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Comparison between direct measurements and indirect estimations of hydraulic conductivity for slope deposits of the North-Western Tuscany, Italy

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INTRODUCTION

Hydraulic conductivity (**K**) is a relevant engineering geology property of deposits (**Slope Deposits – SD**, Fig. 1) that cover the geological bedrock. This parameter is useful for many applications fields such as: simulations of both infiltration and runoff processes, hillslope stability numerical analysis, hydrological studies, etc. Objective of this work is to asses the **spatial variability** of K in vadose zone: along SD depth and in the geographic neighbourhood of the test site, for SD characterized by **different grain size** composition and different **geological bedrock**. Then a comparison between different methodologies of measurement of K have been performed, at last a statistical comparison between measured and estimated values of K has been done in order to assess the reliability of different equations to predict K.

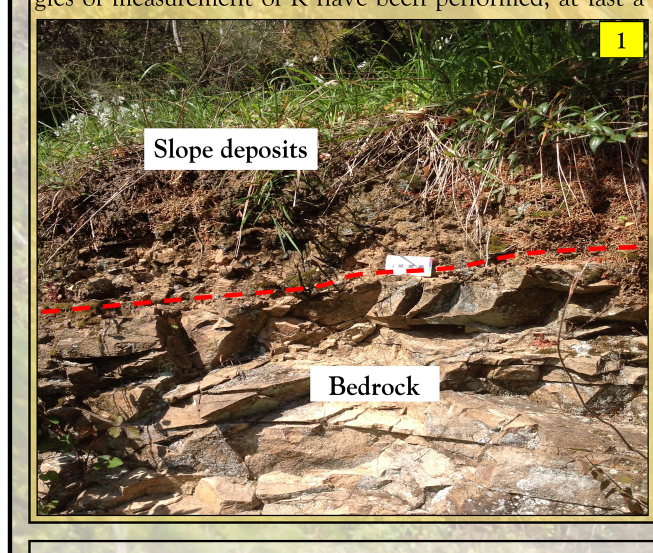


Figure 1. Slope deposits and geologic bedrock (Arenaceous-silty flysch Unit).

MATERIALS AND METHODS

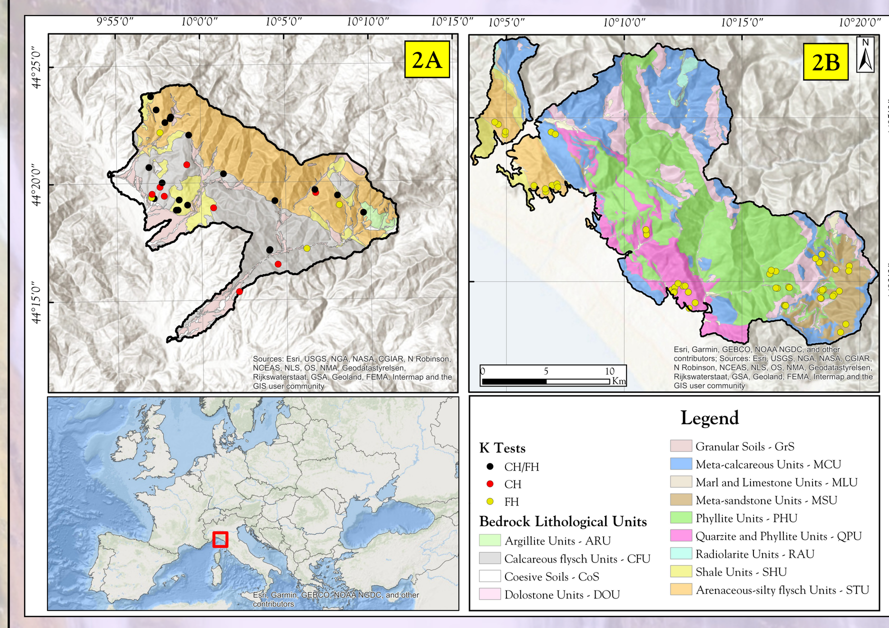


Figure 2. Bedrock lithological units (Disperati et al. 2013, 2018) of the study areas (2A and 2B). CH, FH and CH/FH represent hydraulic conductivity field tests where constant head, falling head and both methods respectively have been performed.

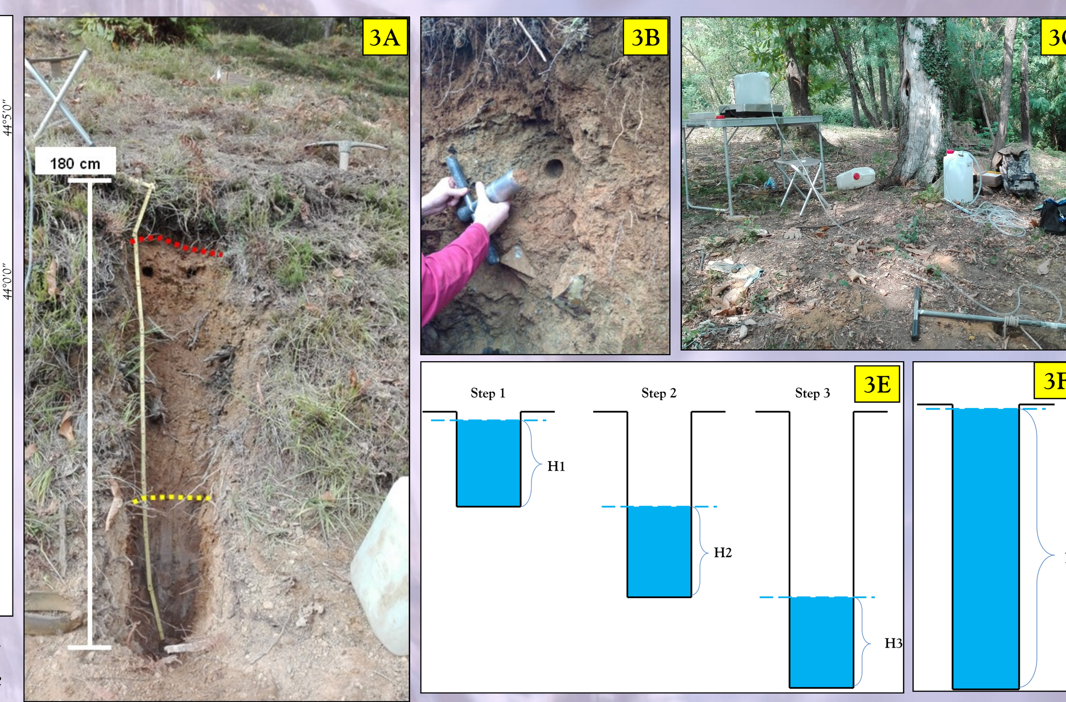


Figure 3. Field survey of SD: profile of SD (A), sampling of bulk density of SD (B), Ktests by means of constant (C) and falling head (D) permeameter, configuration of Ktests: steps of increasing borehole depth (E) and single borehole depth (F).

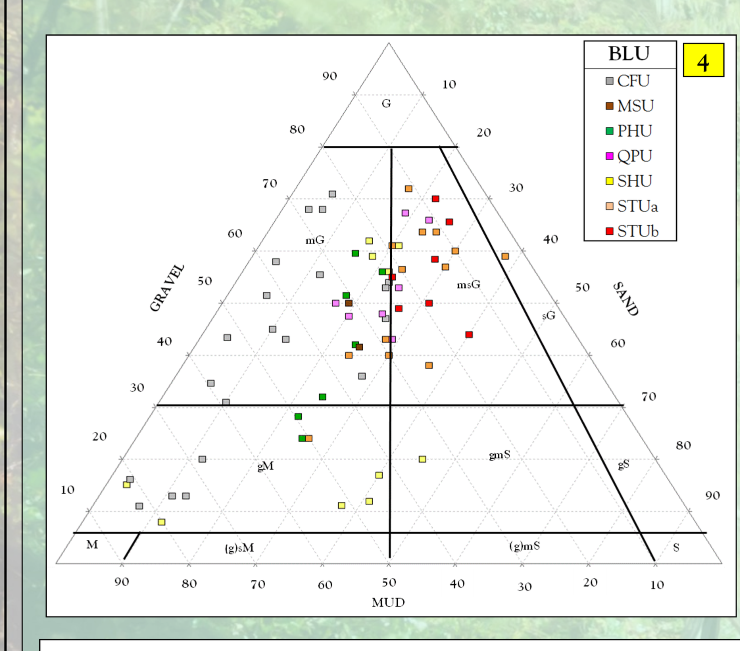
Field survey has been carried out in North-Western Tuscany (Italy) in study areas (Fig. 2A and 2B). For each test site, the following data were collected:

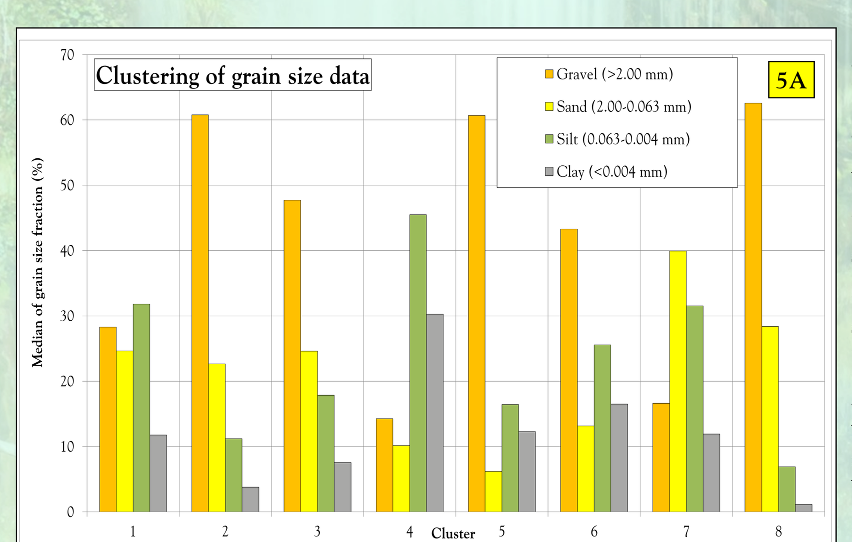
- engineering-geology **profile** of SD (Fig. 3A, **depth** of SD and horizons), estimation of texture and structure;
- sampling for lab analysis: bulk density (Fig. 3B), grain size, Atterberg limits and specific gravity of solids;
- two or more boreholes have been realized close to the SD profile in order to perform hydraulic conductivity tests (Ktests).

A total of **84** measurements sites and **350** Ktests have been performed by means of constant (USBR 7300-89 - Fig. 3C) and/or falling head permeameter (Hvorslev, 1951 - Fig. 3D). Ktests have been performed at increasing depth by successive steps (Fig. 3E) in order to evaluate variation of K along depth, then a test has been conducted for the entire depth of the borehole (Fig. 3F).

RESULTS

1) K-means clustering of grain size data and related hydraulic conductivity





For different bedrock lithological units (BLU), 67 samples (Gsamples) allowed us to obtain grain size information (Fig. 4 - Folk, 1960).

Using **K-means** clustering (MacQueen, 1967), particle size distribution curves have been classified into 8 clusters by using gravel, sand, silt and d10 (grain diameter at 10% passing) as input variables. Fig. 5A shows median of gravel, sand, silt and clay fractions of each cluster.

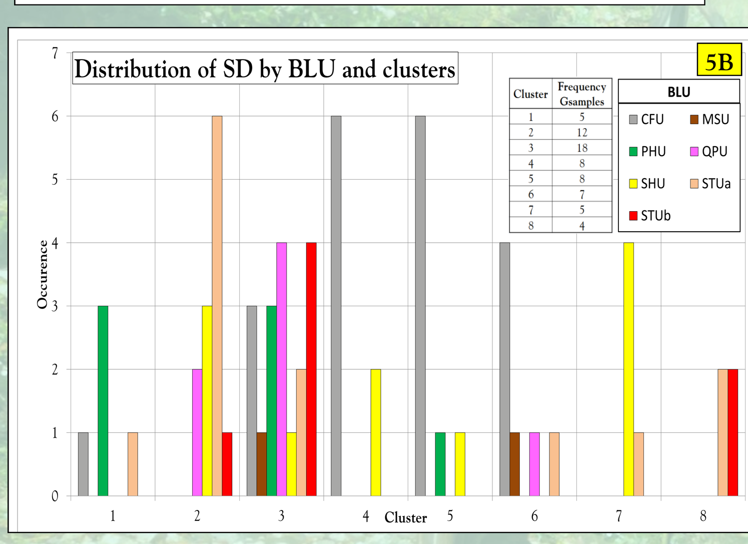
Distribution of BLU of SD of each cluster is reported in Fig. 5B.

Among the 350 Ktests we selected for analysis a **subset** of Ktests fulfilling the following conditions:

a) **lowest distances** from SD profile;

b) K measuring depth performed **close** to Gsamples depth.

Box plots of K for the subset is shown in Fig. 5C for each cluster.



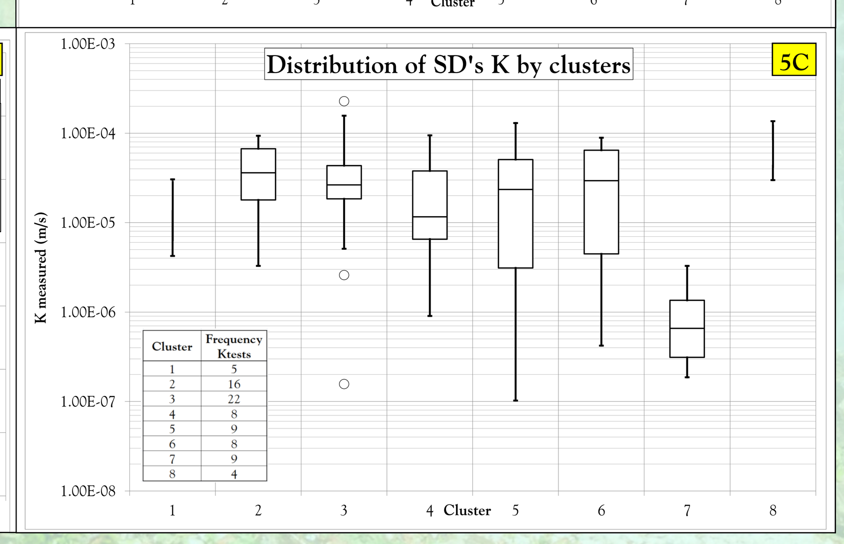


Figure 4. Folk diagram of samples; BLU refer to Fig. 2 with "STUa" and "STUb" representing Arenaceous-silty flysch Unit (STU) of Fig. 2A and 2B respectively.

Figure 5. (A) Median of grain size fraction of Gsamples by clusters; (B) distribution of SD by clusters and relative frequency; (C) box-plot of K and frequency of Ktests by clusters: dots represent outliers; only plots for cluster with Ktests ≥ 6 are reported (for clusters 1 and 8 only K min and max are shown).

2) Constant vs. Falling Head Permeameter

31 Ktests (for 19 test sites) have been performed by means of **both constant** and **falling** head permeameter in order to compare results. Fig. 6 shows scatter plot of K values by different BLU. Statistical comparison is calculated in terms of Geometric Mean Error Ratio (**GMER**) and Geometric Standard Deviation of Error Ratio (**GSDER**, Tietje and Hennings, 1996):

$$\varepsilon_i = \frac{K_p}{K_m}$$

$$GMER = \exp\left(\frac{1}{n}\sum_{i=1}^{n} \ln \varepsilon_i\right)$$

$$GSDER = \exp\left\{\left[\frac{1}{n-1}\sum_{i=1}^{n}\left(\ln \varepsilon_i - \ln GMER\right)^2\right]^{\frac{1}{2}}\right\}$$

- *Km* and *Kp* are measured and predicted hydraulic conductivity. In this case *Km* and *Kp* corresponds to K values obtained by falling and constant head permeameter respectively.
- n is number of data.

Values of GMER and GSDER indicate an overstimation of K obtained by constant head permeameter of about a factor 2 in respect to ones obtained by falling head permeameter.

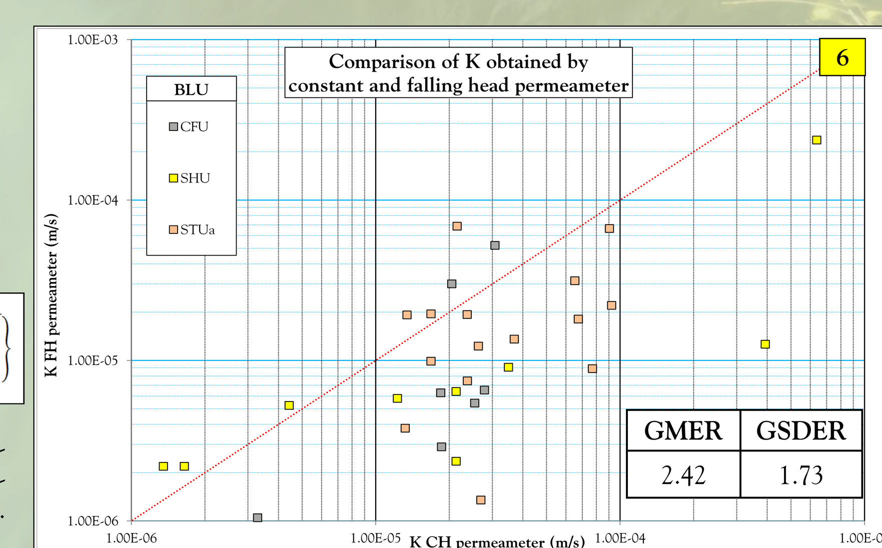


Figure 6. Comparison between K obtained by means of constant (K CH) and falling head (K FH) permeameter within same boreholes. GMER and GSDER follow Tietje and Hennings (1996). Red line represents perfect match.

3) Neighborhood variability of K

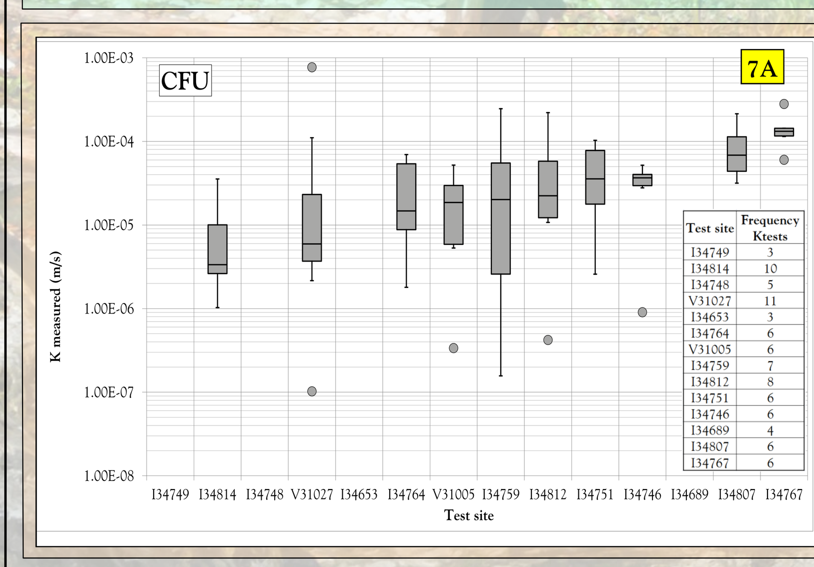
For each test site, Ktests have been performed within boreholes close to the SD profile in order to analyze local variability of K. Ktests have been also realized at different depths to detect variations.

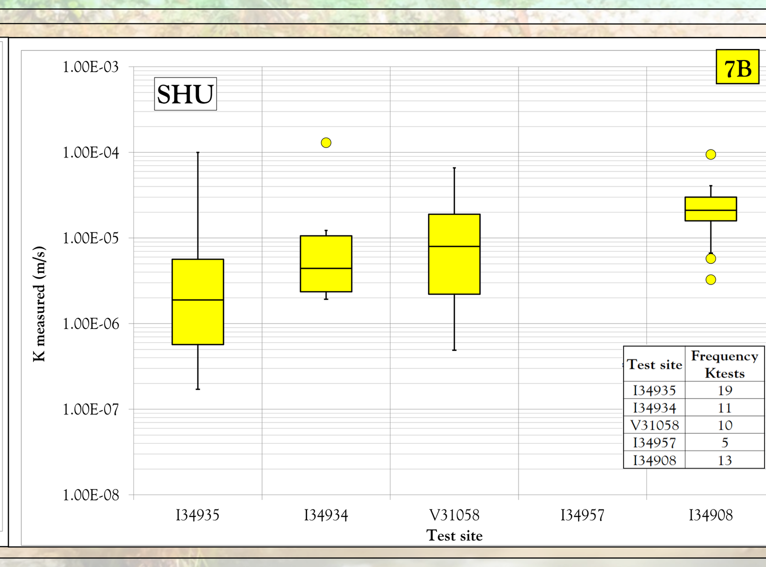
Fig. 7 shows box-plots of K for each test site for three BLU: CFU (Fig. 7A), SHU (Fig. 7B) and STUa (Fig. 7C).

The Modified Interquatile Ranges (MIR) has been calculated, in order to better identify the variability of K for each test site, as follows:

MIR = (ln Q3—ln Q1) *10

where Q1 and Q3 represent first and third quartile respectively (Fig. 8).





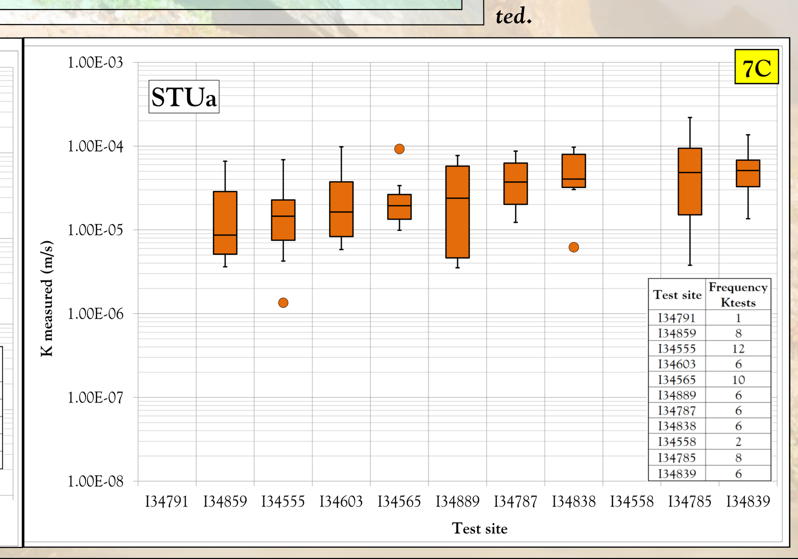


Figure 7. Box plots of K for test sites. Dots are outliers; only plots for sites with ≥ 6 measurements are reported.

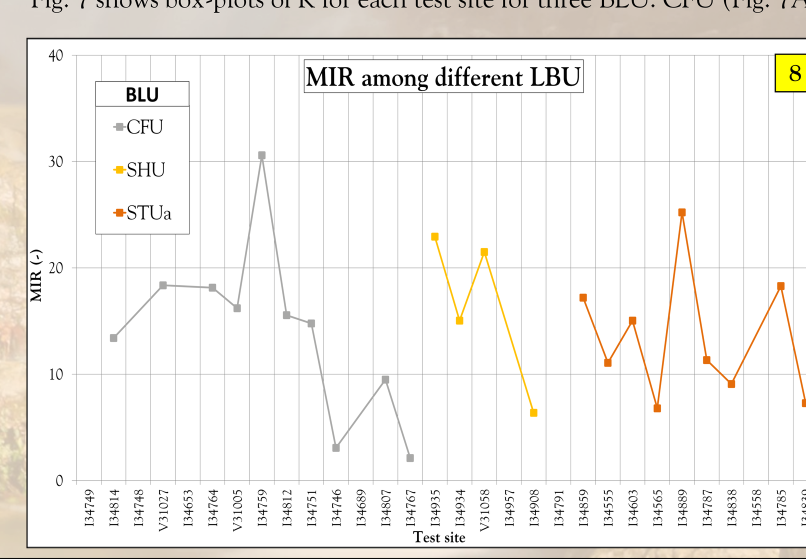
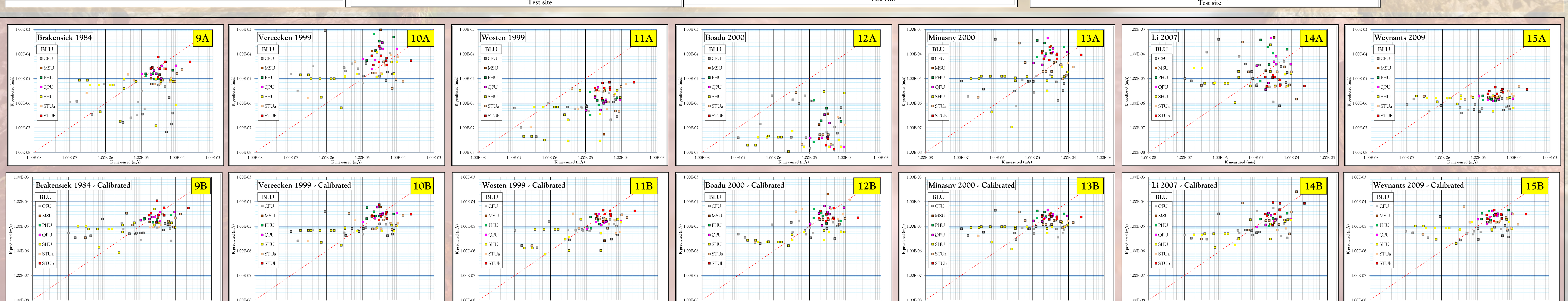
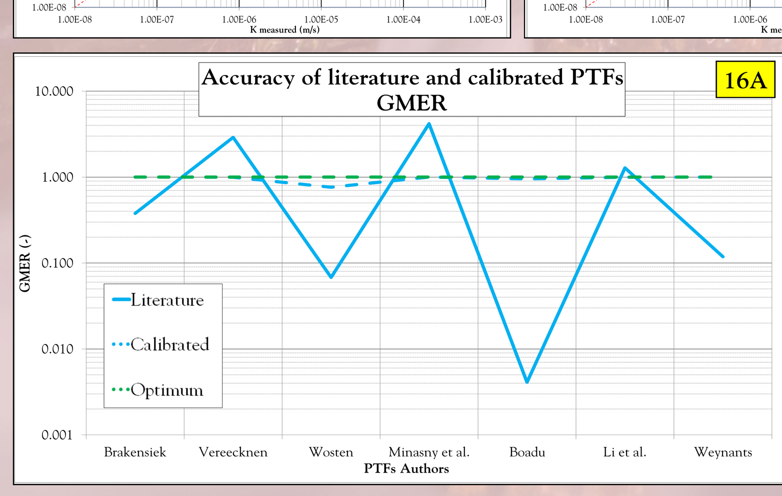
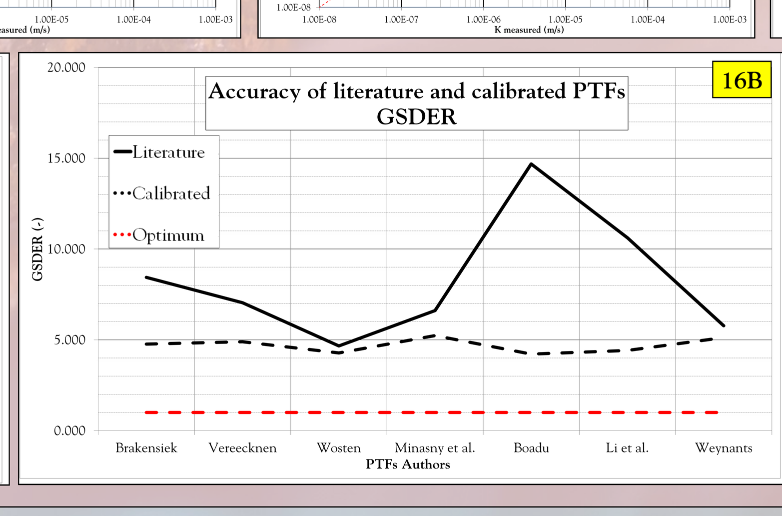


Figure 8. Modified interquatile ranges for same test sites of Fig. 7.







Figures 9 to 15. Comparison bewteen measured K and K obtained by:
A) literature pedotransfer functions;
B) calibrated PTFs.
Red line represents perfect match.

Figure 16. GMER (A) and GSDER (B) related to literature and calibrated PTFs of Figs. 9 to 15.

4) Comparison bewteen literature and calibrated PTFs

Seven pedotransfer functions (PTFs, Brakensiek et al., 1984; Vereecken et al., 1990; Wosten et al., 1999; Boadu, 2000; Minansy et al., 2000; Li et al. 2007; Weynants et al., 2009) that establish an empirical relationship among K and other soil properties such as particle size distribuion, porosity, bulk density, organic matter, etc. have been applied to evaluate the reliability of PTFs to predict K (Figs. 8A to 15A).

Then PTFs have been calibrated by using an automatic calibration algorithm, SCE-UA (Shuffled Complex Evolution method University of Arizona, Duan et al., 1993; Abdelbaki, 2015) in order to optimize the performance of PTFs. This algorithm changes and adjusts the coefficients of original PTFs, not the form of the equation, in order to get best matching bewteen predicted and measured K by calculating for each set of coefficients the objective function:

$$Objective\ Function = \sqrt{(1-GMER)^2 + (1-GSDER)^2}$$

Calibration process stops when the algorithm reaches the minimum value of objective function. New coefficients have been implemented in the calibrated PTFs (Figs. 8B to 15B). For each PTFs, GMER and GSDER have beeen calculated (Figs. 16A-B) in order to evaluate the accuracy of literature and calibrated PTFs to predict K.

CONCLUSIONS

1. Textural classes of Gsamples are mostly muddy gravel (mG), gravelly mud (gM) and muddy sandy gravel (msG, Fig. 4). Different textural classes have been identified by clustering (Fig. 5A). SD of the considered lithological bedrock units (BLU) spread with different fractions among clusters. CFU mostly falls within clusters 4,5,6; instead STUa and STUb fall within clusters 2,3,8; suggesting an effective control of bedrock on engineering geology properties of SD.
2. K varies within 3 order of magnitude (10^{-4}-10^{-7} m/s), anyway, considering the interquatile ranges, most of the data fall between ~$5x10^{-5}$-$5x10^{-6}$ m/s for clusters 2-6; instead K ranges between ~$5x10^{-7}$-10^{-6} m/s for cluster 7, which is mostly made up of sand+mud.
3. Independently of BLU and grain size composition, K obtained by constant head permeameter is about 2 times higher than K by falling head permeameter.
4. K and BLU appear to be roughly correlated. Considering the interquartile ranges, $5x10^{-6}<K_{STU}<10^{-4}$ m/s, while generally $K_{SHU}<2x10^{-5}$ m/s. CFU shows the highest variability and covers ranges of both STUa and SHU (Figs. 7, 8). .
5. PTFs from the literature show high error of prediction in respect to K measured in this work. The calibration procedure here proposed allowed us to enhance accuracy of prediction K. Nevertheless enhancement is generally unsatisfactory for $K<10^{-6}$ m/s.

REFERENCES

- Abdelbaki, A. M. (2016). Using automatic calibration method for optimizing the performance of Pedotransfer functions of saturated hydraulic conductivity. Ain Shams Engineering Journal 7(2): 653-662.
- Boadu, F. K. (2000). Hydraulic conductivity of soils from grain-size distribution: new models. Journal of Geotechnical and Geoenvironmental Engineering 126(8): 739-746.
- Brakensiek, D., Rawls, W. and Stephenson, G. (1984). Modifying SCS hydrologic soil groups and curve numbers for rangeland soils. American Society of Agricultural Engineers.
- Disperati, L., Trefolini, E., Bellantoni, A. and Bonciani, F. (2013). A method for engineering-geological mapping: application to the Arezzo and Lucca provinces (Tuscany, Italy). *Rendiconti Online della Società Geologica Italiana* 24: 101-104.
- Disperati, L., Trefolini, E., D'Addario, E., Mammoliti, E., Papasidero, M.P., Vacca, V., Viti. F. (2018). Engineering geology characterization of slope deposits and physically-based assessment of shallows landslide susceptibility (Alpi Apuane, Italy). Geophysical Research Abstracts Vol. 20, EGU 2018-19093, 2018 EGU General Assembly 2018.
- Duan, Q., Gupta, V. K. and Sorooshian, S. (1993). Shuffled complex evolution approach for effective and efficient global minimization. Journal of optimization theory and applications 76(3): 501-521.
- Folk, R. L. (1980). Petrology of sedimentary rocks, Hemphill Publishing Company.
- Hvorslev, M. J. (1951). Time lag and soil permeability in ground-water observations.
- Li, Y., Chen, D., White, R., Zhu, A. and Zhang, J. (2007). Estimating soil hydraulic properties of Fengqiu County soils in the North China Plain using pedo-transfer functions. Geoderma 138(3-4): 261-271.
- MacQueen, J. (1967). Some methods for classification and analysis of multivariate observations. Proceedings of the fifth Berkeley symposium on mathematical statistics and probability, Oakland, CA, USA.
- Minasny, B. and McBratney, A. B. (2000). Evaluation and development of hydraulic conductivity pedotransfer functions for Australian soil. Soil Research 38(4): 905-926.
- Tietje, O. and Hennings, V. (1996). Accuracy of the saturated hydraulic conductivity prediction by pedo-transfer functions compared to the variability within FAO textural classes. Geoderma 69(1): 71-84.
- USBR 7300-89 (1990). Procedure for Performing Field Permeability Testing by The Well Permeameter. Earth Manual: Part 2. A. W. R. T. P. T. Edition. Denver, Colorado, U.S. Department of the Interior, Bureau of Reclamation: 1234-1235.
- Vereecken, H., Maes, J. and Feyen, J. (1990). Estimating unsaturated hydraulic conductivity from easily measured soil properties. Soil Science 149(1): 1-12.
- Weynants, M., Vereecken, H. and Javaux, M. (2009). Revisiting Vereecken pedotransfer functions: Introducing a closed-form hydraulic model. Vadose zone journal 8(1): 86-95.
- Wösten, J., Lilly, A., Nemes, A. and Le Bas, C. (1999). Development and use of a database of hydraulic properties of European soils. Geoderma 90(3): 169-185.