

## ***Interactive comment on “Characterization of the field saturated hydraulic conductivity on a hillslope: measurement techniques, data sensitivity analysis and spatial correlation modelling” by C. Fallico et al.***

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Received and published: 31 August 2005

### ANSWERS TO THE MAJOR COMMENTS

(1) A mother-tongue speaker actually had already been involved in the revision of the paper text. However, following the suggestions of the Referee # 2, we'll submit the paper to a new language revision with the collaboration of a mother-tongue speaker.

(2) The magnitude level of some kfs values, obtained by ring infiltrometer measurements, seems really high; however an accurate analysis of measurement and data-elaboration stages did not provide any elements leading to retain these data anomalous. For these measurement devices it is very important to verify the attainment of steady state flow, this verification was performed for each of the obtained values. If

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required, we can report the  $dh - t$  diagrams related to the highest  $kfs$  values, where it is possible to see that the steady state flow was clearly reached both for H1 and H2 value of the constant head.

Moreover, we would underline that all the measurements were carried out according to the main suggestions reported in literature (Elrick and Reynolds, 1992; Angulo-Jaramillo et al., 2000).

(3) A rigorous analysis of the uncertainties of the measurements achieved by single-ring pressure and tension disc infiltrometer was beyond the scope of our study. A simple error analysis based on Monte Carlo simulations was, on the contrary, performed in order precisely to assess the effects of small errors in inflow rate evaluation on the obtained values of  $kfs$ ; these errors are assumed equivalent to a possible reading-off error on the device reservoir for which the hypothesis of normal distribution is fully justified. Maybe, in order to make our objectives more evident it is better to modify the text as reported below:

- 1. Replace page 1252, lines 15-25 with: The measurements by single ring pressure infiltrometer require thoroughness and care; to increase the accuracy of measurements it is well-timed to follow the suggestions that may be checked in literature (Heinen and Raats, 1990; Wu et al., 1993; Russo et al., 1997; Elrick and Reynolds, 1992).
- 2. Delete page 1253, lines 16-18, saving the literature references (Elrick & Reynolds, 1992; Ankeny et al., 1991)
- 3. Insert a new paragraph 2.2.3 after paragraph 2.2.2, as reported below: 2.2.3 Simultaneous Equations Approach By the single ring pressure infiltrometer and the tension disc infiltrometer, the SEA approach (eqs. 5 and 10) can yield both positive and negative values for  $kfs$  (Elrick and Reynolds, 1992; Russo et al.; 1997). The negative values of  $kfs$  are physically impossible, but the excessive soil heterogeneity and the preferential flow in macropores change the Q2/Q1 ratio and may lead to negative  $\alpha$  values (Wu et al., 1993). Moreover, the preferential flow due to macropores increases hydraulic conductivity values, so the locations where  $\alpha$  is calculated negative, generally have high  $kfs$  values.
- 4. The current title of the paragraph 2.2.3: "Laboratory measurements" change in: "2.2.4 Laboratory

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measurements”

(4) In the paragraph 3.2.1 we performed a direct comparison among the 3 data sets of  $k_s$ , obtained by the different measurement methods, and we performed a statistical analysis, the main results of which are shown in Tab.1. A direct comparison of the spatially distributed fields of  $k_s$  values derived from the different methods is certainly very interesting, but we thought it better to treat this matter separately, in another paper, to not stray beyond the aims of this paper and to not make this paper dull reading. Anyway, although rigorous spatial comparison was not performed, Fig. 8a and Fig. 8b report a comparison of the magnitude level between laboratory and ring infiltrometer data, which we believed to be particularly meaningful, since they were sampled in the same locations.

(5) The present paper is based on the collection of experimental data obtained by 3 different measurement methods, of which 2 are in-site techniques and 1 in the laboratory. After a first stage dedicated to statistical comparison of 3 different data sets and to data quality assessment (sensitivity analysis), the main innovative goal was the investigation about the possibility of using the largest quantity of data, although they are derived by different measurement approaches. Assuming the spatial correlation structure as the decision-making criteria, the reliability of increasing the amount of data mixing was evaluated.

(6) The undisturbed soil samples utilized for the laboratory analysis were taken in the same locations as the ring infiltrometer measurements in order to perform a direct comparison of the two different measurement methods. As said above, the results of this comparison are reported in paragraph 3.2.2; further elements of discussion on this topic are already provided at the above written answer number (4).

(7) We agree with the suggestions of Referee #2 about the need to reduce the number of figures and there is no problem about eliminating figures: 5a, 5b, 5c, 6a, 6b, 6c, 7a, 7b, and 7c. In this way the statistical analysis of each data set would be represented

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just by the log-probability plot.

## ANSWERS TO THE ADDITIONAL COMMENTS

1) Abstract The abstract was modified following the suggestions of Referee #2. Abstract This work tackles the problem of experimental data quality, considering a large collection of data gathered at an experimental site in the alluvial basin of a Calabrian river (South - Italy). In a restricted zone of this site (40 m x 20 m), in the Autumn of year 2002, the field saturated hydraulic conductivity (kfs) was measured at 30 locations by tension disc infiltrometer, in other 30 locations by pressure ring infiltrometer and other 30 ks values were determined in the laboratory on undisturbed soil cores, taken in the same locations as the single ring infiltrometer measurements. Statistical data analysis showed that the measurements performed by tension disc infiltrometer supplied values of kfs which are on average lower and more homogeneous than the values provided by the other considered measurement techniques. On the data collected using ring and disc infiltrometers a sensitivity analysis of kfs and  $\alpha$ ; to small measurement errors was estimated by a Monte Carlo simulation. The results of this sensitivity analysis showed that the uncertainty on kfs is fairly small for both considered measurement devices, while the uncertainty on  $\alpha$  is small for the disc infiltrometer and it is high for the ring infiltrometer. A specific comparison between ring infiltrometer and laboratory data, referred to the same locations, is useful to recognize the cases in which they show the same order of magnitude. Finally, a new method, based on a data merging procedure giving origin to different sets of data, is suggested to investigate the spatial correlation structure of field saturated hydraulic conductivity, utilizing the largest number of data, acquired by different measurement methods.

2) Page 1248 - Line 23-24 The original sentence was changed to: "Water flow and pollutant transport processes in an unsaturated zone is one of the main topics for the research activity of hydro-geologists and soil scientists..."

3) Page 1249 - Line 6-8 We agree with Referee #2's comments, but we retain that

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our sentence must be read in the light of the remaining contents of the paragraph (in particular lines 17 - 20).

4) + 5) Pag.1249 - Line 9-16 All this part was changed to: “The measurements of hydraulic conductivity, carried out directly in the field to characterize the unsaturated zone, are generally time-consuming and costly, while those of water content and pressure head often prove to be easier and quicker. Therefore in unsaturated subsoil the hydraulic conductivity is often determined as a non-linear function of the matrix potential and water content. Nevertheless, an inverse problem arises, regarding the reliability of the subsurface hydraulic parameter characterization carried out by the cited non-linear functions, that is considering water content and matrix potential as independent variables, rather than hydraulic conductivity.”

6) Page 1249 - Line 19 “modelling issues” was changed to: “model predictions”

7) Page 1249 - Line 24 Reference to Gupta et al., 1998 was taken out.

8) Page 1249 - Line 25 - 29 This part was reformulated: “In this context the present paper tackles the problem of experimental data quality, referring to the large collection of hydraulic conductivity data, gathered at an experimental site in the alluvial basin of a Calabrian river, in South-Italy. In particular, referring to the parameter  $k_S$ , after some reminders.”

9) Page 1250 - Line 9 The last part of this sentence was changed to: “is investigated by estimating the experimental variogram of each one.”

10) Page 1250 - Equation (1) The equation (1) represents the Richards equation, written assuming  $h$  as variable, where, as specified in the text,  $h$  represents the soil water head. The water content is indicated with the symbol  $\theta$ , as specified also in the text (line 19), where it appears in equation (2).

11) Page 1251 - Lines 7-9 As specified in the text, in this sentence we are speaking about field measurement techniques, while the Multi-Step Outflow method is a labora-

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tory method. Nevertheless, to be clearer, in line 9 we changed as follows: “In particular, with respect to the field data concerned”

12) Page 1251 - Line 10 “two tools” was changed to: “two measurement tools”

13) Page 1251 - Lines 10-11 The references in the text was written according to the instructions shown on the EGU - COSIS web site.

14) Pages 1251-1252 - Equations Equation (5) is the main relationship of this section 2.2.1 and it provides the steady-state flow rate out of the constant-head pressure ring infiltrometer. Equations (3) and (4) are included in the text to give a complete reasoning of the discussed topic and to recall its fundamental aspects, even if summarily. Moreover, equation (3) explains the meaning of  $\phi$ , present in (5), while equation (4) is necessary in the text to show the link among  $\phi$ ,  $k_f$  and  $\alpha$ . To explain entirely the meaning and how the cited equations relate to each other is not possible here; for a complete explanation we suggest seeing the references included in the text, that is: - Elrick and Reynolds (1992) (see the References); - Reynolds and Elrick, (1990) (see the References); - Philip, (1985) (see the References). In order to avoid any misunderstanding, we eliminated the beginning of line 20 (“As a consequence”). The sentence becomes: “It is possible, also, to estimate”

15) Page 1252 - Equation (6) The comma was replaced with a dot.

16) Page 1252 - Line 11 The sentence “some warnings should be considered” was reformulated as: “some questions should be taken into account, as shown later.”

17) Page 1252 - Lines 16-25 We have already dealt with this point in answer n. 3 to the major comments.

18) Page 1253 - Equations (7) - (8) This part was re-written following the suggestions of the referee, typing correctly the eq. 8.

19) Page 1253 - Lines 15-18 These lines are reformulated: “Also for disc infiltrometer measurement interpretation some warnings should be taken into account, as showed

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later (Elrick and Reynolds, 1992; Ankeny et al., 1991)” The following sentence: “kts-values ĘĘĘĘĘ..factors”, that could generate confusion, was eliminated.

20) Referee #2 suggests in this point removing section 2.3 to later in the paper. Actually we prefer to keep section 2.3 in the current position, that is, within paragraph 2 dedicated to “Methods”; in fact, this section does not report any result, but only methodological elements.

21) Page 1254 - MC analysis This question has already been dealt with (see the answers to the major comment n. 3).

22) Page 1256 - Line 15 As Referee #2 suggested, we replaced the existing sentence “No other mention will be made to the other data collected” as follows: “Other data will not be used in the remainder of this paper.”

23) Page 1257 - Line 12 We rephrased in this manner: “Ę, standard deviation and Pearson asymmetry were considered.”

24) Page 1257 - Figures This question was previously dealt with in the major comment n.7.

25) Page 1257 - Line 20 The current sentence “Ęthe following elements can be observed” was reformulated: “Ęthe following conclusions can be drawn:” Moreover, about the results presented in this page, we refer again to major comment n.5, already treated.

26) Page 1258 - Line 17 We agree with Referee #2 and reformulate the “likelihood index” as “comparison index”.

27) Page 1258 - MC analysis This question has already been dealt with (see the answer to the major comment n. 3).

28) Data merging criteria we used do not simply consist in the junction of different data sets; as emphasized in the answer major comment n. 5, a data merging criteria

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was proposed in order to maximize the use of the available experimental information derived from different measurement methods. Precisely this data merging criteria has allowed the reliability of results based on different level of data-mixing to be evaluated. Therefore, the investigations about the possibilities of merging ks-data, derived from different measurement methods, represents an innovative contribution of the present paper.

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Interactive comment on Hydrology and Earth System Sciences Discussions, 2, 1247, 2005.

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