formulas is the most used way. These formulas are based on the grain-size distribution curves, which are usually obtained from exploration drills. Every formula has effective grain size of the material, which is obtained from grain-size distribution curve. Results obtained in this way is 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 vary even more then order 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 respect autors recomendation.

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

Software is developed in C++ using Qt framework and it is licensed under GNU General Public License version 3. (http://www.gnu.org/licenses/). Executable version for Windows operating systems as well as code itself can be found on https://github.com/mdotlic/qGrains.

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

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INTRODUCTION

Software qGrains is intended for estimation of hydraulic conductivity based on granulometry 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 on vertical, for all, or for choosed drills. It is possible to make profiles, with choosing different drills, or displays on the terrain map for different depth intervals or selected surfaces.

qGrains can be used for analyzing and displaying choosen percentage involvement on the granulometry curve, or displaying percentage involvment for choosen grain-size.

Using qGrains is it possible to make space classification, sistematization and schematization of sediments based on choosen percentage involvement or choosen grain-size. This can be usefull part of preparation for higher level of hydrogeological interpretation, for example making hydrodinamical model.

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

QGRAINS

INTRODUCTORY REMARKS

qGrains can be started in 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.

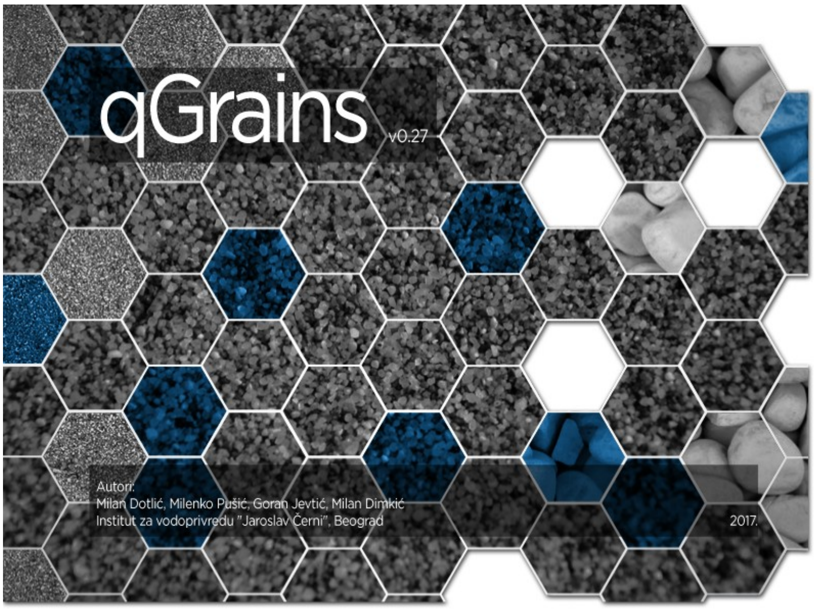


Figure 1. Splash screen of qGrains

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

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

qGrains saves files with extension *.qgra*, which is similar to Excel *.csv* format. This file can be imported into Excel and work with him as needed, although this is not recomended.

SOFTWARE STRUCTURE

Software *qGrains* is made as majority of standard Windows application. Main window, Figure 2. consist of title bar, menu bar, tabs and status bar.

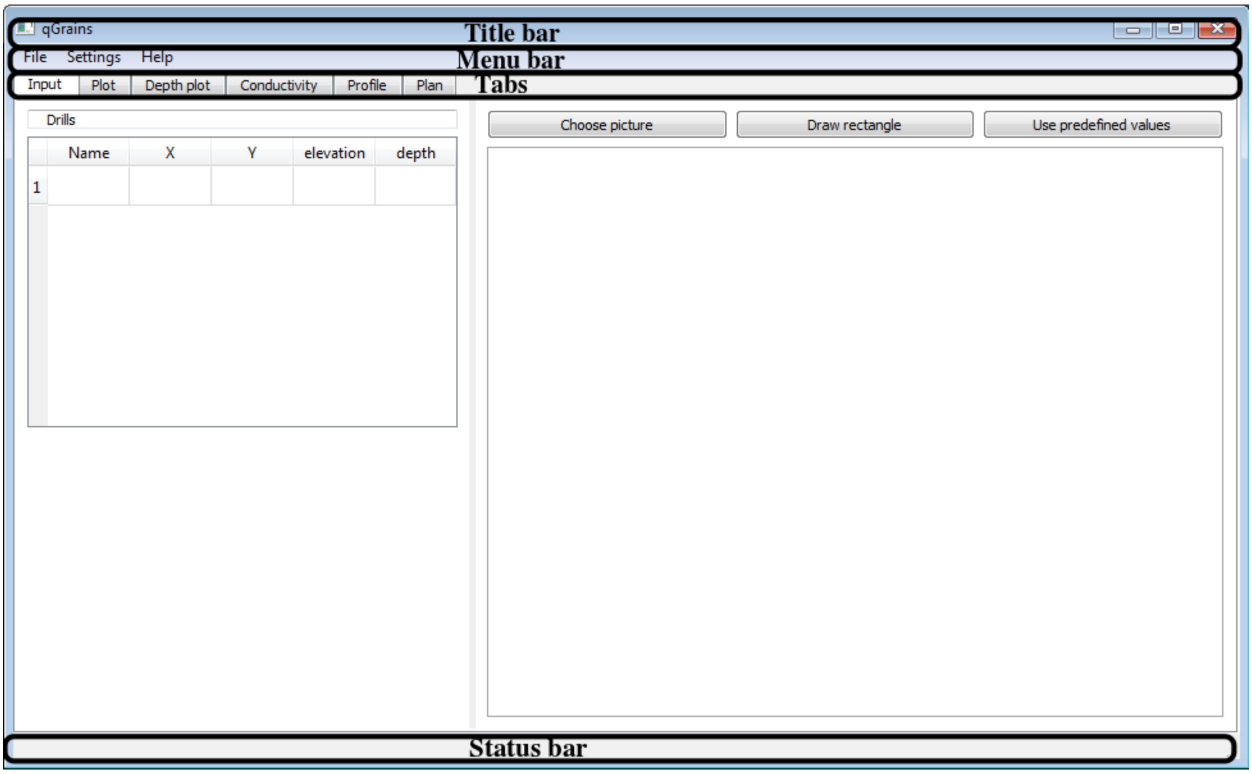


Figure 2. Main window of qGrains

Title bar displays the name of active file and optionst for minimization, maximization and closing application window.

Menu bar consist of submenus *File, Settings, and Help.*

We have following tabs *Input, Plot, Depth plot, Conductivity, Profile, Plan,* each of them will be explained later.

FILE

Menu *File,* Figure 3, consists of:

New – new file (shortcut Ctrl+N)

Open – loading old file (shortcut Ctrl+O)

Open from csv – loading specific form of Rockworks model

Add – adding new drills on existing ones

Save – save file (prečica Ctrl+S)

Save As – save file with different name

Quit – quit qGrains

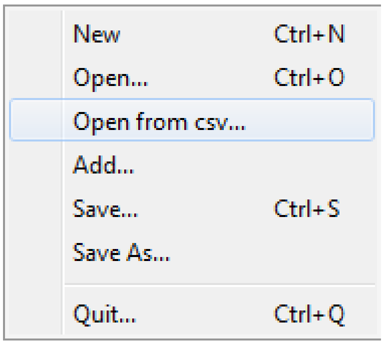


Figure 3. File meni

Option *Open from csv* gives possibility of loading csv file generated from Rockworks. In Excel file which is output of Rockworks there is sheet *Interval,* 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.

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

Option *Add* there is so we could combine more *.qgra* files.

SETTINGS

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

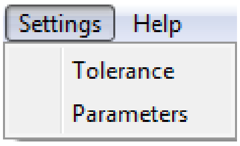


Figure 4. Settings menu

Click on option *Tolerance* opens window, Figure 5, in which tolerance can be set. This number represents tolerance for percentual involvement, we will dedicate more attention on this later in this text.

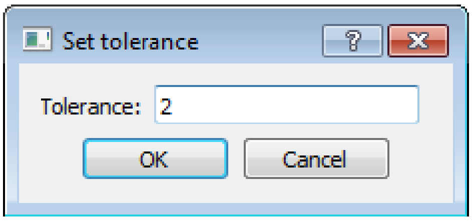
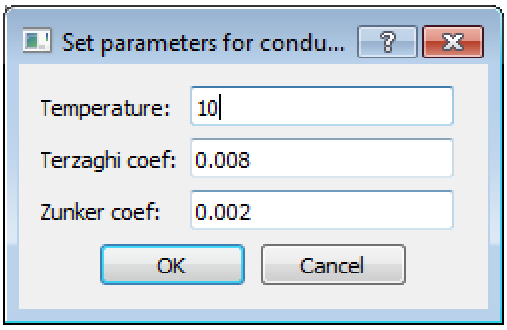


Figure 5. Tolerance

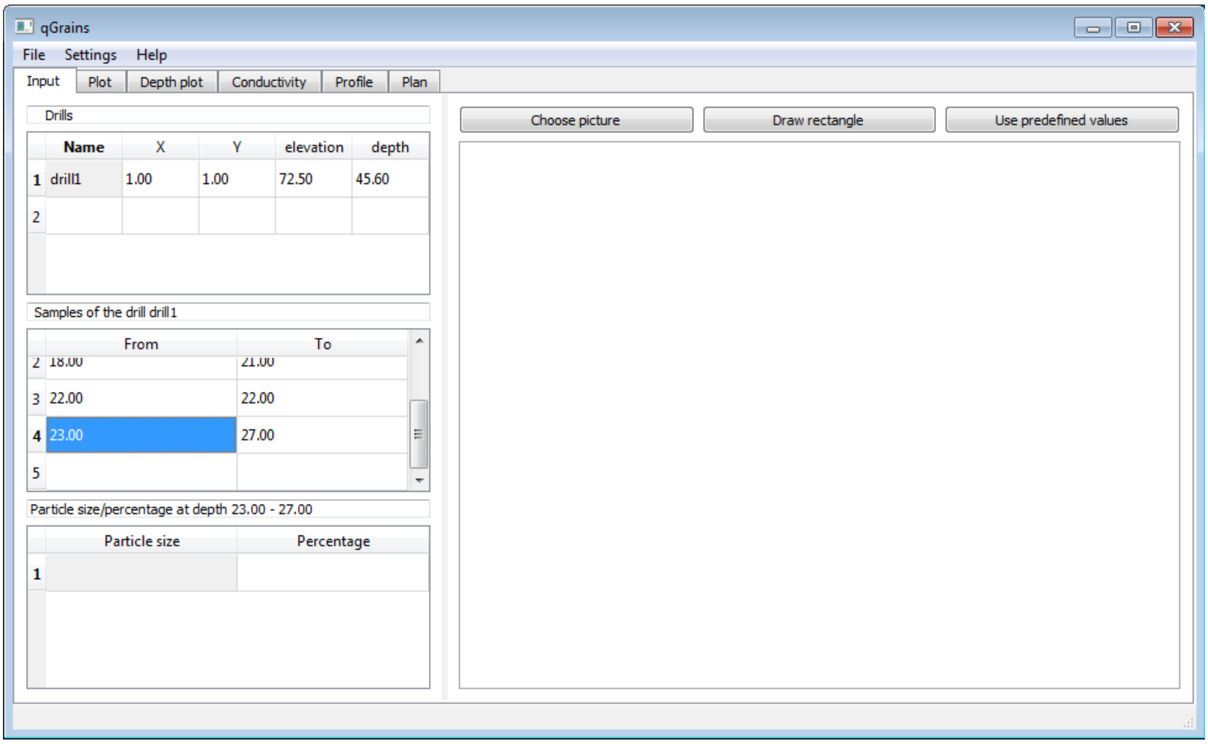
Click on option *Parameters* opens window, Figure 6, in which we set temperature value, as well as Terzaghi and Zunker coefficent which are used for estimation of hydraulic conductivity



Slika 6. Parameters

INPUT TAB

Input tab serves for inputing data about 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 digitalization of data from pictures.



Slika 7. Input tab

The upper table on the left side is for input drills data: name of the drill, x position, y position, elevation (meters above see 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 the point then we should enter same value in column *From* and *To*. This table do not allow entering 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 tables there is always an empty row in the end which serves for inputing new data. We can always change data in tables.

Remark: Data in all three tables on *Input* tab can be copied from Excel. If the copied data 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 is incorect (for example text, and it should be number) *qGrains* will through warning.

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

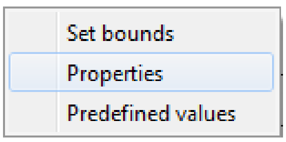


Figure 8. Menu obtained with rigth click on graphical display on the Input tab

Click on button *Choose picture* opens dialog for choosing scanned document with granulometry curves. After choosing picture in *.jpg* file format it appers in part for graphical display, Figure 9. In upper left corner of the graphical display writes 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,* 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 first point is clicked button *Draw rectangle* changes name into *First point is clicked,* when second point is clicked button label is back to *Draw rectangle.* Greater precision in setting rectangle can be achived by zooming picture.

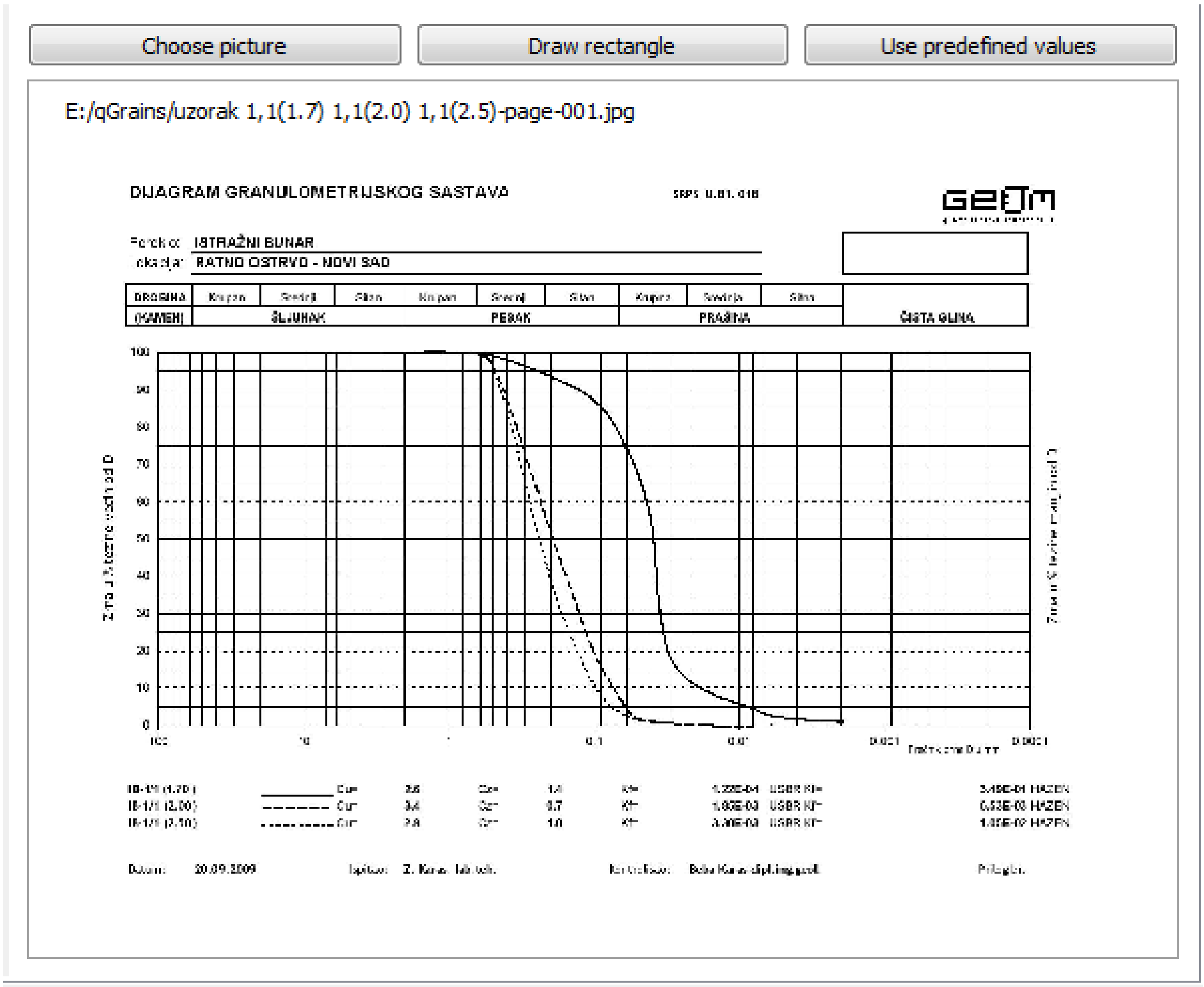


Figure 9. Loaded picture on graphical display

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

After drawing 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 sample from the middle table on the left and double click onto granulometry curve on graphical display, clicked point is automatically entred into lower table on the left. If the sample is not selected then double click on graphical display does not do anything. All points (with coordinates grain size and percentage) from the selected sample are drawn on graphical display. Mouse hovering on graphical display, when rectangle is drawn, shows referent values in the status bar and also near cursor. If we have more pictures with granulometry curves we repeat this procedure.

Remark: Software does not save scanned picture, this is only help for inputing data into tables.

Remark: It is impossible to enter the 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, also label of this button is changed to *Predefined value* - „value". At the beginning prefined values are 1, 5, 10, 15, 17, 20, 30, 50, 60, 85 and 99, but it can be easily changed, added or removed by choosing option *Set predefined* *values,* which can be found in menu that is obtained by right click on graphic display. Choosing this option activates dialog, Figure 10. In first line of this dialog we input new predefined values, which appers in the list bellow. Click on some value and *Delete* button on keybord removes value from the list.

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

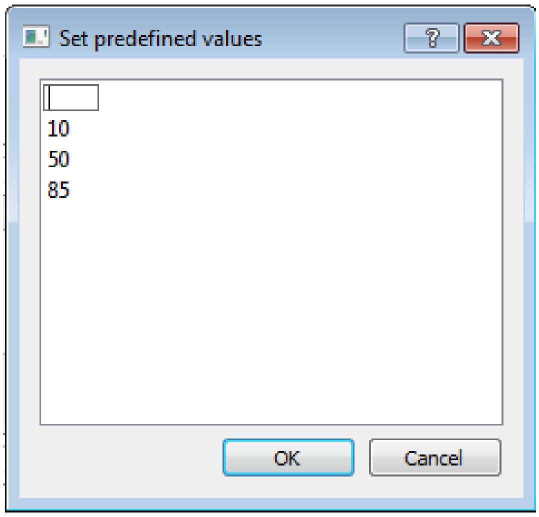


Figure 10. Dialog for adding and removing predefined values

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

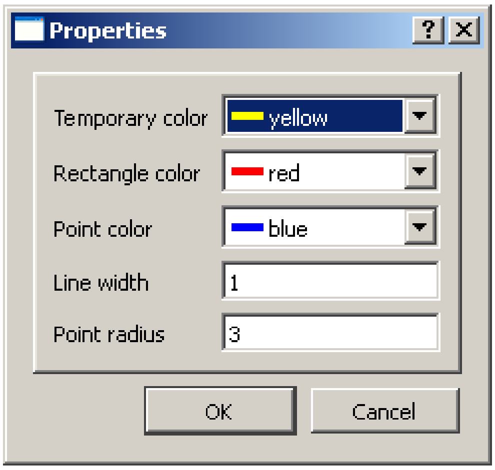


Figure 11. Dialog for setting options of the graphical display

PLOT TAB

Tab *Plot* is for plotting granulometry curves which are inputed in Input tab. Similarly, as in Input tab this tab is visually divided ova kartica je vizuelno divided on left side with tables and right side with graphical display, Figure 12.

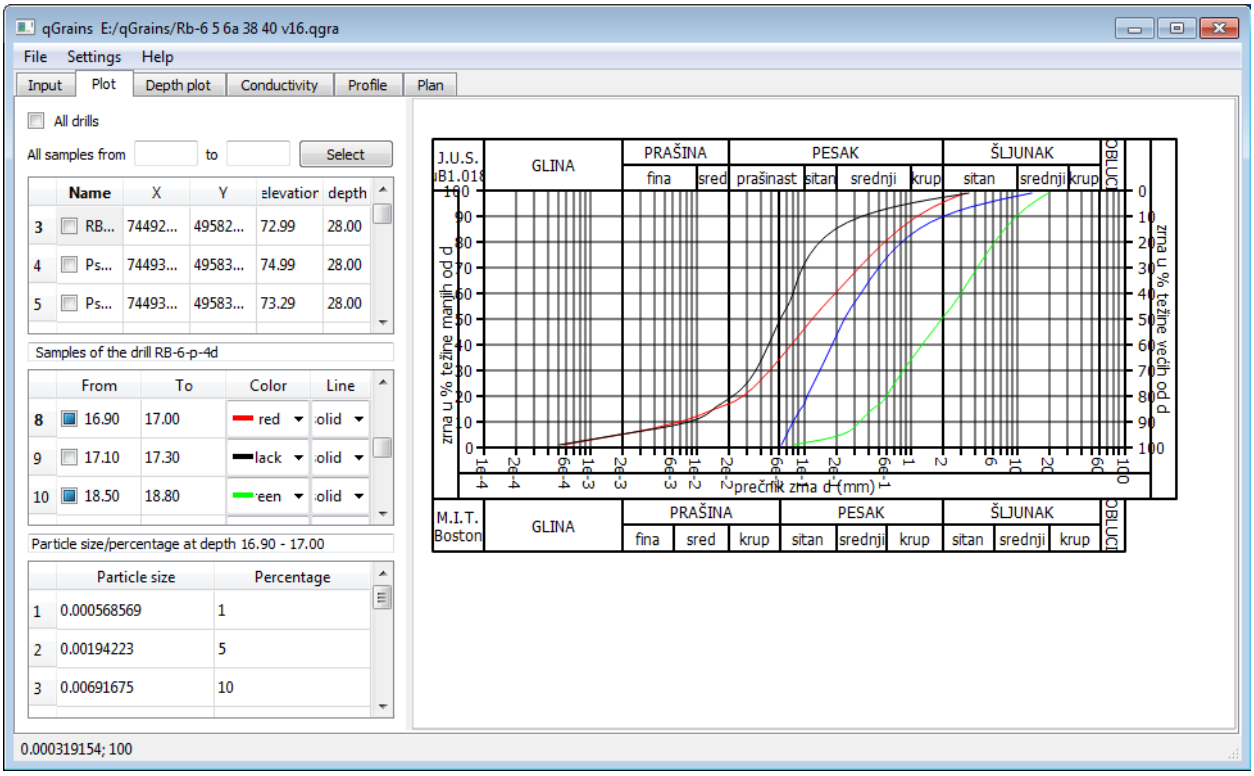


Figure 12. Plot tab

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 in the middle with samples, click on the sample activates table with grain size and percentage. Checking specific sample his granulometry curve is shown in the graphical display. For every sample we can choose color and line type of its granulometry curve. Checking specific drill all its samples are checked. Checking box *All drills* checks all drills, while unchecking unchecks all drills. Writting values in fields *From* and *To* and clicking on button *Select* checks all samples in all drills whose depths are in selected interval. Data in tables with drills and samples cannot be changed on this tab, but only on the Input tab. Right click on the left side invokes menu with option *Set samples as elev*, respectively is *Set samples as depth*, changes samples representation to elevation, respectively depth.

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

Remark: Litological classification according to grain size has two scales JUS (old Jugoslavian standard) and MIT standard.

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

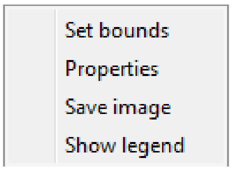


Figure 13. Menu obtained with right click onto graphical display on Plot tab

Click on option *Set bounds* activates dialog in which x-span and look of the frame is set

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

Click on *Save image* activate window for saving picture that is currently active on graphical display.

Click on *Show legend(Hide legend)* shows (or hide) legend.

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

Note that click on the drill name in the table shows its sample table, while checking 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* serves 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 previous tabs, both tab *Depth vs d* and *Depth vs %* are visually divided onto left side with tables and right side with graphical display.

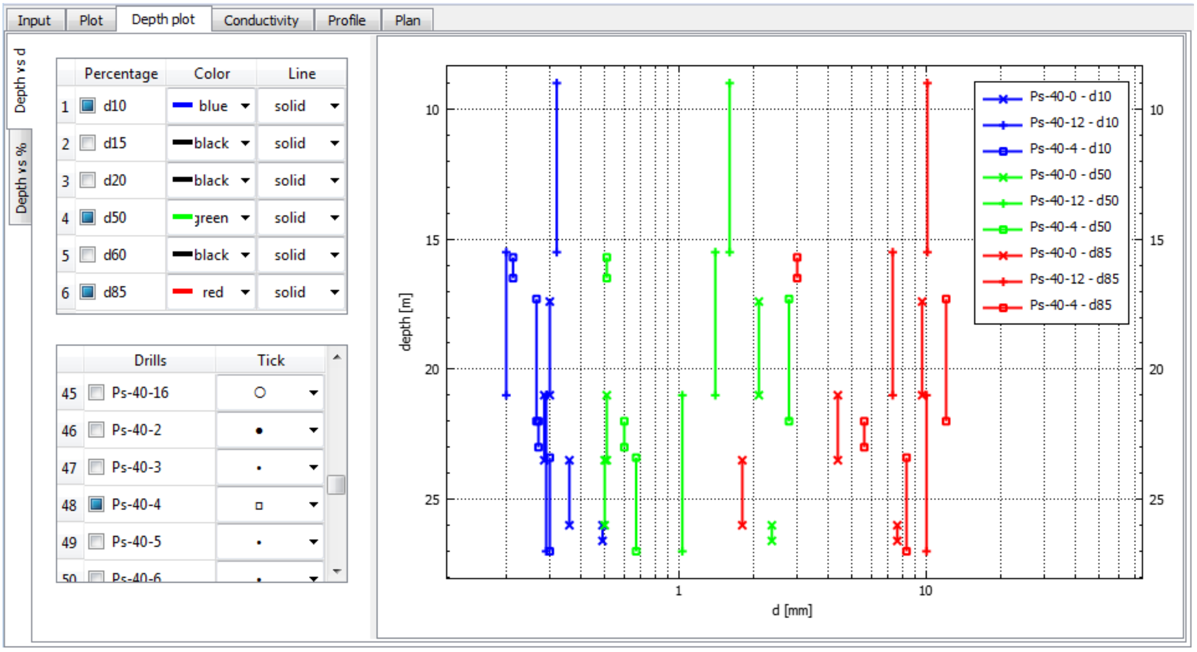


Figure 14. Depth plot tab

Depth vs d tab

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

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

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

(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 ploted because it is not „near" enough for d_{10} (10%± tolerance).

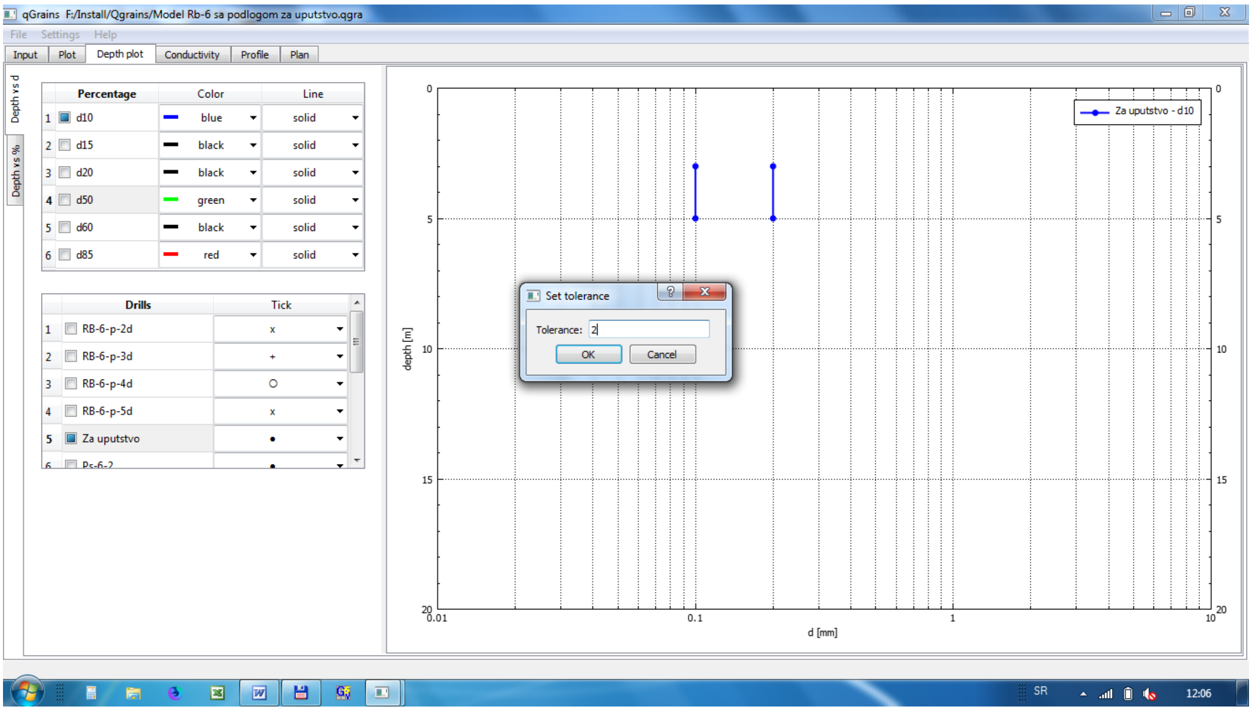
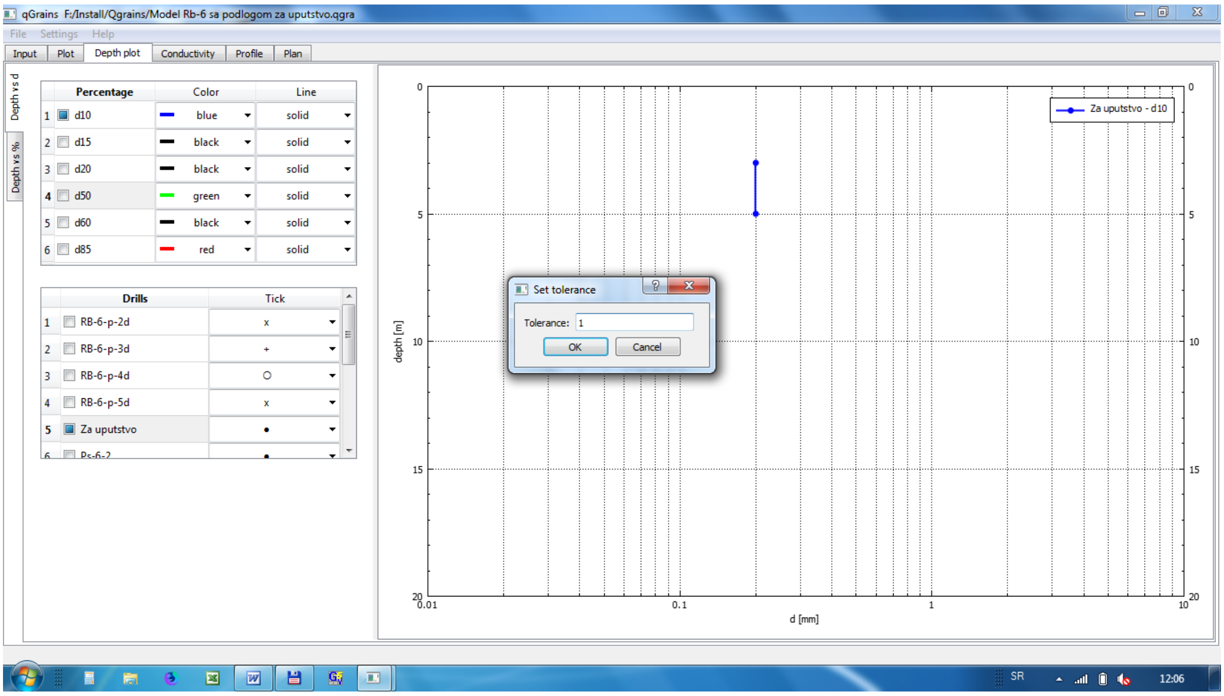


Figure 15. Example of inadequate tolerance (toelrance = 2)

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

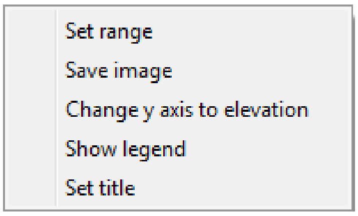


Slika 16. Plot for tolerance = 1

Lower table serves for choosing drills for which graphs of selected percentage will be ploted. Here we can also set ending points tick.

Remark: all samples from choosen drills are always shown.

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



Slika 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

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 (following logi *from to*). In this table, beside check box for choosing which grain size should be shown, we can also choose color and line type. Lower table serves for choosing drills which are going to be shown on the graphical display and also type of ending points tick type.

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 we enter in the upper table to show 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 is from 3 m to 5 m, Figure 18.

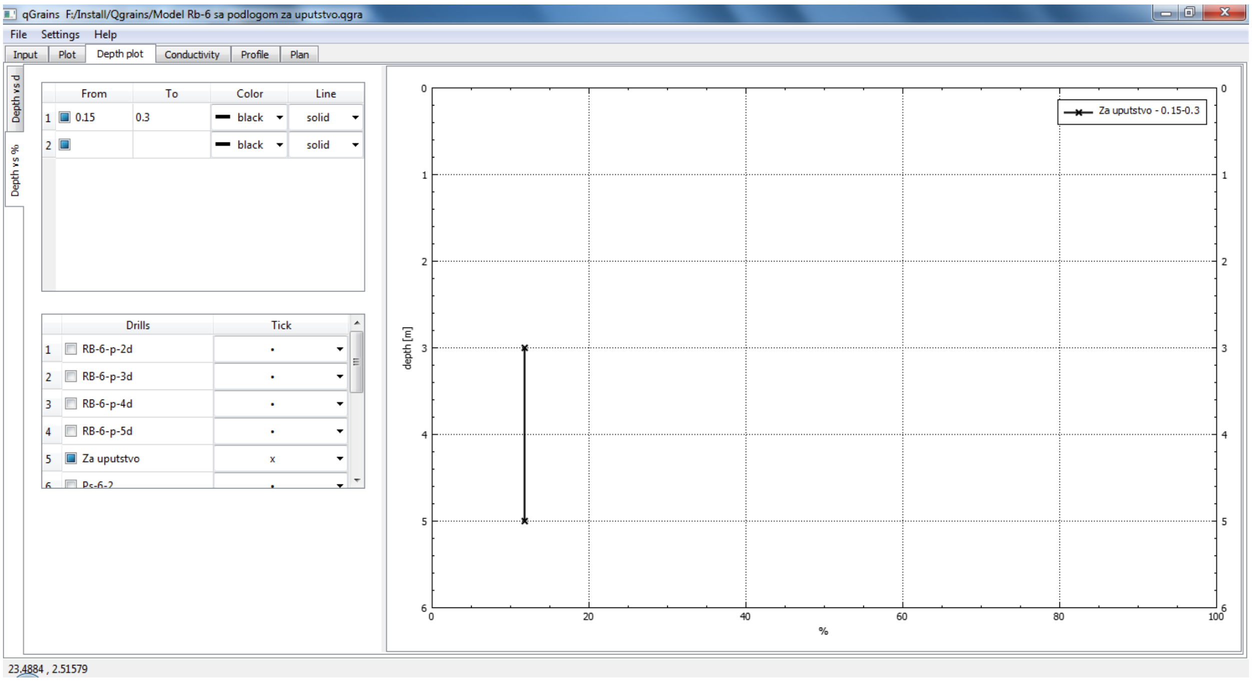


Figure 18. ***Depth vs %*** **tab**

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

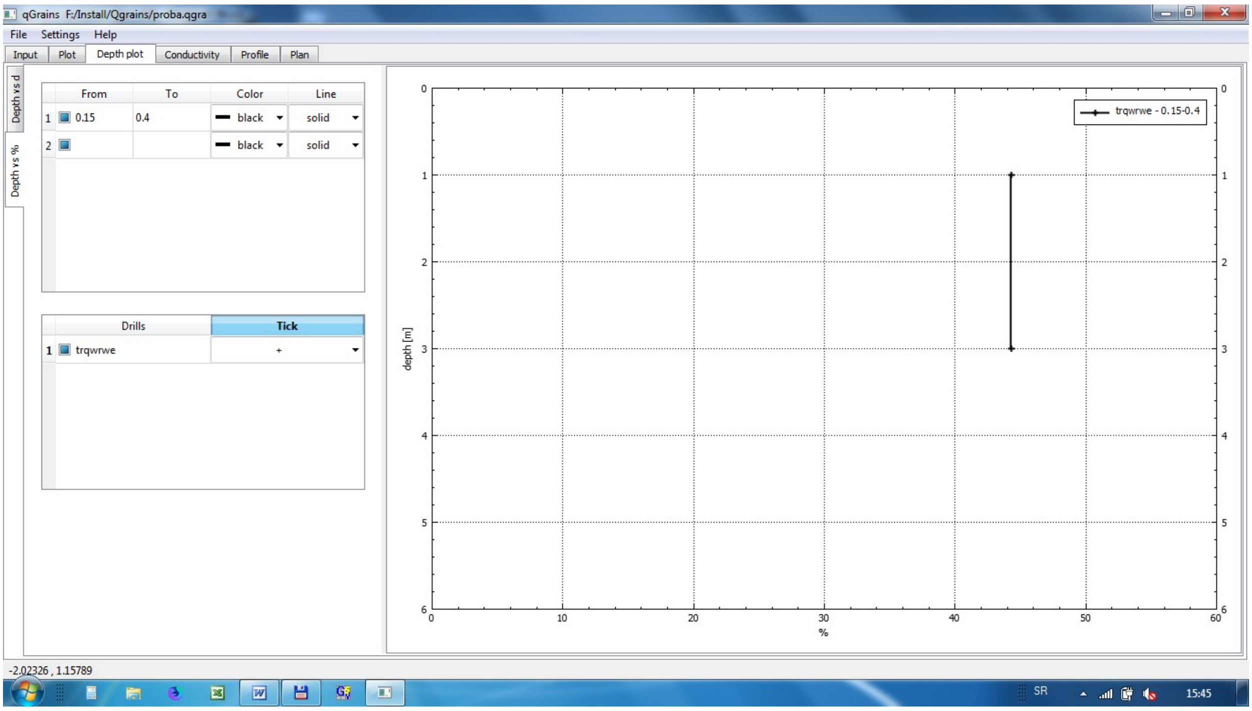
x=20% - 0% = 20%,

and y is from 3 m to 5 m of depth. Minus 0% in previous expression because smallest inputed point has grain size 0.15mm, and we are taking first point that is less or equal and if there is none such point we tke zero.

If we put in the upper table to show 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 is from 3 m to 5 m of depth, Figure 19. As we dont have procentage for grain size 0.4 mm, with linear interpolation from the closest points we have value 52.5%.

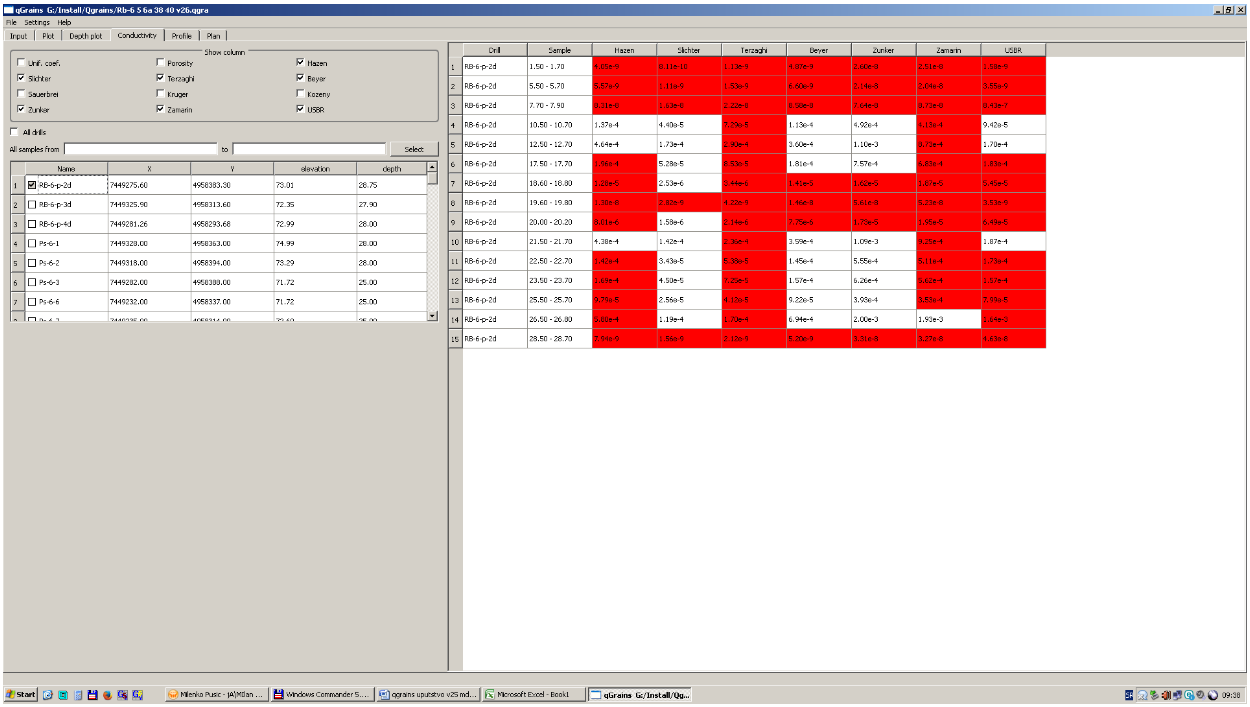


Slika 19. ***Depth vs %*** **tab**

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

CONDUCTIVITY TAB

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



Slika 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.

With red color are noted cells where author of the formula does not recomend using of his formula, based on the granulometry samlpe.

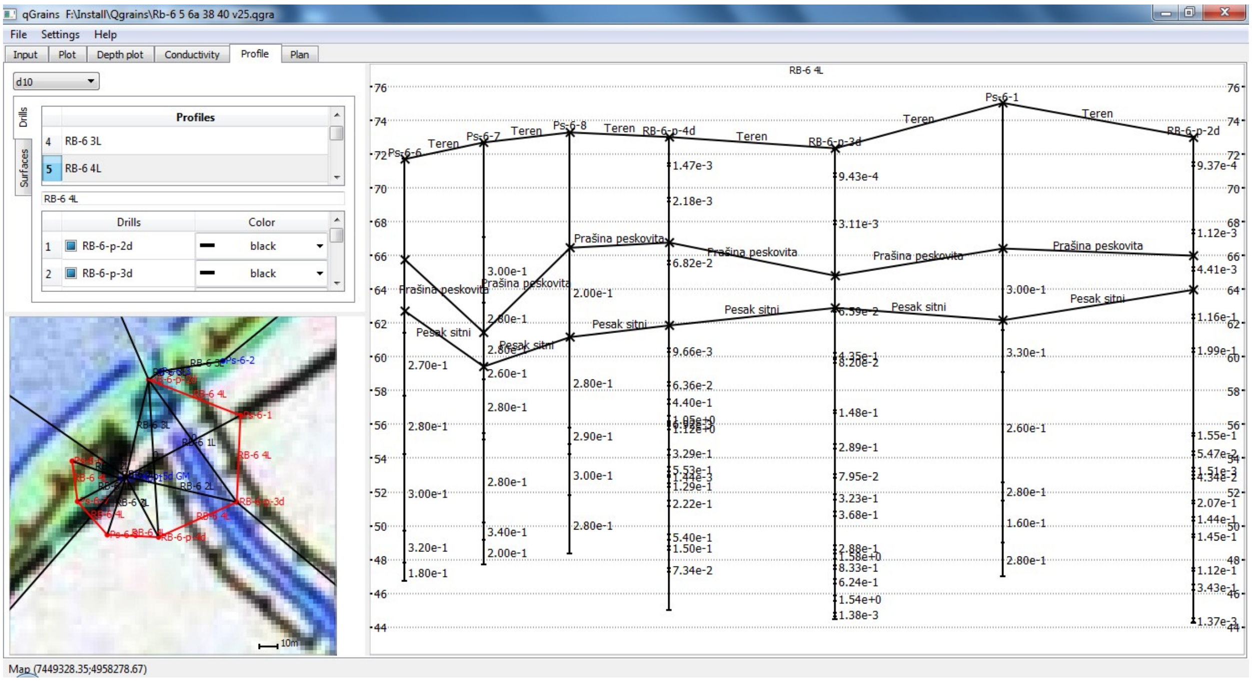
Results are shown in the table on the right side. Right click on this table gives option *export to csv.* This option saves data of this table in *.csv* file, suitable for use in Excel.

Remark: In *.csv* file we have hydraulic conductivity by all authors, no matter on choosing in qGrains.

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

PROFILE TAB

This tab, Figure 25, serves for graphical reprezentation of the given input and obtained results of material parameters along choosed profiles, and also for defining buondary contact surfaces between schematized layers and its visualization.



Slika 25. ***Profile*** **tab**

Profile consists of: combo box for choosing material parameter which will be shown, 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 shown we can choose amongs: 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 appears for entering interval for grain size. In this case 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. Right click invokes menu with option *Select all drils from profile XXX on Plot tab.* Click on that option all previously selected samples on Plot tab are deselected, and samples from all drills present in a selected profile are selected.

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

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

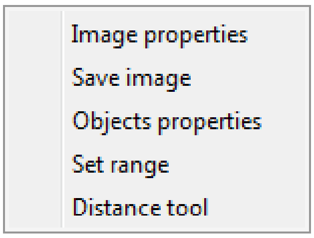


Figure 26. Menu that opens with right click on the map

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

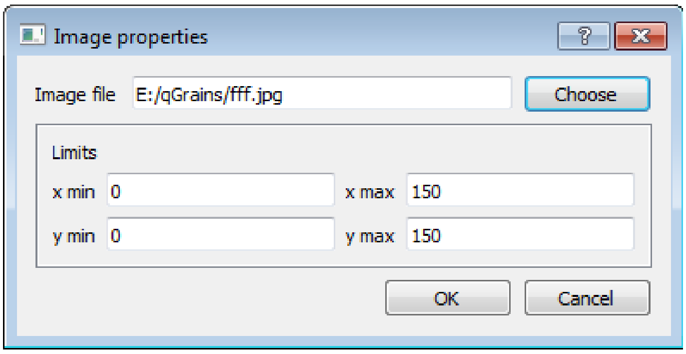
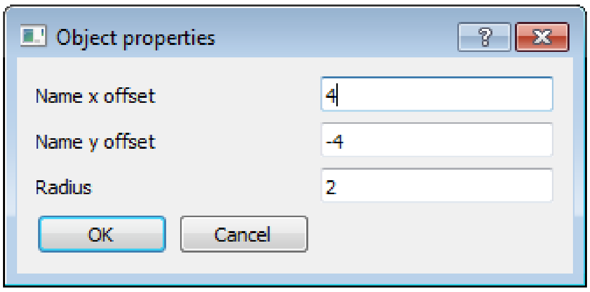


Figure 27. Dialog *Image properties*

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



Slika 28. *Object properties* dialog

In this 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 shown.

Click on *Distance tool* activates distance tool.

Double click inside the drill circle on the map, that drill is checked (or unchecked) in the table. Checked drills on the map is shown with red color, and uncheked are shown with blue color. Hoovering with 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 shown with black color and active profile is shown 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 shown, Figure 29. Also, on the graphical display choosen surfaces are also shown. Value of selected material parameter is grey colored if *d efective* is contradicting grain size recomended for using formula.

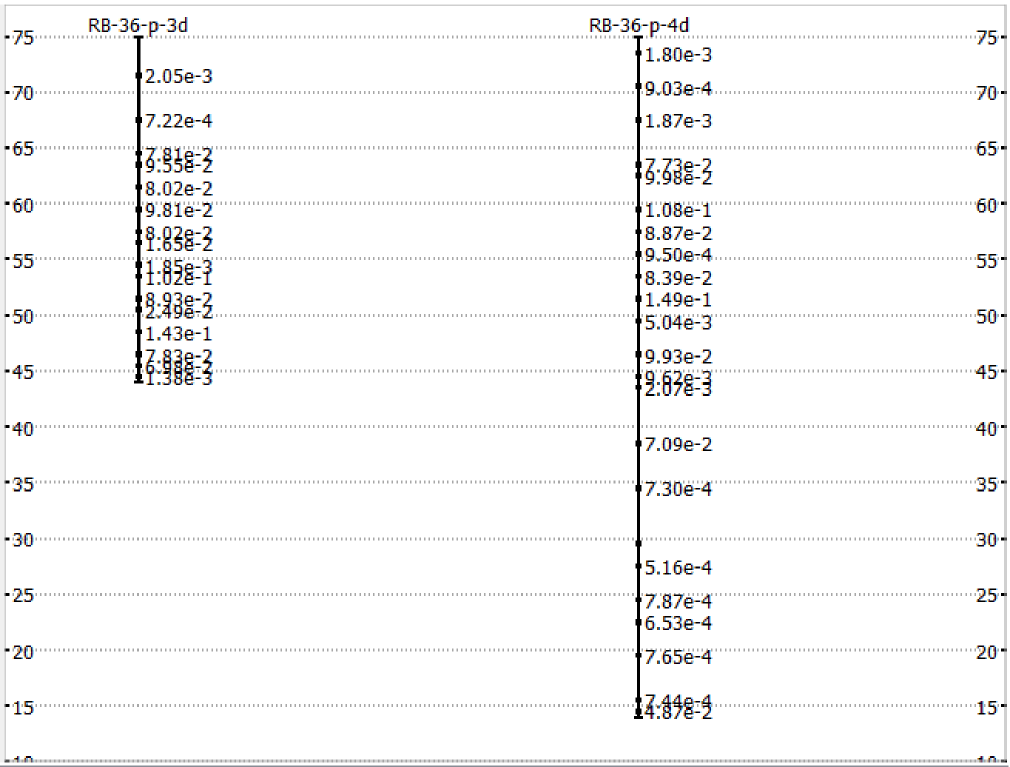
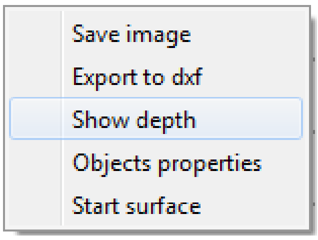


Figure 29. Example of drills on graphical display

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

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



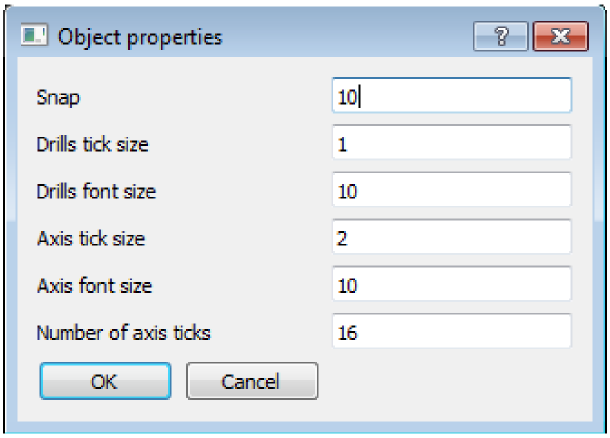
Figuere 30. Menu that is obtained by right clicking on graphical display on *Profile* tab

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.



Slika 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 inputed orderly on each of the drills that is inlcudede for showing in profile. On *Surface* tab name of the surface is automatically shown (at first as ordinal) 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 becames pink colored 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 with following procedure. Select surface that we want to delete and press *Delete* button on the keyboard. When surface is selected it is also possible to move points that are making it. We can add points to any surface with following procedure. Select desired surface and then right click on graphical display, on obtained menu (same as on Figure 30 with one more option *Add point to selected surface)* click on this additional option starts addition of new points.

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

PLAN TAB

This tab, Figure 32, serves for graphical displays on the terrain map of the material parameters for different depth intervals or selected surfaces. It contains part for choosing section or interval, part for choosing material parameter, part for choosing calculation domain for isolines, and 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 showing. For *depth* samples whose depth is between From and To are shown. For *elevation* samples whose heights are between From and To are shown.

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 shown. When there is more than sample in selected range we found their arithmetic mean and that is shown on the map. Value and name of the drill are shown 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.

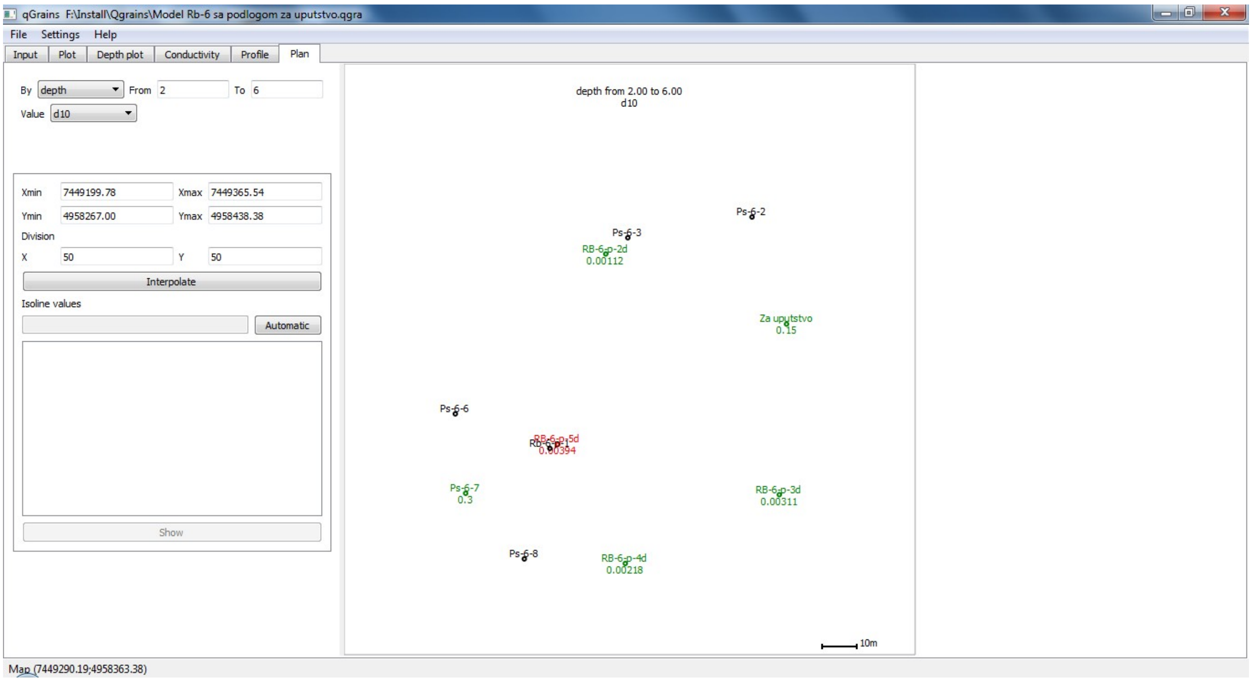


Figure 32. *Plan* tab

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. Heaights of the surfaces by the drills are shown on the map. Drill name is shown in black color if surface does not have value in that drill. Drill name and value are shown in green color if the surface has value in that drill.

If *thickness* is selected then two more combo boxes appears and on both we can choose surface previously defined on *Profile* tab.

Right click invokes menu (if *depth*, *elevation* or *thickness* are selected) *Select on Plot tab*. Click on that option all previously selected samples on Plot tab are deselected, and samples from all drills present between given depths, elevations or surfaces are selected on the Plot tab.

Whenever we change selection in *By* combo box map display is changed.

In the part for calculation of isolines it is necessary to input rectangele 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 whole domain.

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

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

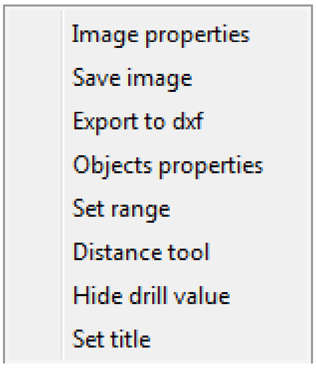
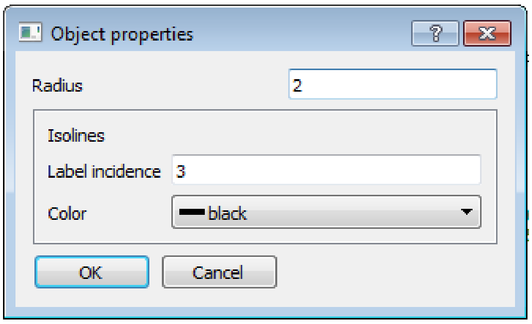


Figure 33. Menu that is obtained by right clicking on the map on Plan tab

Click on *Image properties* activates dialog as in Figure 27 and has the same purpose as it was 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 on Figure 34, where we can adjust drill radius size on the map, color of the isolines and also label incidence.



Slika 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. On the map besides title there are writen settings that are choosen.

THEORY

Hydraulic conductivity is the fundamental parameter for groundawater 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:

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 quotient 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 sortion, 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. Avereged fluid velocity is quotient of Darcy velocity and porosity.

From equations (2) we can see that fluid velocity is directly proportional to hydraulic conductivity, therefore error in estimation of hydraulic conductivity directly influence velocity and discarge precision. In nature, hydraulic conductivity of medium is non-uniformly distributed in space, this points out even more to 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, aim research, natural conditions and others limiting factors.

Methods that use empirical formulas and data of grains size distribution curves for hydraulic head estimation are advantegeous because they are easy and fast to use. Main flaw of these methods is representativity 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 san be seen as (Vukovic, Soro, 1991,1992):

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

where:

g – gravitation, $[LT^{-2}]$,

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

C – nondimensional coefficient, which depends on a number of parameters of porous medium (grain sortion, grain shape, petrography compound, heterogenity, etc.),

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

n – porosity, [-].

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

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

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

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

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

where:

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

η – uniformity coefficient, [-].

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

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

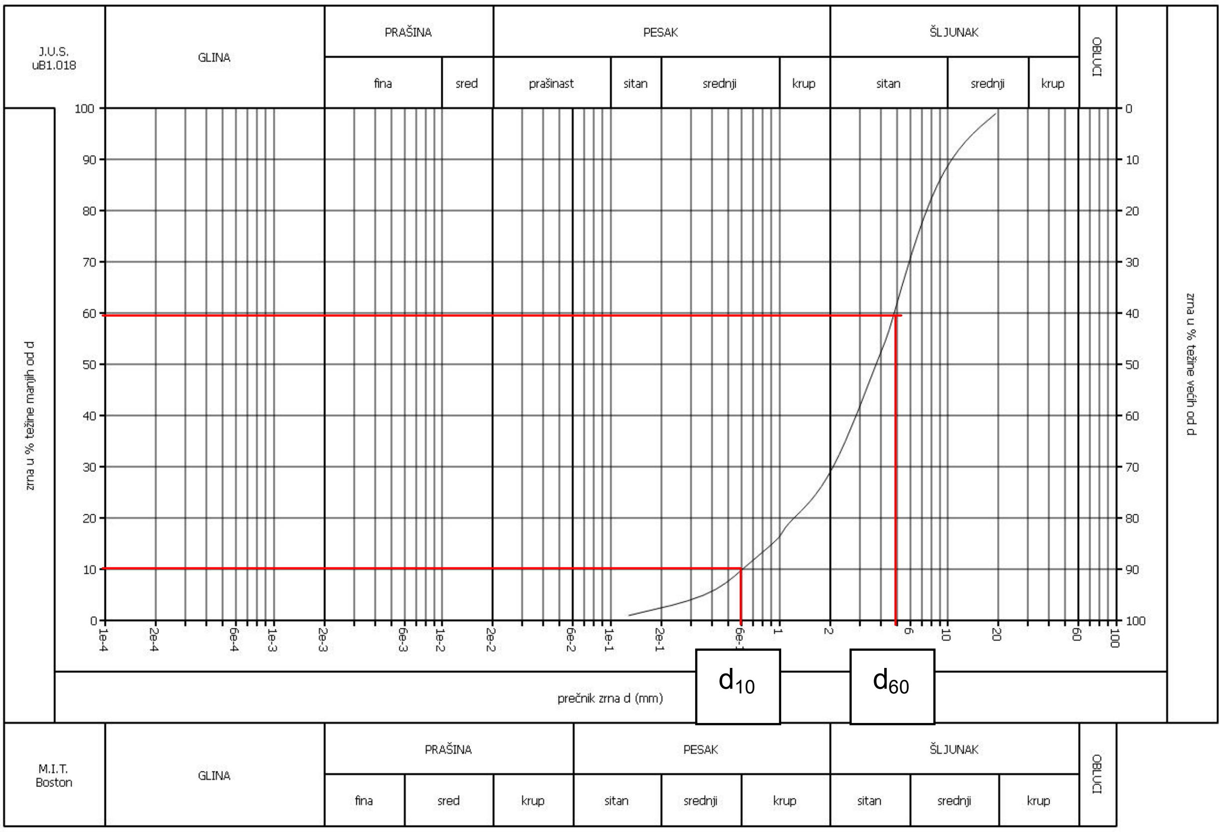


Figure 35. Granulometry curve and grains with 10% and 60% percentage

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

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

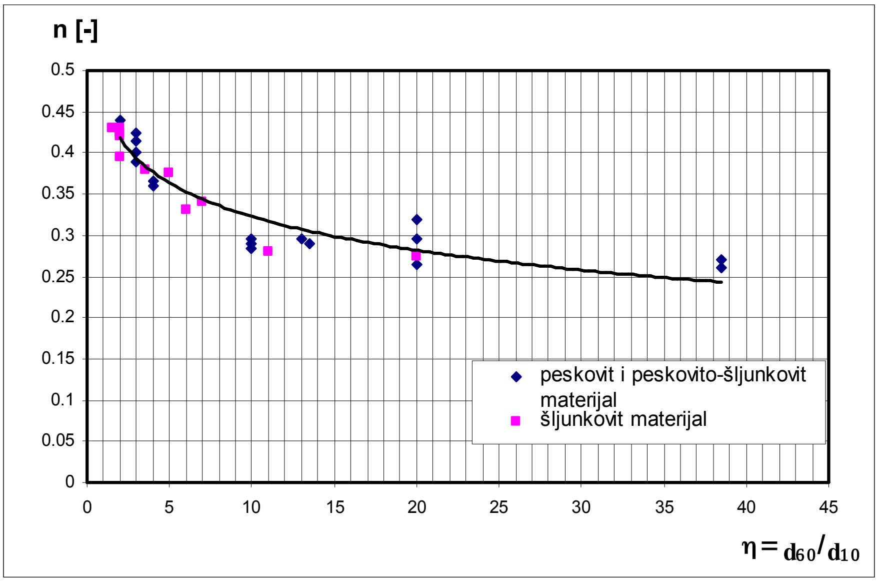


Figure 36. Dependance of porosity (*n*) from uniformity coefficient (*η*) (Istomina, 1957)

Based on Figure 2, we have formula for estimation of porosity from uniformity coefficient:

$$n = -0.059 \cdot \ln \eta + 0.4588 \tag{7}$$

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

In practice porous medium is composed of various sized grains, therefore there are differnt ways to define efective radius of grain size. Oftenly used are sizes which refers to 10%, 17% or 20% involvement on granulometry curve of porous medium (Vuković, Soro, 1991, 1992).

Note that in all formulas efective 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 labaratorical experiments with sandy samples. Their application is mainly limited with grain size. Some formulas are limited by the size of uniformity coefficients (Hazen, Bejer, Kriger, USBR). Constants given here are taken as recomendation from authors, or as median reprezentative values.

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

Tabela 1. Formulas for hydraulic conductivity estimation

	Autor	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	$K = 0.011 \cdot \frac{g}{\nu} \cdot n^{3.287} \cdot d_{10}^2$	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 $\eta < 5$

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