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Soil quality — Determination of unsaturated hydraulic conductivity and water-retention characteristic — Wind's evaporation method

Qualité du sol — Détermination de la conductivité hydraulique en milieu non saturé et de la caractéristique de rétention en eau — Méthode par évaporation de Wind

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 11275 was prepared by Technical Committee ISO/TC 190, *Soil quality*, Subcommittee SC 5, *Physical methods*.

This corrected version of ISO 11275:2004 incorporates the following corrections of inadvertent omissions:

a) in Equation (5) a minus sign has been added to the numerator on the right-hand side of the equation;

b) in Equation (9) a fourth term, $\widehat{\varphi}_{i,j+1}$, has been added to the right-hand side of the equation.

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Introduction

Soil water content and matric pressure are related to each other and determine the water-retention characteristics of a soil. Soil water, which is in equilibrium with free water, is at zero matric pressure (or suction) and either the soil is saturated or the gaseous phase occurs only as small bubbles. As a saturated soil dries, the matric pressure decreases (i.e. becomes more negative), and the largest pores empty of water. Progressive decreases in matric pressure will continue to empty finer pores until eventually water is held in only the finest pores. Not only is water removed from soil pores, but the films of water held around soil particles are reduced in thickness. Therefore, a decreasing matric pressure is associated with decreasing soil water content[8],[9]. Laboratory or field measurements of these two parameters can be made; and the relationship (which can be reported graphically, in tabular form, or possibly as an equation) is called the soil water-retention characteristic. The relationship extends from saturated soil to oven-dry soil (approximately 0 kPa to about -10^6 kPa matric pressure).

The soil water-retention characteristic is different for each soil type. The shape and position of the curve relative to the axes depend on soil properties such as texture, density and hysteresis associated with the wetting and drying history. Individual points on the water-retention characteristic curve may be defined for specific purposes.

The hydraulic conductivity is a measure of the rate at which liquid water can move through the soil under the influence of variations in matric pressure from point to point within the soil. The hydraulic conductivity of unsaturated soil depends on the same factors as does the soil water-retention characteristic, also showing hysteresis. As a saturated soil dries, the hydraulic conductivity decreases, and it is convenient to express the hydraulic conductivity corresponding to the soil water-retention characteristic as a function of the decreasing matrix pressure.

The results obtained using these methods can be used, for example:

— to provide an assessment of the equivalent pore-size distribution (e.g. identification of macro- and micro-pores);

— to determine indices of plant-available water in the soil and to classify soil accordingly (e.g. for irrigation purposes);

— to determine the drainable pore space (e.g. for drainage design, pollution risk assessments);

— to monitor changes in the structure of a soil (caused by e.g. tillage, compaction or addition of organic matter or synthetic soil conditioners);

— to ascertain the relationship between the negative matric pressure and other soil physical properties (e.g. hydraulic conductivity, thermal conductivity);

— to determine water content at specific negative matric pressures (e.g. for microbiological degradation studies);

— to estimate other soil physical properties.

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Soil quality — Determination of unsaturated hydraulic conductivity and water-retention characteristic — Wind's evaporation method

1 Scope

This International Standard specifies a laboratory method for the simultaneous determination in soils of the unsaturated hydraulic conductivity and of the soil water-retention characteristic. It is applicable only to measurement of the drying or desorption curve. Application of the method is restricted to soil samples which are, as far as possible, homogeneous. The method is not applicable to soils which shrink in the range of matric head $h_\mathrm{m} = 0$ cm to $h_\mathrm{m} = -800$ cm.

The range of the determination of the conductivity depends on the soil type. It lies between matric heads of approximately $h_\mathrm{m} = -50$ cm and $h_\mathrm{m} = -700$ cm.

The range of the determination of the water-retention characteristic lies between matric heads of approximately $h_\mathrm{m} = 0$ cm and $h_\mathrm{m} = -800$ cm.

NOTE 1 An infiltrometer method can be used to determine hydraulic conductivities near saturation.

NOTE 2 ISO 11274 gives methods to determine the water-retention characteristic for matric heads between 0 cm and $-15\,000$ cm.

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2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 10381-1, *Soil quality — Sampling — Part 1: Guidance on the design of sampling programmes*

ISO 10381-4, *Soil quality — Sampling — Part 4: Guidance on the procedure for investigation of natural, near-natural and cultivated sites*

ISO 11274, *Soil quality — Determination of the water-retention characteristic — Laboratory methods*

ISO 11276, *Soil quality — Determination of pore water pressure — Tensiometer method*

ISO 11461, *Soil quality — Determination of soil water content as a volume fraction using coring sleeves — Gravimetric method*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

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3.1
hydraulic conductivity
K
factor of proportionality between the soil water flux density, v, and the hydraulic gradient ∇h_{h} in Darcy's equation, assuming isotropic conditions, i.e.

$$v = -K \nabla h_{\text{h}}$$

NOTE For the purposes of this document, conductivity is used synonymously for unsaturated hydraulic conductivity.

3.2
soil water-retention characteristic
retention characteristic
relation between soil water content and soil matric head of a given soil (sample)

3.3
gravitational head
amount of work that must be done in order to transport reversibly and isothermally an infinitesimal quantity of water, identical in composition to the soil water, from a pool at a specified elevation and at atmospheric pressure, to a similar pool at the elevation of the point under consideration, divided by the mass of water transported

3.4
matric head
amount of work that must be done in order to transport reversibly and isothermally an infinitesimal quantity of water, identical in composition to the soil water, from a pool at the elevation and the external gas pressure of the point under consideration, to the soil water at the point under consideration, divided by the mass of water transported

3.5
pneumatic head
amount of work that must be done in order to transport reversibly and isothermally an infinitesimal quantity of water, identical in composition to the soil water, from a pool at atmospheric pressure and at the elevation of the point under consideration, to a similar pool at the external gas pressure of the point under consideration, divided by the mass of water transported

3.6
pressure head
tensiometer head
sum of the matric and pneumatic heads

NOTE The pneumatic head is assumed to be zero for the purposes of this method. On this basis, the pressure head equals the matric head.

3.7
hydraulic head
sum of the matric, pneumatic and gravitational heads

4 Symbols

a height, in centimetres;

h_{a} pneumatic head, in centimetres;

h_{h} hydraulic head $= h_{\text{a}} + h_{\text{g}} + h_{\text{m}}$, in centimetres;

h_{g} gravitational head, in centimetres;

h_{m} matric head, in centimetres;

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h_p pressure head = tensiometer head $h_a + h_m$, in centimetres;

i compartment and tensiometer index;

j time and measurement interval index;

k compartment index;

K unsaturated hydraulic conductivity, in centimetres per day (cm·d^{-1});

m mass, in kilograms;

m_e mass of soil sample at the end of the test, in kilograms;

t time, in days (d)

v soil water volume flux density, in centimetres per day (cm·d^{-1});

V volume, in cubic metres;

z vertical coordinate, in centimetres;

φ water content as volume fraction;

ρ_w density of water, in kilograms per cubic metre.

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5 Principle

Undisturbed samples of soil are taken from the field in accordance with ISO 10381-1. Each soil sample is first wetted to near saturation in the laboratory. Then the sample is allowed to dry by evaporation from the top surface; at known times during this period, pressure heads are measured at different depths in the sample using tensiometers, and the mass of the sample is measured. These measurements are continued until air enters any of the tensiometers. This can take a few days to two weeks depending on the type of soil. At the end of the test, after completing these measurements, the sample is dried and weighed, and its water content is calculated for each of the measurement times.

The sample is considered as two or more compartments (sub-samples), one for each tensiometer. For each of the measurement times, the water content of each compartment is calculated from the water content of the whole sample and the tensiometer readings. The soil water-retention characteristic and the unsaturated hydraulic conductivity are calculated from these data using an adaptation[1] of Wind's evaporation method[2]. The method treats the soil sample as being homogeneous in its hydraulic properties and assumes one-dimensional flow.

6 Apparatus

6.1 Equipment for sampling undisturbed soil.

Usually metal or plastic sleeves of known dimensions are used, together with equipment to push the sleeves into the soil. Usually the sampling sleeves are used to retain the sample throughout the test, and therefore it is necessary to pre-drill holes for the tensiometers. The dimensions of the soil samples are dependent on the soil type and the purpose of the investigation. The height of a sample shall be less than or equal to its diameter, to prevent the acquisition of redundant data. In most cases a height of 8 cm and a diameter of 10 cm are suitable for stone-free soils.

The height shall be large enough to accommodate 2 to 4 tensiometers. However, larger heights delay the drying of the lower compartments unduly, so that the determination may take too long, and may require an increase in the number of measurement times. The ratio of the diameter to the height should be just above unity, e.g. 10:8, to provide reasonably uniform conditions across the sample without requiring too broad a sample.

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6.2 Container and polyamide mesh, to saturate the soil samples.

6.3 Balance, capable of weighing to within ± 0,1 % of the mass of the soil sample.

A balance dedicated to a sample for the duration of the test is preferable to reduce possible disturbances.

6.4 Tensiometer system, capable of measuring heads with an accuracy better than ± 1 cm (see ISO 11276).

The lengths of the tensiometers shall be smaller than half the diameter of the sample. The diameters of the tensiometers shall be less than 10 % of the height of the sample.

6.5 Equipment to install the tensiometers (see ISO 11276), i.e. an auger or similar device, of suitable dimensions to bore holes into which the tensiometers will fit closely.

6.6 Materials to create seals between the sleeve and the tensiometers.

6.7 Drying oven, capable of maintaining a temperature of (105 ± 2) °C.

7 Procedure

7.1 Preparation and measurements

7.1.1 Sampling

Take soil samples from the field in accordance with ISO 10381-4. It is essential that undisturbed soil samples be used, since soil structure has a strong influence on the hydraulic properties. Use a ring with a cutting edge if sleeves are used. Press the sampling ring into the soil with a hydraulic jack or similar device. Dig out the sample carefully, and remove the surplus soil. If the soil sample has been compacted or its structure disturbed during sampling or transportation, it shall not be used for this determination.

7.1.2 Sample preparation

Prepare the sample as follows.

a) Measure the height and diameter of the soil sample.

b) Place a circle of mesh, or similar hydrophilic closely woven material, at the bottom of the sample. Secure the mesh with an elastic band or similar, and place the sample on a supporting sheet. The mesh and sheet will retain the soil sample. Place the sample in a container for wetting (from here on, the term sample refers to the soil in a sleeve with its retaining mesh).

c) Wet the sample from the bottom, proceeding gradually to prevent air entrapment, as follows. Set the water level in the container equal to or lower than the base of the sample. Ensure good contact between the mesh and the water to enable wetting by capillary rise. Depending on the soil type, raise the water level after a few hours (sand) or a few days (clay). Increase the water level gradually until it is 0,5 cm below the top of the sample. Maintain this level for at least one day and until it is apparent that the soil at the surface of the sample is moist. Then set the water level just under the base of the sample, and let the sample drain. Check the height of the sample, and report any changes. Remove the sample from the container.

   The structure of some soils is not stable under saturated conditions. Such soils should not be saturated completely. They may be wetted either by placing them in a container in which the water level is maintained at the base of the sample, or by use of a suction table (see ISO 11274).

d) Seal the bottom and sides of the sample in such a way that water can only evaporate from the top. Seal the top of the sample whilst the tensiometers are installed and until ready to let the evaporation begin.

e) The sample is regarded as comprising two or more compartments above each other [see Figure 1 a)]. Use compartments of equal height, or use compartments which decrease in height towards the top of the

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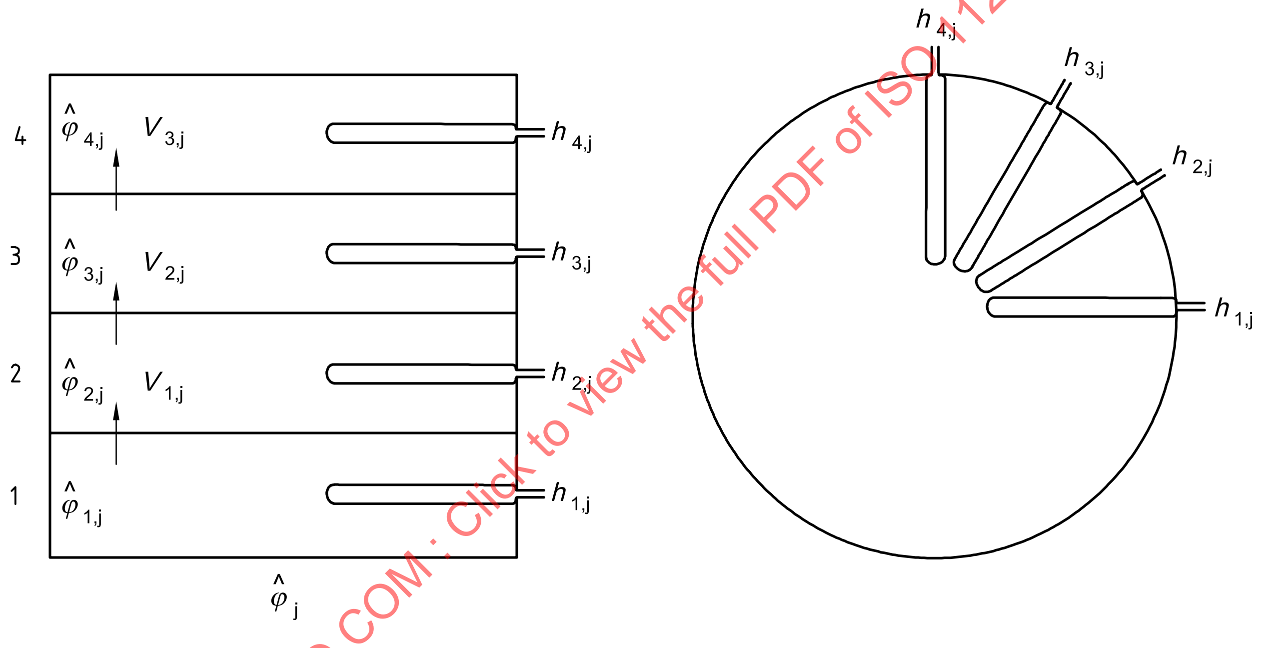
sample. For instance, four tensiometers could be installed at 1 cm, 3 cm, 5 cm and 7 cm depths in a sample 8 cm high, thus giving four compartments which are each 2 cm high.

The distance between the centre of a tensiometer and an end of the sample shall be not less than the diameter of the tensiometer.

f) Bore a close-fitting hole for a tensiometer into each compartment using an auger or similar device (see ISO 11276). It is essential to obtain a smooth installation, minimum disturbance and a good contact between the soil and the tensiometer. Fill the tensiometers with deaerated water. Install the tensiometers horizontally in each compartment in accordance with ISO 11276 and in such a way that their vertical projections do not intersect [see Figure 1 b)]. Arrange the set-up so that the vertical positions of the tensiometers are at the mid-heights of the hypothetical compartments. If applicable, seal the gaps between the tensiometers and the sleeve to prevent evaporation.

g) Record the vertical positions of the tensiometers and the total volume of the holes made in the soil to accommodate them.



a) Side view b) Top view

Figure 1 — Schematic overview of the sample with compartments and tensiometers

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7.1.3 Measurements

Record the temperature and humidity during the test.

Perform the test preferably in a room with constant temperature and humidity.

Put the sample on a balance. Connect the tensiometers to a read-out unit in accordance with ISO 11276, if applicable. Let the sample and tensiometers equilibrate. Determine the hydraulic equilibrium by measuring the height of the hydraulic heads, and permit evaporation to begin when the hydraulic heads of all the tensiometers are equal to within ± 1 cm. Commonly this situation is reached after several hours.

As the mechanical contact between the equipment on the balance and the other parts of the set-up (e.g. tubing or signal and power cables) influences the measured mass of the sample, care should be taken that this mechanical contact is as small as possible and invariant during these measurements.

When pore-water pressures are measured, it is necessary to convert the pressure measurements to pressure heads.

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NOTE 1 It is possible to use one of the following methods. Use the conversion table in ISO 11274 to convert the pressure reading to a pressure expressed in cmH_2O. Convert the latter pressure reading to a head reading, in centimetres, by multiplying by 1; or use the conversion table of ISO 11276; or use a suitable equation.

Allow evaporation from the top of the sample. At intervals, determine the total mass, m_j (j = 1,..., number of measurement interval), the pressure heads, h_{ij} (i = 1,..., number of tensiometer), and time, t_j. Repeat the measurements regularly, for instance every 2 h. The maximum time between intervals should not exceed 8 h. Stop when air enters any tensiometer. Usually, this happens between $h_p = -800$ cm and $h_p - 900$ cm. If air causes problems at higher pressure heads, replace the tensiometer, wet or saturate the sample again, and restart the test.

Determine the total mass of the soil sample at the end of the test, m_e. Dry the soil to constant mass at 105° C, and determine its average water content, $\overline{\varphi_\mathrm{e}}$ as specified in 7.2.1.

NOTE 2 The measurements require approximately 2 days for clays and 2 weeks for coarse sands in an environment with a temperature of 20° C and a relative humidity of 50 %. The measurements require more time for sands due to the larger amount of water that has to evaporate before a pressure head of −800 cm is reached.

7.2 Calculations

7.2.1 Calculate the average water content, $\overline{\varphi_\mathrm{e}}$, as a volume fraction of the whole soil sample at the end of the test in accordance to ISO 11461. Correct the volume of the soil sample by subtracting the volume occupied by the tensiometers.

7.2.2 Calculate the average water content as a volume fraction of the whole soil sample at interval j using the equation:

$$\overline{\varphi_j} = \frac{m_j - m_\mathrm{e}}{\rho_\mathrm{w} V} + \overline{\varphi_\mathrm{e}} \tag{1}$$

where:

$\overline{\varphi_j}$ is the average water content, as a volume fraction, of the soil sample at interval j;

$\overline{\varphi_\mathrm{e}}$ is the average water content, as a volume fraction, of the soil sample at the end of the test;

m_j is the mass of the soil sample at interval j, in kilograms;

m_e is the mass of the soil sample at the end of the test, in kilograms;

ρ_w is the density of water, in kilograms per cubic metre (≈ 1 000 kg·m^{-3});

V is the volume of the soil sample, in cubic metres.

Calculate the average water content of the whole sample for every interval j.

NOTE The set of computer programs METRONIA[2] permits the calculations given in 7.2.3 to 7.2.9.

7.2.3 Calculate the mean pressure head in the soil sample using the following equation:

$$\overline{h_j} = \frac{1}{n}\sum_{i=1}^{n} h_{i,j} \tag{2}$$

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where

$\overline{h_j}$ is the mean pressure head in the soil sample at interval j, in centimetres;

$h_{i,j}$ is the pressure head of tensiometer i at interval j, in centimetres;

n is the number of tensiometers, i.e. of compartments.

Calculate the average water content of the whole sample for every interval j.

7.2.4 Fit a continuous curve through all pairs $\overline{h_j}$ and $\overline{\varphi_j}$ to approximate the retention characteristic.

7.2.5 Calculate the estimated water content, $\widehat{\varphi}_{i,j}$, for compartment i at interval j, using the measured pressure head $h_{i,j}$ and the estimated retention characteristic. Calculate these for all compartments.

Calculate the mean estimated water content at interval j using the following equation:

$$\overline{\widehat{\varphi}_j} = \frac{1}{a} \sum_{i=1}^{n} a_i \widehat{\varphi}_{i,j} \tag{3}$$

where

$\overline{\widehat{\varphi}_j}$ is the mean estimated water content of the soil sample at interval j;

$\widehat{\varphi}_{i,j}$ is the estimated water content of compartment i at interval j;

a is the total height of the soil sample, in centimetres;

a_i is the height of compartment i, in centimetres.

Correct $\widehat{\varphi}_{i,j}$ for every compartment using the following equation:

$$\widehat{\varphi}_{i,j}{}^{*} = \frac{\overline{\varphi_j}}{\overline{\widehat{\varphi}_j}} \widehat{\varphi}_{i,j} \tag{4}$$

where

$\widehat{\varphi}_{i,j}{}^{*}$ is the corrected estimated water content of compartment i at interval j;

$\overline{\varphi_j}$ is the water content calculated in 7.2.2.

Calculate $\widehat{\varphi}_{i,j}{}^{*}$ for all intervals.

Fit a continuous curve through the pairs $h_{i,j}$ and $\widehat{\varphi}_{i,j}{}^{*}$ for all compartments and intervals to approximate the retention characteristic.

7.2.6 Repeat the calculations of 7.2.5 until the improvement is not significant. The pairs $h_{i,j}$ and $\widehat{\varphi}_{i,j}{}^{*}$ and the curve of the last iteration describe the retention characteristic as a table and as a curve respectively.

7.2.7 For interval j, calculate the gradient of the pressure head for adjacent compartments i and $i+1$ using the equation:

$$\frac{\Delta h_p}{\Delta z} = \frac{-\sqrt{h_{i+1,j+1} \cdot h_{i+1,j}} + \sqrt{h_{i,j+1} \cdot h_{i,j}}}{z_{i+1} - z_i} \tag{5}$$

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where

$\Delta h_p/\Delta z$ is the gradient of the pressure head;

$h_{i,j}$ is the pressure head in compartment i at interval j, in centimetres;

$h_{i,j+1}$ is the pressure head in compartment i at interval $j+1$ (the interval after interval j), in centimetres;

z_i is the position of the tensiometer in compartment i, in centimetres;

z_{i+1} is the position of the tensiometer in compartment $i+1$ (the compartment above compartment i), in centimetres;

if $\Delta h_p/\Delta z$ is not significantly less than -1, do not calculate conductivity for a compartment at interval j.

Calculate the gradients between all adjacent compartments ($n-1$ times).

NOTE A threshold for $\Delta h_p/\Delta z$ can be estimated when the standard deviation of the measurement noise of h_p, $s(h_p)$, is known. An appropriate method is to calculate an unsaturated hydraulic conductivity only if $\Delta h_p/\Delta z < -1 - 3s(h_p)/\Delta z$.

7.2.8 For interval j, calculate the volume flux densities between adjacent compartments i and $i+1$ using the following equation:

$$v_{i,j} = \frac{1}{t_{j+1} - t_j} \sum_{k=1}^{i} a_k(\widehat{\varphi}_{k,j} - \widehat{\varphi}_{k,j+1}) \tag{6}$$

where

$v_{i,j}$ is the volume flux density from compartment i to $i+1$ between intervals j and $j+1$, in centimetres per day;

t_j is the time at interval j, in days;

a_k is the height of compartment k ($k = 1$ is the bottom compartment), in centimetres;

$\widehat{\varphi}_{k,j}$ is the estimated water content of compartment k at interval j.

7.2.9 Calculate the unsaturated conductivity using Darcy's equation:

$$K_{i,j}(\overline{h}_{i,j}) = -\frac{v_{i,j}}{\frac{\Delta h_\mathrm{h}}{\Delta z}} = -\frac{v_{i,j}}{\frac{\Delta h_p}{\Delta z} + 1} \tag{7}$$

where

$K_{i,j}(\overline{h}_{i,j})$ is the conductivity at a pressure head $\overline{h}_{i,j}$, in centimetres per day;

$v_{i,j}$ is the volume flux density, calculated in 7.2.8, in centimetres per day;

$\Delta h_\mathrm{h}/\Delta z$ is the gradient of the hydraulic head;

$\Delta h_p/\Delta z$ is the gradient of the pressure head, calculated in 7.2.7.

Calculate the matching pressure head, $\overline{h}_{i,j}$ using the equation:

$$\overline{h}_{i,j} = -\sqrt[4]{h_{i,j} \cdot h_{i+1,j} \cdot h_{i,j+1} \cdot h_{i+1,j+1}} \tag{8}$$

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