qGrains – Software for hydraulic conductivity estimation from granulometry

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Abstract—**Software qGrains is intended for estimation of hydraulic conductivity based on granulometry analysis of samples taken from exploration drills. Using qGrains, it is possible to make space classification, sistematization and schematization of sediments based on choosen percentage involvement or choosen grain-size. This is a usefull part of preparation for a higher level of hydrogeological interpretation, for example making hydrodinamical model.**

I. Introduction

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 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 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 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. Despite this well known limitations of hydraulic conductivity estimates from grain-size analyses, there are no simpler or more economical measurement-based techniques for obtaining it from aquifer samples.

Earliest attemp to relate hydraulic conductivity to grain size was a work published by Hazen [1] in 1892. Since that time, a large number of estimations have been developed. Review of 10 and 20, oftenly used estimations can be found in [2] and [3], respectively. Exhaustive review of 45 estimations can be found in [6].

There are a few software tools built over the empirical estimates of hydraulic conductivity from grain-size distribution curve [2, 4, 5]. Software qGrains is more than just a tool for hydraulic conductivity estimation, it is a complete application for granulometry analysis with graphical visualization over terrain map or over profile sections. It has no limitations on a number of drills or number of samples in a model.

Besides for estimation of hydraulic conductivity software qGrains can be used for space classification, sistematization and schematization of sediments based on choosen percentage involvement or choosen grain-size. This is a useful part in preparation of hydrodinamical model for a groundwater simulation softwares such as MODFLOW [7], FEFLOW [8], WODA[9], etc.

Software is developed in C++ using Qt framework and it is licensed under GNU General Public License version 3. Executable version for Windows systems as well as the code itself and user manual can be found on https://github.com/mdotlic/qGrains.

II. Theoretical background

Hydraulic conductivity is the fundamental parameter for groundwater flow computation. This parameter depends on porous medium but also on fluid, in this case water. It represents the ease with which fluid can move through pore space.

In accordance with [2], based on the laminar flow of groundwater, schematized with system of pipes with different radius, the general form of the relationship between hydraulic conductivity (K) and grain-size is expressed as

$$K=\frac{g}{\nu}N\varphi(n)d_e^2 ,$$

where g is the gravitational constant [LT^{-2}], ν is the kinematic viscosity of water [L^2T^{-1}], N is the non-dimensional coefficient, which depends on a number of parameters of porous medium, $\varphi(n)$ is the function that defines relation between real and schematized porous medium, n is the porosity [-], and d_e is an effective radius of grains in porous medium [L]. Porosity n is derived in [2] from the empirical relationship with the uniformity coefficient η as follows

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

where η is the uniformity non-dimensional coefficient and is given by:

$$K=d_{60}/d_{10} .$$

Values d_{60} and d_{10} represents grain diameter in millimeters for which, 60% and 10% of the sample respectively, are finer than.

The values of N, $\varphi(n)$ and d_e are dependent on the different methods used in the grain-size analysis. Complete formula for estimations can be found in Table I. All of these empirical formulas are to be used strictly within their domains of applicability [10].

TABLE I.
FORMULAS FOR HYDRAULIC CONDUCTIVITY ESTIMATION

	Author	Formula	Area of implementation
1.	Hazen	$K=6\cdot10^{-4}\cdot\frac{g}{v}\cdot[1+10(n-0.26)]\cdot d_{10}^2$	0.1 mm < d_{10} <3 mm $\eta=\frac{d_{60}}{d_{10}}<5$
2.	Slichter	$K=0.01\cdot\frac{g}{v}\cdot n^{3.287}\cdot d_{10}^2$	0.01 mm < d_{10} <5 mm
3.	Terzaghi	$K=0.008\cdot\frac{g}{v}\cdot\left(\frac{n-0.13}{\sqrt[3]{1-n}}\right)^2\cdot d_{10}^2$	1 mm < d_{10} <2 mm
4.	Beyer	$K=6\cdot10^{-4}\cdot\frac{g}{v}\cdot\log\frac{500}{\eta}\cdot d_{10}^2$	0.06 mm < d_{10} <0.6 mm $1<\eta<20$
5.	Sauerbrei	$K=0.00375\cdot\frac{g}{v}\cdot\frac{n^3}{(1-n)^2}\cdot d_{17}^2$	d_{17} <0.5 mm
6.	Kruger	$K=4.35\cdot10^{-5}\cdot\frac{g}{v}\cdot\frac{n}{(1-n)^2}\cdot d_{ef}^2$	0.2 mm < d_{ef} <1 mm $\eta>5$
7.	Kozeny	$K=0.0083\cdot\frac{g}{v}\cdot\frac{n^3}{(1-n)^2}\cdot d_{ef}^2$	1 mm < d_{ef} <2 mm
8.	Zunker	$K=0.002\cdot\frac{g}{v}\cdot\left(\frac{n}{1-n}\right)^2\cdot d_{ef}^2$	0.1 mm < d_{ef} <1 mm
9.	Zamarin	$K=0.0082\cdot\frac{g}{v}\cdot\frac{n^3}{(1-n)^2}\cdot(1.275-1.5\cdot n)\cdot d_{ef}^2$	1 mm < d_{ef} <2 mm
10.	USBR	$K=4.8\cdot10^{-4}\cdot\frac{g}{v}\cdot d_{20}^{2.3}$	0.2 mm < d_{ef} <1 mm $\eta<5$

The empirical formulas for hydraulic conductivity estimation are mainly derived from laboratory experiments with sandy samples. Their application is mainly limited with a grain-size. Formulas used in qGrains are taken from [2].

III. SOFTWARE DETAILS

Software qGrains is a standard Windows application. Main window (Figure 1.) consists of a title bar, a menu bar, tabs and status bar.

There are six main tabs in the application: *Input, Plot, Depth plot, Conductivity, Profile, Plan*.

Input tab serves for inputing data related to drills and samples. Data can be inputed using tables or through graphical part through digitalization of scanned data.

Plot tab is used for plotting granulometric curves which are inputed in the Input tab. Granulometric curves can have different colors or line style and only selected ones appear on the graphical display of this tab. Graphical display allows zooming and dragging and has a painted frame. Frame limits, language, line thickness or color can

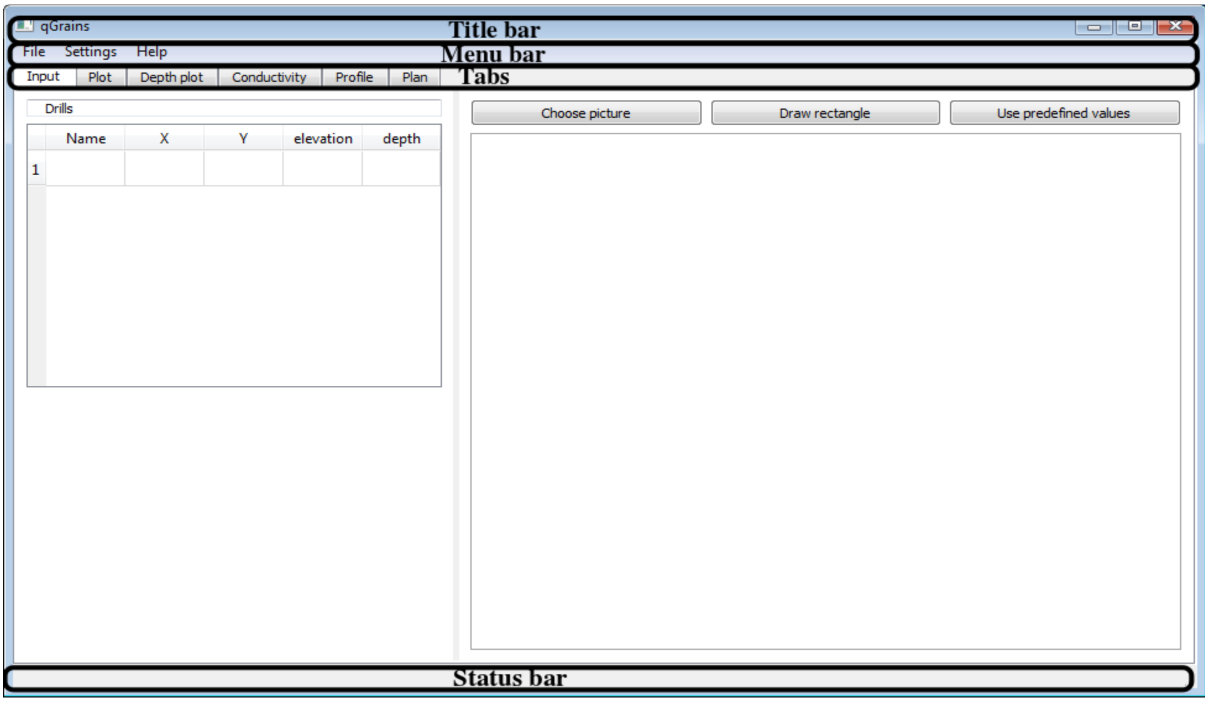

Figure 1. qGrains main window

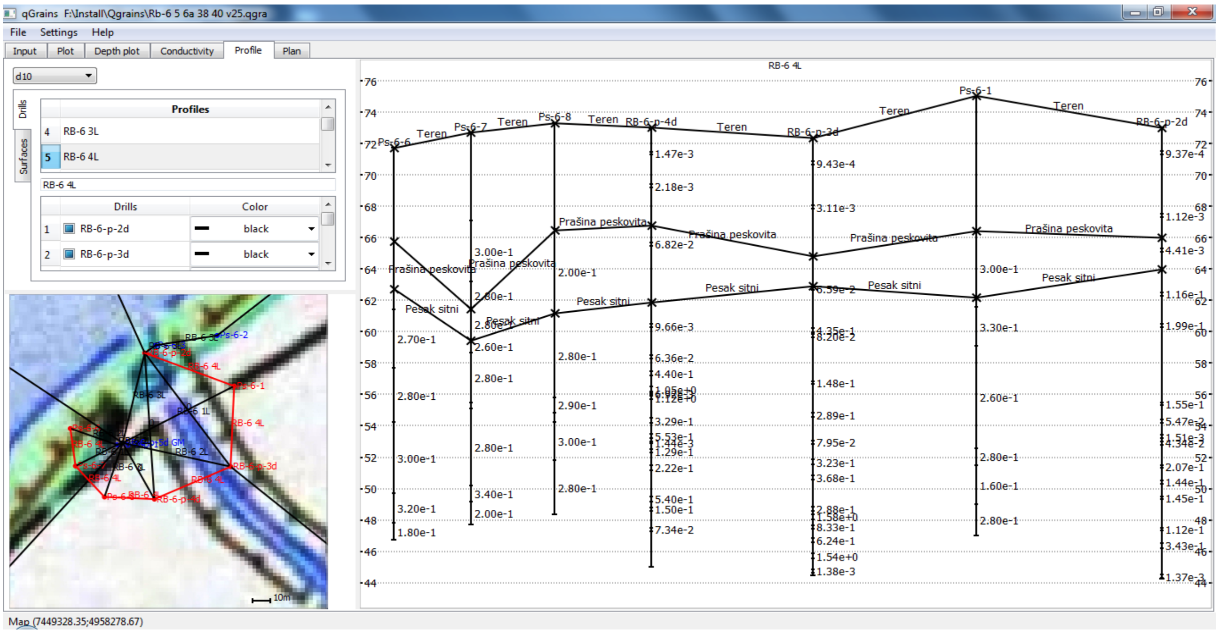

Figure 2. Profile tab

be changed. Frame admits two lithological classification based on grain size: JUS (old Yugoslavian standard) and MIT standard. When hovering mouse over graphical display the status bar shows values of grain size and percentage involvement.

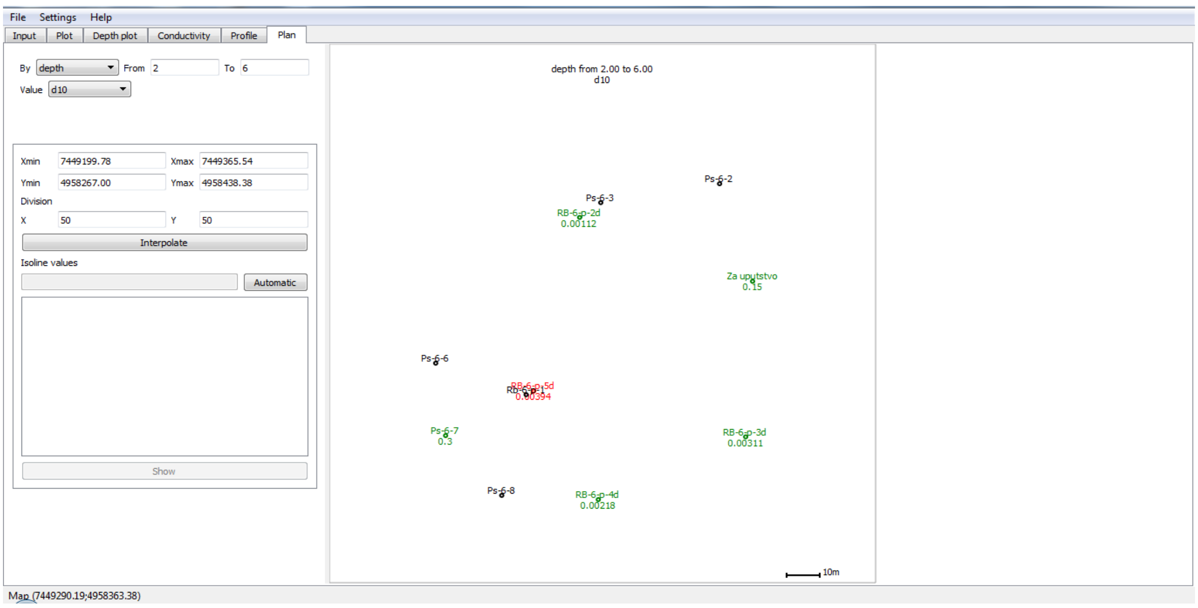

Figure 3. Plan tab

Depth plot has two vertically aligned tabs: *Depth vs d* and *Depth vs %*. Tab Depth vs d is used for plotting graphs of depth (or elevation) relative to grain size. Tab Depth vs % serves for plotting graph of depth (or elevation) relative to percentage. We can change color or line type for a certain percentage involvement and grain size respectively for *Depth vs d* and *Depth vs %.*

Conductivity tab is used for estimation of porosity, coefficient of uniformity, and hydraulic conductivity. Only values for selected samples and selected author formulas are shown in the table. If the are of implementation is not satisfied the cell background color is highlighted to red.

Profile tab serves for graphical representation of the given input and obtained results of the material parameters along chosen profiles, which can be costume defined (Figure 2.). Also, this tab is used for defining boundary contact surfaces between schematized layers and its visualization. Custom profiles on this tab are defined on the georeferenced map.

Plan tab is used for graphical display terrain map with the material parameters for different depth intervals or selected surfaces. On this tab we can calculate isolines of material parameters and display it in graphical part. Terain map is georeferenced and can be imported from some .jpg file. This tab and Profile tab represents the main strength of the qGrains.

Generally, graphical displays in all tabs allows zooming and dragging, and also saving pictures in .jpg file format or in some cases .dxf file format (AutoCAD file format).

IV. Conclusion

Granulometry analysis offer a convenient and low-cost means of acquiring preliminary estimates of hydraulic conductivity. Software qGrains works with 10 mostly used estimates of hydraulic conductivity. Code architecture allows an easy expansion with others estimates.

Software qGrains besides estimation of the hydraulic conductivity allows complex analysis, interpretation and visualization of the grain-size composition taken from the drill samples. It represents a convenient tool for data preparation of hydrodinamical models.

Software qGrains is C++/Qt desktop application with code, documentation, and also Windows executable freely available at https://github.com/mdotlic/qGrains.

Acknowledgment

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