Scientific Research Publishing

Journal of Geoscience and Environment Protection, 2021, 9, 25-52
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

Development of an Ontology-Based Knowledge Network by Interconnecting Soil/Water Concepts/Properties, Derived from Standards Methods and Published Scientific References Outlining Infiltration/Percolation Process of Contaminated Water

Stephanos D. V. Giakoumatos, Anastasios K. T. Gkionakis

School of Maritime and Industrial Studies, University of Piraeus, Piraeus, Greece
Email: sgiakoum@webmail.unipi.gr, sgiakou@hotmail.com, tgkion@gmail.com

How to cite this paper: Giakoumatos, S. D. V., & Gkionakis, A. K. T. (2021). Development of an Ontology-Based Knowledge Network by Interconnecting Soil/Water Concepts/Properties, Derived from Standards Methods and Published Scientific References Outlining Infiltration/Percolation Process of Contaminated Water. *Journal of Geoscience and Environment Protection, 9,* 25-52.
https://doi.org/10.4236/gep.2021.91003

Received: December 1, 2020
Accepted: January 15, 2021
Published: January 18, 2021

Abstract

The present work deals with the development of an Ontology-Based Knowledge Network of soil/water physicochemical & biological properties (soil/water concepts), derived from ASTM Standard Methods ($ASTM_{i,n}$) and relevant scientific/applicable references (published papers—$PP_{i,n}$) to fill up/bridge the gap of the information science between cited Standards and infiltration discipline conceptual vocabulary providing accordingly a dedicated/internal Knowledge Base (KB). This attempt constitutes an innovative approach, since it is based on externalizing domain knowledge in the form of Ontology-Based Knowledge Networks, incorporating standardized methodology in soil engineering. The ontology soil/water concepts (semantics) of the developed network correspond to soil/water physicochemical & biological properties, classified in seven different generations that are distinguished/located in infiltration/percolation process of contaminated water through soil porous media. The interconnections with arcs between corresponding concepts/properties among the consecutive generations are defined by the relationship of dependent and independent variables. All these interconnections are documented according to the below three ways: 1) dependent and independent variables interconnected by using the logical operator "*depends on*" quoting existent explicit functions and equations; 2) dependent and independent variables interconnected by using the logical operator "*depends on*" quoting produced implicit functions, according to Rayleigh's method of indices; 3) dependent and independent variables interconnected by using the logical operator "*re-*

lated to" based on a logical dependence among the examined nodes-concepts-variables. The aforementioned approach provides significant advantages to semantic web developers and web users by means of prompt knowledge navigation, tracking, retrieval and usage.

Keywords

Infiltration, Percolation, ASTM Standards, Soil/Water Contamination, Knowledge Base, Ontology Network, Semantics, Porous Media

1. Introduction

A Knowledge Base (KB) in knowledge engineering is a commonly accepted information structure over a discipline that combined with artificial intelligence and expert systems, where information can be easily retrieved in a rapid way and deployed in numerous applications, outlining the relationship with the software engineering, information integration and knowledge management (Studer et al., 1998). KBs form ontological mappings (Ontologies) by employing concepts (semantics) and rigid internal relationships amid its network corpus. Clearly defined concepts (conceptualization—explicitly or implicitly), shared (controlled) vocabulary and leveled up/down generations/classes (taxonomies) have to be built up inconsequential hierarchies (Genesereth & Nilsson, 1987; Gruber, 1995; Guarino, 1995; Uschold & Grüninger, 1996; Borst, 1997; Roche, 2003) to support such a structure.

Ontology-Based Knowledge Networks gradually are being applied to a vast range of disciplines, such as in soil science, by describing soil properties, processing and their interaction (Du et al., 2016; Heeptaisong & Srivihok, 2010). Ontologies as a formal description of knowledge set, with suitably placed concepts within a domain strictly bound by well-defined relationships are applied in artificial intelligence in order to provide to all users an interaction framework with various application systems i.e. communication models between (KB) users and machines (Weng & Chang, 2008).

In soil science, pollutant's fate via infiltration/percolation is considered to be a multi-stage processing and undoubtedly a major concern in industrial ecology. Precipitated water runoffs could arise contamination problems on account of their penetration from humic topsoil to lower surface layers. Mikkelsen et al. (1997) presented a case of heavy traffic roads. Soil crust rehabilitation in the aftermath of a pollution incident, could be remarkably aided by already building up ontological structures dedicated to infiltration phenomena applied to various accidental cases (Du & Cohn, 2016).

Infiltration is approached as a complex both biological & physicochemical process during which an aquatic solution (potentially contaminated with insoluble/dispersed particles or micelles), penetrates the ground under the gravity force and/or the capillary action. The partial sub-processes which are taking place until the infiltration water reaches the groundwater table are, inter alia, common filtration, chemical reaction (depending on the layers of sedimentary rock/soil the water is passing through), biochemical conversion, sedimentation, coagulation, flocculation (Lassabatere et al., 2010).

In general, the infiltration rate depends mainly on 1) ground surface loading with (waste) water; 2) the soil porosity; and 3) the vegetation coverage. An introspection reveals interdependences of numerous parameters among others, type, bulk density and texture of the soil, canopy coverage and topsoil biomass production (Wang et al., 2017; Patle et al., 2018; Wood et al., 1987; Tejedor et al., 2013). The given physicochemical parameters are of variant importance/gravity in terms of inducing the evolution of the ongoing phenomenon.

In the present paper, an Ontology-Based Knowledge Network is developed of soil/water physicochemical & biological properties (soil/water concepts), derived from ASTM standards and published scientific references in order to describe the infiltration/percolation process of contaminated water. The developed/proposed Ontology-Based Knowledge Network can be adopted as a tool for the semantic representation of infiltration/percolation process of contamination water through soil structure and porous media.

2. Methodology

In this section, a comprehensive Ontology-Based Knowledge Network design and construction is described/summarized by the below presented steps.

1) Determination of the initial ontology concept.

2) Determination and proper selection of other sub-concepts, which could be fitted in the ontology network, and correspond to soil/water physicochemical & biological properties.

3) Identification of soil/water physicochemical & biological properties through an extensive research of ASTM Standards and scientific published references.

4) Documentation of three possible ways that could justify the interconnections between all the ontology sub-concepts of our interest and relevant soil/water physicochemical & biological properties.

As regards the first step, the "infiltration rate" of contaminated water in the soil (porous medium), it was established as the initial conceptual property of our ontology network. Interconnection of the afore-mentioned properties is achieved by adopting a framework of concepts interrelated with soil/water properties and partial sub-processes which are taking place during the process.

The infiltration rate could be measured and monitored by well-established techniques fully described by standard methods and practices recommended by a widely recognized standardization organization such as the American Society for Testing & Material (ASTM) and relative scientific published papers. This is indispensable for obtaining results comparable with the ones obtained in similar experimental models, under similar conditions, since some of these observations are obtained with more precise measurements that are described through standardized methods i.e. ASTM standards and scientific published papers.

According to the structure of the network, all the nodes/concepts/physicochemical and biological properties are interconnected by using the principles set by dependent and independent variables. This set of dependent and independent variables justified and documented by three possible ways, as they are describing below:

1) Dependent and independent variables interconnected by using the logical operator "depends on" quoting existent explicit functions and equations;

2) Dependent and independent variables interconnected by using the logical operator "depends on" quoting produced implicit functions, by implementing Rayleigh's method of indices;

3) Dependent and independent variables interconnected by using the logical operator "related to" based on a logical dependence between the examined nodes-concepts-variables.

The last Rayleigh's method of indices is based on the fundamental principle of dimensional homogeneity of physical variables involved in this problem. The dependent variable is identified and expressed as a product of all the independent variables raised to an unknown integer exponent. Equating the indices of n fundamental dimensions of the variables involved, n independent equations are obtained. Finally, these n equations are solved to obtain the dimensionless groups.

3. Implementation

Under the form of the directed/developed ontology network, shown in Figure A2 of the **Appendix**, it can be easily supported by a computer program through several ready-to-use packages already available in the market. All these nodes/concepts/properties are represented by ASTM standards and scientific published papers in an integrated Ontology-Based Knowledge Network, Figure A1 of the **Appendix**, a part of which is shown in Figure 1 of the current page.

Each node of ASTM standard and published paper has a set of references to other ASTM standards or/and published papers. All the nodes of scientific published papers and ASTM standards are symbolized as $PP_{i,n}$ and $ASTM_{i,n}$ respectively, where i denotes the generation number, and n denotes the member number of each generation. Starting from a certain ASTM standard, related with the topic under consideration (e.g. "Infiltration Rate Determination Using Double-Ring Infiltrometer with Sealed-Inner Ring", according to D5093-15 ASTM Standard Test Method, in the case of the present work), we may represent it as well as its references with points or vertices or nodes interconnected with arcs directed from the initial standard to its references. These references are all members of the first generation with the initial standard as unique parent. Each member of the first generation has other referenced ASTM standards or/and published papers of its own, creating a second generation, and so forth until the seventh generation is achieved in our case. Evidently, the initial standard as well as any

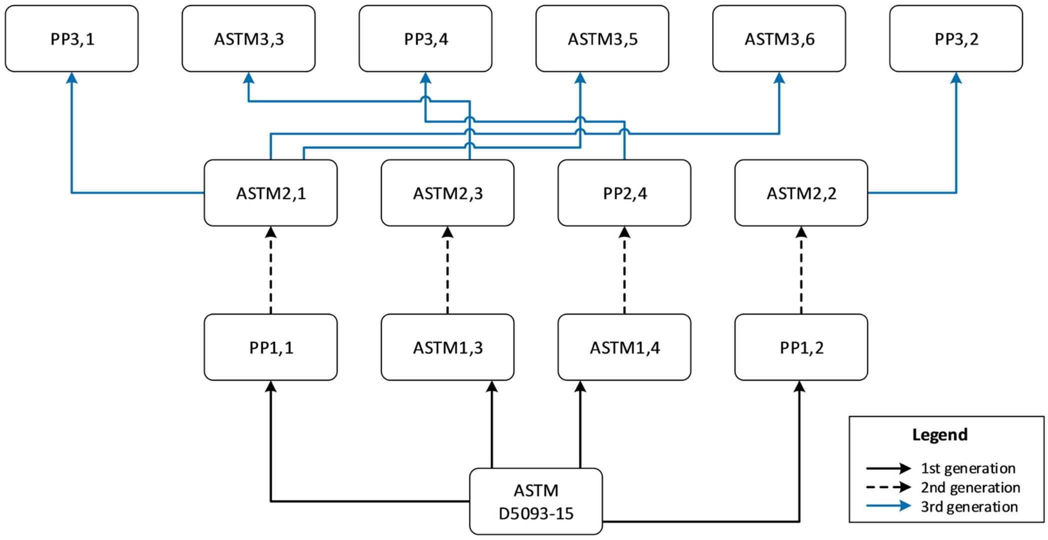

Figure 1. Part of the ontology-based knowledge network of ASTM standards and scientific published papers for estimating the infiltration rate of contaminated water.

member of the *i* generation may be a member of one or more generations i.e. a member of the *i* ($i = 0, 1, 2, \ldots$) generation may also appear as a member of the j generation, provided that $j \geq i + 2$.

Values, indicating dependence of applying a standard or/and published paper (especially of carrying out a standard test) on the previous application of another standard or/and published paper of the next generation, are assigned to each arc, so that a network is obtained from the directed multi-graph. These values vary from zero, indicating no dependence whatsoever, up to one, indicating full dependence (e.g. Table 1 & Table 2). Dependence concerning only knowledge that must be acquired for carrying out successfully a standard test is considered to be zero. Dependence of carrying out a standard test on the provision of a material with certain specifications varies from one to zero.

In the application example of current page, the selected initial "Standard Test Method for Field Measurement of Infiltration Rate Using Double-Ring Infiltrometer with Sealed-Inner Ring", under the code number ASTM D5093-15 (2015), has four arcs leading to corresponding referenced scientific published papers ($PP_{1,1}$ & $PP_{1,2}$) and ASTM standards ($ASTM_{1,3}$ & $ASTM_{1,4}$) as shown in Figures 1-3. The same procedure continues to the next generation and so forth until the seventh generation is formed. The integrated Ontology-Based Knowledge Network with all its ASTM standards and scientific published papers is presented in Figure A1 of the **Appendix**. However, a partial network that includes all the nodes of the first three generations is presented in Figure 1.

The dependence indices are considered as Boolean parameters, obtaining the values one or zero (meaning "referenced" or "not referenced", respectively) for sake of simplicity.

The interconnections between all nodes/concepts which represents soil/water physicochemical and biological properties and sub-processes of the integrated

Table 1. Adjacency matrix for first generation relations, in accordance with part of the ontology-based knowledge network shown in **Figure 2**.

	ASTM D5093	$PP_{1,1}$	$PP_{1,2}$	$ASTM_{1,3}$	$ASTM_{1,4}$
ASTM D5093	0	1	1	1	1
$PP_{1,1}$	0	0	0	0	0
$PP_{1,2}$	0	0	0	0	0
$ASTM_{1,3}$	0	0	0	0	0
$ASTM_{1,4}$	0	0	0	0	0

Table 2. Adjacency matrix for second generation relations, in accordance with part of the ontology-based knowledge network shown in **Figure 2**.

	$PP_{1,1}$	$PP_{1,2}$	$ASTM_{1,3}$	$ASTM_{1,4}$	$ASTM_{2,1}$	$ASTM_{2,2}$	$ASTM_{2,3}$	$PP_{2,4}$
$PP_{1,1}$	0	0	0	0	1	0	0	0
$PP_{1,2}$	0	0	0	0	0	1	0	0
$ASTM_{1,3}$	0	0	0	0	0	0	1	0
$ASTM_{1,4}$	0	0	0	0	0	0	0	1
$ASTM_{2,1}$	0	0	0	0	0	0	0	0
$ASTM_{2,2}$	0	0	0	0	0	0	0	0
$ASTM_{2,3}$	0	0	0	0	0	0	0	0
$PP_{2,4}$	0	0	0	0	0	0	0	0

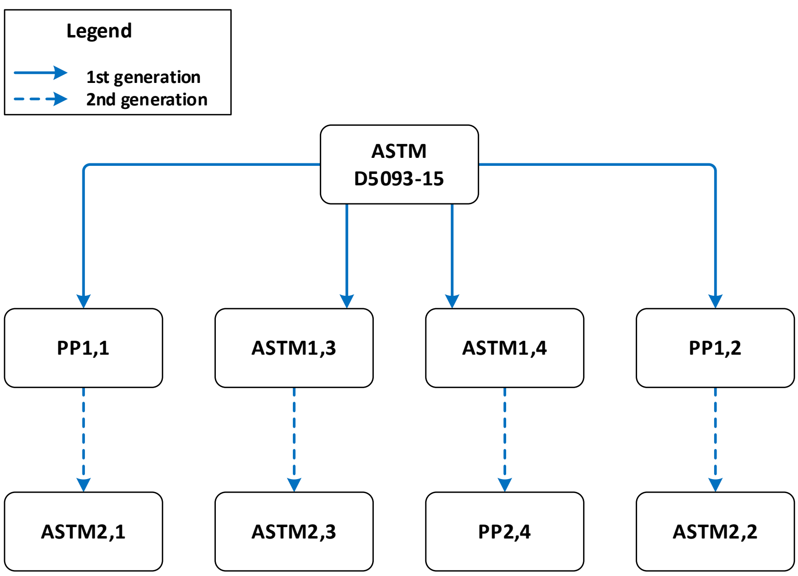

Figure 2. A tree representation of merely a part of the network of scientific published papers and ASTM standards for estimating the infiltration rate of contaminated water.

Ontology-Based Knowledge Network of **Figure A2** of the **Appendix**, are presented and depicted with arcs. Each single arc consists of a starting point and a final point edge. In order to find and justify the correlations between all the nodes/concepts of **Figure A1** & **Figure A2** of the **Appendix**, the selected concepts are corresponding to dependent and independent physical variables. According to the structure of the network, a dependent physical variable is the starting point of an arc that ends up (final pointed arc edge), to an independent variable. All these interconnections are documented according to the below three ways: 1) dependent and independent variables interconnected by using the logical operator "depends on" quoting existent explicit functions and equations, 2) dependent and independent variables interconnected by using the logical operator "depends on" quoting produced implicit functions, according to Rayleigh's method of indices, presented in **Tables A1-A7** of the **Appendix 3**) dependent and independent variables interconnected by using the logical operator "related to" based on a logical dependence between the examined nodes-concepts-variables. All the above-described methods are detailed presented in the "contribution" column of **Tables A1-A7** in the **Appendix** along with a Terminology Table in (SI units) of **Table A8**.

$PP_{1,1}$: Lassabatere et al. (2010), Effect of the settlement of sediments on water infiltration in two urban infiltration basins, Geoderma, 156(3-4), 316-325.

$PP_{1,2}$: Assouline (2013), Infiltration into soils: Conceptual approaches and solutions, Water resources research, 49(4), 1755-1772.

$ASTM_{1,3}$: ASTM C1585-20 (2020), Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes.

$ASTM_{1,4}$: ASTM D3385-18 (2018), Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer.

$ASTM_{2,1}$: ASTM D3385-18 (2018), Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer.

$ASTM_{2,2}$: ASTM D5126-16e1 (2016), Standard Guide for Comparison of Field Methods for Determining Hydraulic Conductivity in Vadose Zone.

$ASTM_{2,3}$: ASTM C1792-14 (2014), Standard Test Method for Measurement of Mass Loss versus Time for One-Dimensional Drying of Saturated Concretes

$PP_{2,4}$: Di Prima et al. (2016), Testing a new automated single ring infiltrometer for Beerkan infiltration experiments, Geoderma, 262, 20-34.

4. Discussion

The network presented on **Figure A1** of the **Appendix** is structured by using all relevant ASTM standardization available to build up rigid constructed generations. Nonetheless, no other international fully approved standardized methodology was adopted (e.g. ISO, DIN, BS, EN etc.). A terminology Table is an integral part of the Ontology-Based Knowledge Network and is a very useful medium to avoid scientists of boundary disciplines misapprehension/misleading to even basic concepts.

The following presented paradigm could be a characteristic one to hydraulic engineers and earth scientists that their activities are located in between interdisciplinary knowledge areas. The term "infiltration" forms a continuum with "percolation" and "seepage" terms, so that several authors use them interchangeably, as quasi synonyms. From a topological point of view infiltration is considered to be the water movement into the soil while percolation refers to the water path within/through the soil until it reaches the water table. Consequently, it seems that there is a first interface between the infiltration and percolation zones as well as another subsequent interface between percolation zone and water table. On the other hand, seepage is the slow escape/leakage of water on or near the earth surface simulating a downhill route possible formed by natural phenomena or local constitution of earth, implying difference in permeability enhanced by the presence of clay-loam soils and certain minerals.

5. Conclusion

The presented multi-generation ontological network, which employs standardization of techniques/methods relevant to sedimentation during and after infiltration, is merely the beginning of a forthcoming profound interdisciplinary expansion. The corresponding network of standards and recommended practices might receive further enrichment, incorporated e.g. ISO/EN standards and more profound phenomenological knowledge related to porous media infiltration. This could be achieved by presented new interconnections among conceptual levels and deeper generation formation analysis upon the already proposed structure.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Assouline, S. (2013). Infiltration into Soils: Conceptual Approaches and Solutions. *Water Resources Research, 49,* 1755-1772. https://doi.org/10.1002/wrcr.20155

ASTM C1585-20 (2020). *Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes*. West Conshohocken, PA: ASTM International.

ASTM C1792-14 (2014). *Standard Test Method for Measurement of Mass Loss versus Time for One-Dimensional Drying of Saturated Concretes*. West Conshohocken, PA: ASTM International.

ASTM D3385-18 (2018). *Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer*. West Conshohocken, PA: ASTM International.

ASTM D5093-15 (2015). *Standard Test Method for Field Measurement of Infiltration Rate Using Double-Ring Infiltrometer with Sealed-Inner Ring*. West Conshohocken, PA: ASTM International.

ASTM D5126-16e1 (2016). *Standard Guide for Comparison of Field Methods for Determining Hydraulic Conductivity in Vadose Zone*. West Conshohocken, PA: ASTM International.

Borst, W. N. (1997). *Construction of Engineering Ontologies for Knowledge Sharing and Reuse*. Enschede: Centre for Telematics and Information Technology (CTIT). https://www.semanticscholar.org/paper/Construction-of-Engineering-Ontologies-for-Sharing-Borst/205e142ca3eb360be04988c80cbe3819523868f1

Di Prima, S. et al. (2016). Testing a New Automated Single Ring Infiltrometer for Beerkan Infiltration Experiments. *Geoderma, 262,* 20-34. https://doi.org/10.1016/j.geoderma.2015.08.006

Du, H. et al. (2016). An Ontology of Soil Properties and Processes. *15th International Semantic Web Conference,* Kobe, 17-21 October 2016, 30-37. https://doi.org/10.1007/978-3-319-46547-0_4

Genesereth, M. R., & Nilsson, N. J. (1987). *Logical Foundations of Artificial Intelligence*. Los Altos, CA: Morgan Kaufmann.

Gruber, T. R. (1995). Toward Principles for the Design of Ontologies Used for Knowledge Sharing. *International Journal Human-Computer Studies, 43,* 907-928. https://doi.org/10.1006/ijhc.1995.1081

Guarino, N. (1995). Ontologies and Knowledge Bases: Towards a Terminological Clarification. In *Towards Very Large Knowledge Bases* (pp. 25-32). Amsterdam: IOS Press. https://www.researchgate.net/publication/220041941_Ontologies_and_knowledge_bases_towards_a_terminological_clarification

Heeptaisong, T., & Srivihok, A. (2010). Ontology Development for Searching Soil Knowledge. *The 9th International Conference on e-Business (iNCEB2010),* Bangkok, 18-19 November 2010, 102-107. https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.463.2552&rep=rep1&type=pdf

Lassabatere, L. et al. (2010). Effect of the Settlement of Sediments on Water Infiltration in Two Urban Infiltration Basins. *Geoderma, 156,* 316-325. https://doi.org/10.1016/j.geoderma.2010.02.031

Mikkelsen, P. S. et al. (1997). Pollution of Soil and Groundwater from Infiltration of Highly Contaminated Stormwater—A Case Study. *Water Science and Technology, 36,* 325-330. https://doi.org/10.2166/wst.1997.0687

Patle, G. T. et al. (2018). Estimation of Infiltration Rate from Soil Properties Using Regression Model for Cultivated Land. *Geology, Ecology & Landscapes, 3,* 1-13. https://doi.org/10.1080/24749508.2018.1481633

Roche, C. (2003). Ontology: A Survey. *IFAC Symposium Proceedings, 36,* 187-192. https://doi.org/10.1016/S1474-6670(17)37715-7

Studer, R. et al. (1998). Knowledge Engineering: Principles and Methods. *Data & Knowledge Engineering, 25,* 161-198. https://doi.org/10.1016/S0169-023X(97)00056-6

Tejedor, M. et al. (2013). Soil Properties Controlling Infiltration in Volcanic Soils (Tenerife, Spain). *Soil Science Society of America Journal, 77,* 202-212. https://doi.org/10.2136/sssaj2012.0132

Uschold, M., & Grüninger, M. (1996). Ontologies: Principles, Methods and Applications. *The Knowledge Engineering Review, 11,* 93-136. https://doi.org/10.1017/S0269888900007797

Wang, P. et al. (2017). Effects of Urbanization, Soil Property and Vegetation Configuration on Soil Infiltration of Urban Forest in Changchun, Northeast China. *Chinese Geographical Science, 28,* 482-494. https://doi.org/10.1007/s11769-018-0953-7

Weng, S. S., & Chang, H. L. (2008). Using Ontology Network Analysis for Research Document Recommendation. *Expert Systems with Applications, 34,* 1857-1869. https://doi.org/10.1016/j.eswa.2007.02.023

Wood, J. C. et al. (1987). Important Factors Influencing Water Infiltration and Sediment Production on Arid Lands in New Mexico. *Journal of Arid Environments, 12,* 111-118. https://doi.org/10.1016/S0140-1963(18)31181-9

Appendix

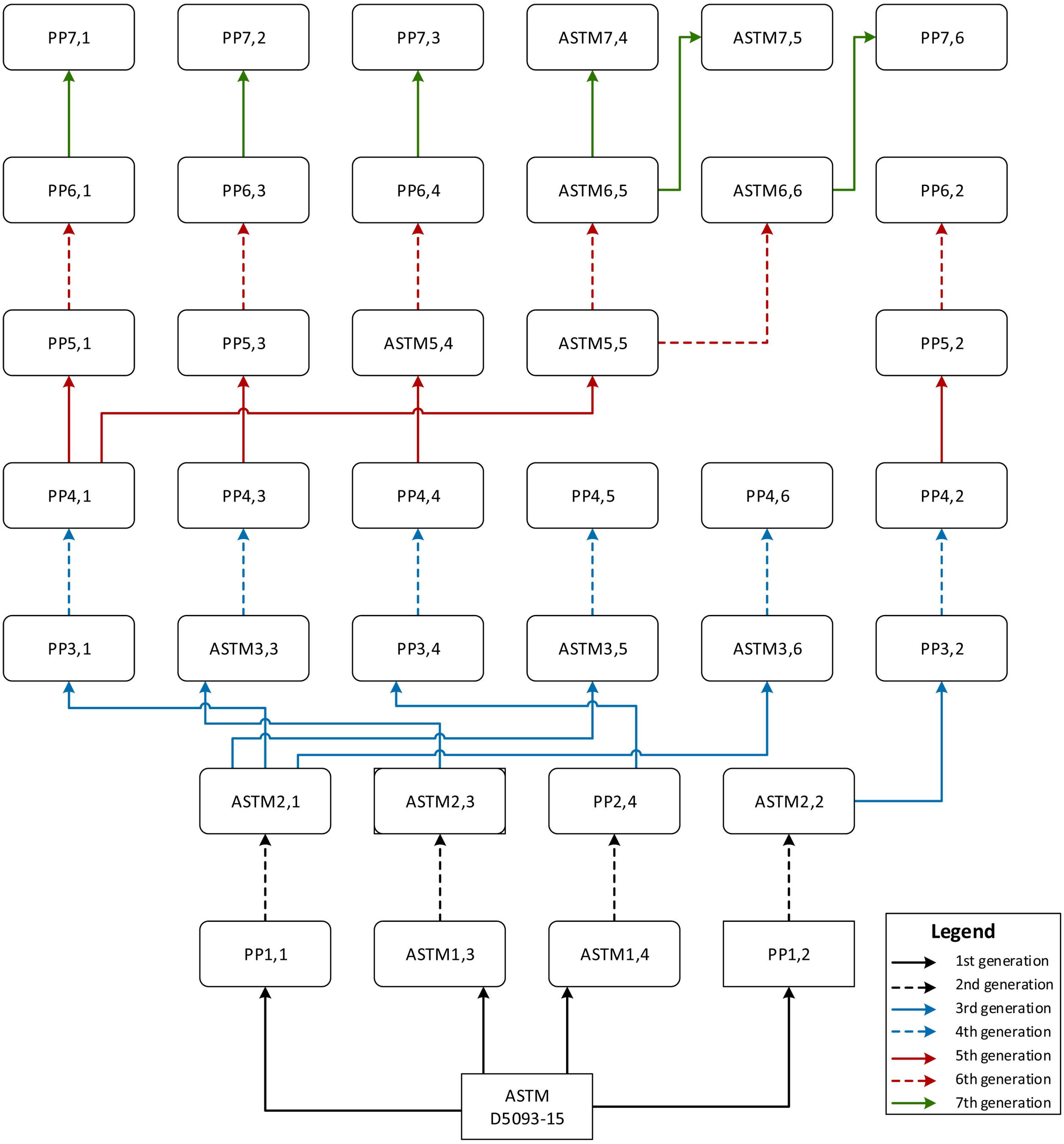

Figure A1. The integrated ontology-based knowledge network that represents the interconnections between ASTM standards ($ASTM_{i,n}$) and scientific published papers ($PP_{i,n}$) formed in accordance with the third column named "node" of each Tables A1-A7 of the **Appendix**.

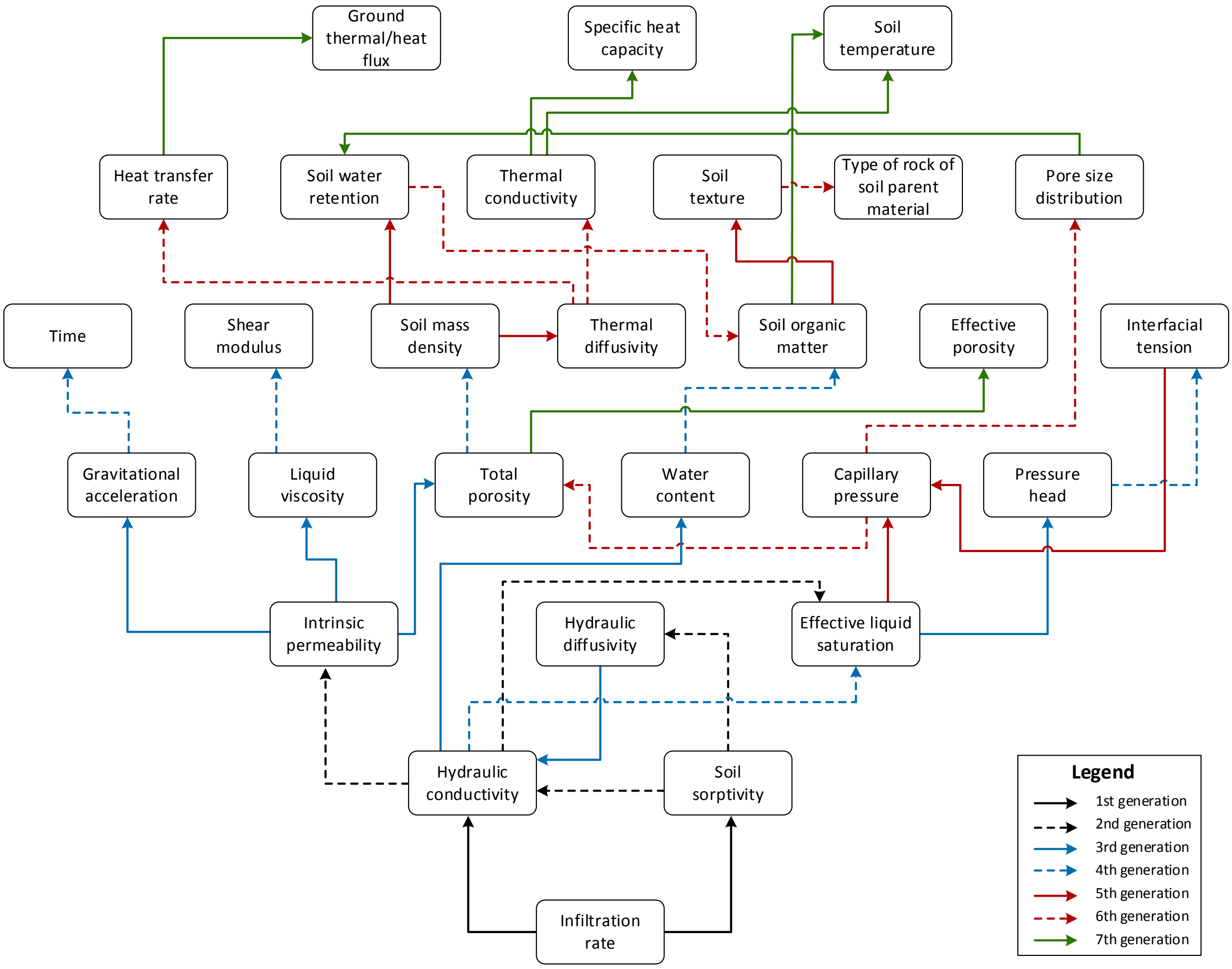

Figure A2. The integrated ontology-based knowledge network that represents the interconnections between soil/water concepts/properties formed in accordance with the fifth column named "concept" of each Tables A1-A7 of the **Appendix**.

Table A1. Description of all nodes (see Figure A1) under the form of Standards or published papers and the corresponding concepts (see Figure A2) which are included in the first generation.

Row	Column	Node	Appendix references	Concept	Depends on/related to	Contribution
0 Generation						
0	1	ASTM D5093-15	[7]	Infiltration rate	0	1
1st Generation						
Row	**Column**	**Node**	**Appendix references**	**Concept**	**Depends on/related to**	**Contribution**
1	1	$PP_{1,1}$	[28]	Hydraulic conductivity	ASTM D5093-15	The infiltration rate $q(t)$ *depends on* saturated hydraulic conductivity (K_s) according to the equation [28], 5c, page 318: $q(t)=\frac{S}{2*\sqrt{t}}+\left[A*S^2+B*K_s\right]$, where the terms, definitions and dimensions of $\left(q(t),S,t,A,B,K_s\right)$ are presented in detail in the terminology (Table A8) of the **Appendix**. (S) refers to the sorptivity and (A, B) are constants depended on shape parameter values.
1	2	$PP_{1,2}$	[15]	Soil sorptivity	ASTM D5093-15	The infiltration rate $q(t)$ into a porous material *depends on* soil sorptivity (S), for narrow pore size distributions in accordance with the equation 14, on page 1758, on [15]: $q(t)=K_s+\frac{1}{2}*S*t^{-0.5}*\left(1+\frac{\beta_o*K_s*t^{0.5}}{S}\right)^{-2}$ initially introduced by Brutsaert, 1977, where the terms, definitions and dimensions of $\left(q(t),K_s,S,t,\beta_o\right)$ are presented in detail in terminology (Table A8) of the **Appendix**. For clarification purposes, (S) refers to the sorptivity.
1	3	$ASTM_{1,3}$	[2]	Soil Sorptivity	ASTM D5093-15	The infiltration rate $q(t)$ *depends on* soil sorptivity (S), according to the implicit function: $q(t)=\left(\frac{z}{t}\right)*f\left((Sh),\left(\frac{t^2*\gamma}{\rho_w*z^3}\right),\left(\frac{\gamma}{\psi*z}\right),(Ri),\left(\frac{t*\gamma}{\mu*z}\right),\left(\frac{z}{v_z*t}\right),\left(\frac{t^2*\gamma}{\rho_s*z^3}\right),\left(\frac{z^2}{k_{intr}}\right),(Sc),\left(\frac{z}{H}\right),\left(\frac{z}{t^{0.5}*S}\right)\right)$ where the terms, definitions and dimensions of $\left(q(t),z,t,Sh,\gamma,\rho_w,\psi,Ri,\mu,v_z,\rho_s,k_{intr},Sc,H,S\right)$ are presented in detail in the terminology (Table A8) of the **Appendix**. Rayleigh's method of indices was deployed along with the echelon matrix procedure as an additional confirmation method.
1	4	$ASTM_{1,4}$	[5]	Hydraulic conductivity	ASTM D5093-15	The infiltration rate $q(t)$ *depends on* hydraulic conductivity (K) according to the implicit function: $q(t)=\left(\frac{H}{t}\right)*f\left((Sh),(Sc),\left(\frac{\mu}{\psi*t}\right),\left(\frac{H}{g*t^2}\right),\left(\frac{H}{v_z*t}\right),\left(\frac{H^2}{A}\right),(Re),\left(\frac{\mu*t}{\rho_s*H^2}\right),\left(\frac{H^2}{k_{intr}}\right),\left(\frac{H^2}{t*D}\right),(Ri),\left(\frac{\mu*H}{t*\gamma}\right),\Phi,\theta,S_e,n,i\right)$ where the terms, definitions and dimensions of $\left(q(t),H,t,Sh,Sc,\mu,\psi,g,v_z,A,Re,\rho_s,k_{intr},D,Ri,\gamma,\Phi,\theta,S_e,n,i\right)$ are presented in detail in the terminology (Table A8) of the **Appendix**. (A) refers to cross section of the infiltrometer cylinder, (Φ) is the total porosity, (θ) is the liquid content/soil-water content, (n) is the pore size distribution index. Rayleigh's method of indices was deployed along with the echelon matrix procedure as an additional confirmation method.

Table A2. Description of all nodes (see Figure A1) under the form of standards or published papers and the corresponding concepts (see Figure A2) which are included in the second generation.

2nd Generation						
Row	Column	Node	Appendix references	Concept	Depends on/ Related to	Contribution
2	1	$ASTM_{2,1}$	[5]	Intrinsic Permeability	$PP_{1,1}$	Hydraulic conductivity (K) *depends on* intrinsic permeability (k_{intr}), according to the implicit function: $$K=(v_z)*f\left(\left(\frac{v_z}{q}\right),\left(\frac{\rho*v_z^2}{\psi}\right),\left(\frac{1}{Ri}\right),\left(\frac{1}{Re}\right),\left(\frac{H^2}{A_{inf}}\right),\left(\frac{\rho}{\rho_s}\right),\left(\frac{H^2}{k_{intr}}\right),\left(\frac{H}{v_z*t}\right),\left(\frac{v_z*H}{D}\right),\left(\frac{\rho*v_z^2*H}{\sigma}\right),\Phi,\theta,S_e,n,i\right)$$ The terms, definitions and dimensions of $(K,v_z,q,\rho,\psi,Ri,Re,H,A_{inf},\rho_s,k_{intr},t,D,\sigma,\Phi,\theta,S_e,n,i)$ are presented in detail in the below terminology (Table A8) of the **Appendix**. For clarification purposes, (q) refers to infiltration rate, (Φ) is the total porosity, (θ) is the liquid content/soil-water content, (n) is pore size distribution index. Rayleigh's method of indices was deployed along with the echelon matrix procedure as an additional confirmation method.
2	2	$ASTM_{2,2}$	[8]	Hydraulic conductivity	$PP_{1,2}$	Soil sorptivity (S) *depends on* hydraulic conductivity (K), according to the implicit function: $$S=\left(\frac{z}{t^{0.5}}\right)*f\left(\left(\frac{z}{q*t}\right),(Sh),(Re),\left(\frac{\gamma}{\psi*z}\right),(Ri),\left(\frac{t*\gamma}{\mu*z}\right),\left(\frac{z}{v_z*t}\right),\left(\frac{t^2*\gamma}{\rho_s*z^3}\right),\left(\frac{z^2}{k_{intr}}\right),(Sc),\left(\frac{z}{H}\right),\left(\frac{z}{h_c}\right),\Phi,\theta,n\right)$$ Where the terms, definitions and dimensions of $(S,z,t,q,Sh,Re,\gamma,\psi,Ri,\mu,v_z,\rho_s,k_{intr},Sc,H,h_c,\Phi,\theta,n)$ are presented in detail in the below terminology (Table A8) of the **Appendix**. For clarification purposes, (q) refers to infiltration rate, (Φ) is the total porosity, (θ) is the liquid content/soil-water content, (n) is pore size distribution index. Rayleigh's method of indices was deployed along with the echelon matrix procedure as an additional confirmation method.
2	3	$ASTM_{2,3}$	[3]	Hydraulic Diffusivity	$ASTM_{1,3}$	Soil sorptivity (S) *depends on* hydraulic diffusivity (D), according to the implicit function: $$S=\left(\frac{z}{t^{0.5}}\right)*f\left((Sh),\left(\frac{M}{\rho*z^3}\right),\left(\frac{M}{\psi*t^2*z}\right),\left(\frac{z}{g*t^2}\right),\left(\frac{\mu*t*z}{M}\right),\left(\frac{M}{\rho_s*z^3}\right),\left(\frac{z^2}{k_{intr}}\right),(Sc),\left(\frac{M}{t^2*\gamma}\right)\right)$$ Where the terms, definitions and dimensions of $(S,z,t,Sh,M,\rho,\psi,g,\mu,\rho_s,k_{intr},Sc,\gamma)$ are presented in detail in the terminology (Table A8) of the **Appendix**. For clarification purposes, (M) refers to the initial liquid mass. Rayleigh's method of indices was deployed along with the echelon matrix procedure as an additional confirmation method.
2	4	$PP_{2,4}$	[20]	Effective liquid saturation	$ASTM_{1,4}$	Hydraulic conductivity (K) *depends on* effective saturation or degree of saturation (S_e), according to Van Genuchten-Mualem model [20], (equation 15c, page 23) initially introduced by van Genuchten, 1980 and Mualem, 1976: $$K(\theta)=K_s*S_e^l*\left[1-\left(1-S_e^{\left(\frac{1}{m}\right)}\right)^m\right]^2$$ where the terms, definitions and dimensions of $(K(\theta),K_s,S_e,m)$ are presented in detail in the terminology (Table A8) of the **Appendix** (where $m=1-\frac{1}{n}$).

Table A3. Description of all nodes (see **Figure A1**) under the form of Standards or published papers and the corresponding concepts (see **Figure A2**) which are included in the third generation.

3rd Generation						
Row	**Column**	**Node**	**Appendix references**	**Concept**	**Depends on/ Related to**	**Contribution**
3	1	$PP_{3,1}$	[35]	Total porosity	$ASTM_{2,1}$	The intrinsic permeability (k_{int}) *depends on* & can be calculated by combining Hagen-Poiseuille flow equation to Darcy's law and *depends on* the total porosity (Φ) according to equation (eq. 2, page 274): $k_{int}=\frac{\Phi}{8*\int_0^{\infty} f(r)*\mathrm{d}r}\int_0^{\infty} f(r)*r^2*\mathrm{d}r$, where the terms, definitions and dimensions of $(k_{int},\Phi, f(r),r)$ are presented in detail in the terminology (Table A8) of the **Appendix**.
3	2	$PP_{3,2}$	[43]	Water content	$ASTM_{2,2}$	Relative hydraulic conductivity (K_r) *depends on* water content (θ) according to the Mualem equation (1976), (eq.21, page 515): $K_r=\Theta^{1/2}*\left[\int_0^{\Theta}\frac{1}{h(x)}*\mathrm{d}x \Big/ \int_0^{1}\frac{1}{h(x)}*\mathrm{d}x\right]^2$, $\Theta=\frac{\theta-\theta_r}{\theta_s-\theta_r}$ where the terms, definitions and dimensions of (K_r,Θ,h,θ) are presented in detail in the terminology (Table A8) of the **Appendix**.
3	3	$ASTM_{3,3}$	[5]	Hydraulic conductivity	$ASTM_{2,3}$	Hydraulic diffusivity (D) *depends on* Hydraulic conductivity (K) according to the implicit equation: $D=(q*d_{inner})*f\left(\left(\frac{K}{q}\right),\left(\frac{1}{Re}\right),\left(\frac{K^2*\rho_s}{\psi}\right),\left(\frac{K^2}{g*d_{inner}}\right),\left(\frac{K^2*d_{inner}^2*\rho_s^2}{\rho^2*v_z^2*d_{grain}^2}\right),\left(\frac{d_{inner}^2}{k_{intr}}\right),\left(\frac{d_{inner}}{K*(t_i-t_p)}\right),\left(\frac{d_{inner}}{K*(t_p-t_f)}\right),\left(\frac{d_{inner}}{z}\right),\left(\frac{K^2*d_{inner}*\rho_s}{\sigma}\right),\left(\frac{d_{inner}}{H}\right),\Phi,\theta\right)$ where the terms, definitions and dimensions of $(D,q,Re,d_{inner},K,\rho_s,\psi,g,\rho,v_z,d_{grain},k_{intr},t_i,t_p,t_f,z,\sigma,H,\Phi,\theta)$ are presented in detail in the terminology (Table A8) of the **Appendix**. For clarification purposes, (q) refers to infiltration rate, (Φ) is the total porosity, (θ) is the liquid content/soil-water content. Rayleigh's method of indices was deployed along with the echelon matrix procedure as an additional confirmation method.
3	4	$PP_{3,4}$	[42]	Pressure head	$PP_{2,4}$	Water retention (θ) is *depended on* pressure head (h) according to Van Genuchten model (1980) which predicts the hydraulic conductivity (K) from the water retention curve and is expressed as the following given relationship (eq. 2 & 3, page 892): $\theta=\left(\frac{1}{1+(a*h)^b}\right)^c(\theta_s-\theta_r)+\theta_r$, where the terms, definitions and dimensions of $(\theta,a,h,b,c,\theta_s,\theta_r)$ are presented in detail in the terminology (Table A8) of the **Appendix**. For clarification purposes, (a,b,c) are parameters defined (ad hoc by Van Genuchten, 1980).

Continued

3	5	$ASTM_{3,5}$	[11]	Liquid viscosity	$ASTM_{2,1}$	Intrinsic permeability (k_{intr}) *depends on* liquid viscosity (μ), according to the implicit equation: $k_{intr} = h_c^2 * f\left(\left(\frac{h_c}{q*t}\right),(Sh),\left(\frac{h_c}{v_z*t}\right),(Sc),\left(\frac{\rho_s*h_c^2}{\psi*t^2}\right),\left(\frac{\rho_s*h_c^2}{\mu*t}\right),(Ri),\left(\frac{h_c^2}{t*D}\right),(Re),\left(\frac{h_c}{z}\right),(Ca),\left(\frac{C_i}{t*\left(\frac{dC_i}{dt}\right)}\right),\left(\frac{T_i}{h_c*\left(\frac{dT}{dz}\right)}\right),\Phi,\theta,S_e,n,i,K_s\right)$ Where the terms, definitions and dimensions of $\left(k_{intr},h_c,q,t,Sh,v_z,Sc,\rho_s,\psi,\mu,Ri,D,Re,z,Ca,C_i,T_i,T,\Phi,\theta,S_e,n,i,K_s,\frac{dC_i}{dt}\right)$ are presented in detail in the terminology (Table A8) of the **Appendix**. (q) refers to infiltration rate, (Φ) is the total porosity, (θ) is the liquid content/soil-water content, (n) is pore size distribution index, (K_s) is fluid solubility. Rayleigh's method of indices was deployed along with the echelon matrix procedure as an additional confirmation method.
3	6	$ASTM_{3,6}$	[10]	Gravitational acceleration	$ASTM_{2,1}$	Intrinsic permeability (k_{intr}) *depends on* gravitational acceleration (g), according to the implicit equation: $k_{intr} = h_c^2 * f\left(\left(\frac{h_c}{q*t}\right),(Sh),\left(\frac{h_c}{v_z*t}\right),(Sc),\left(\frac{\rho_s*h_c^2}{\psi*t^2}\right),\left(\frac{\rho_s*h_c^2}{\mu*t}\right),(Ri),\left(\frac{h_c^2}{t*D}\right),(Re),\left(\frac{h_c}{z}\right),(Ca),\left(\frac{C_i}{t*\left(\frac{dC_i}{dt}\right)}\right),\left(\frac{T_i}{h_c*\left(\frac{dT}{dz}\right)}\right),\Phi,\theta,S_e,n,i,K_s\right)$ Where the terms, definitions and dimensions of $\left(k_{intr},d_{grain},q,t,Sh,Re,Sc,\mu,\psi,\rho_s,d_{ring},Ri,D,\sigma,h_c\right)$ are presented in detail in the terminology (Table A8) of the **Appendix**. For clarification purposes, (q) refers to infiltration rate. Rayleigh's method of indices was deployed along with the echelon matrix procedure as an additional confirmation method.

Table A4. Description of all nodes (see Figure A1) under the form of Standards or published papers and the corresponding concepts (see Figure A2) which are included in the fourth generation.

4th Generation						
Row	**Column**	**Node**	**Appendix references**	**Concept**	**Depends on/ Related to**	**Contribution**
4	1	$PP_{4,1}$	[33]	Soil mass density	$PP_{3,1}$	According to Nimmo (2004) equation $\alpha = \left(1 - \frac{\rho_s}{\rho_p}\right)$ (equation 1, page 3), total porosity (α) or (Φ) *depends on* soil bulk density (ρ_s) and soil mass density or particle density (ρ_p), where the terms, definitions and dimensions of (α, ρ_s, ρ_p) are presented in detail in the terminology (Table A8) of the **Appendix**.
4	2	$PP_{4,2}$	[21]	Soil organic matter	$PP_{3,2}$	Water content is *related to* Soil Organic Matter (SOM). Soil organic matter content and composition effects on water content and soil water potential (pages 2282, 2285)[1].
4	3	$PP_{4,3}$	[32]	Effective liquid saturation	$ASTM_{3,3}$	Hydraulic conductivity (K) *depends on* Effective liquid saturation (S_e) according to Kozeny's approach and Corey's effective saturation definition (Mualem 1976), (equation 1 & 2, page 513): $K(\theta) = K_s * (S_e)^n$, $S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r}$ Where the terms, definitions and dimensions of $(K(\theta), K_s, S_e, \theta, \theta_r, \theta_s, n)$ are presented in detail in the terminology (Table A8) of the **Appendix**. Where (θ) is the liquid content/soil-water content and (n) is a shape parameter.
4	4	$PP_{4,4}$	[19]	Interfacial tension	$PP_{3,4}$	Pressure head (h), *depends on* interfacial tension (σ) according to Young-Laplace equation, (equation 3, page 1011): $h = -\frac{2 * \sigma * \cos\varphi}{\rho * r * g}$ Where the terms, definitions and dimensions of $(h, \sigma, \varphi, \rho, r, g)$ are presented in detail in the terminology (Table A8) of the **Appendix**. (φ) is the average contact angle of the liquid-air interface and (r) is the average pore space.
4	5	$PP_{4,5}$	[38]	Shear modulus/ Modulus of rigidity	$ASTM_{3,5}$	The viscosity (η) of the fluid *depends on* & can be varied by the variation of the angular relaxation frequency (ω_1) and the shear modulus (c_{44}), according to the equation: $\eta = \frac{c_{44}}{\omega_1}$, (equation 9, page 239), where the terms, definitions and dimensions of (η, c_{44}, ω_1) are presented in detail in the below terminology (Table A8) of the **Appendix**.
4	6	$PP_{4,6}$	[22]	Time	$ASTM_{3,6}$	The gravitational acceleration (g) *related to* time.

[1]No model/function or quantitative path exists, interconnecting the concepts, though experimentally proven.

Table A5. Description of all nodes (see Figure A1) under the form of Standards or published papers and the corresponding concepts (see Figure A2) which are included in the fifth generation.

5th Generation						
Row	**Column**	**Node**	**Appendix references**	**Concept**	**Depends on/ Related to**	**Contribution**
5	1	$PP_{5,1}$	[33]	Soil water retention	$PP_{4,1}$	The relation of pore-size to particle-size distribution is certain. Large pores can be associated with large and smaller particles (page 8). Consequently, pore-size and particle size distribution are *related to* measured soil water retention (page 5)[2]
5	2	$PP_{5,2}$	[26]	Soil texture	$PP_{4,2}$	Evidence suggests that soil texture influences the content, the distribution and the composition of soil organic matter (SOM) (pages 207, 208). Consequently, soil organic matter is *related to* soil texture.[3]
5	3	$PP_{5,3}$	[16]	Capillary pressure	$PP_{4,3}$	Effective liquid saturation (S_e) *depends on* Capillary pressure (P_c), according to Corey approximation equation (equation 10, page 10) $S_e=\left(\frac{c}{P_c}\right)^2$, where the terms, definitions and dimensions of (S_e, c, P_c) are presented in detail in the below terminology (Table A8) of the **Appendix**. For clarification purposes, (c) is a constant.
5	4	$ASTM_{5,4}$	[14]	Capillary Pressure head	$PP_{4,4}$	Interfacial tension (γ) *depends on* capillary pressure head (h_c), according to the implicit function: $$\gamma=\left(\frac{z}{t^2}\right)*f\left(\left(\frac{z}{q*t}\right),(Sh),\left(\frac{z}{v_z*t}\right),(Sc),\left(\frac{\mu}{\psi*t}\right),\left(\frac{t*\mu}{\rho_s*z^2}\right),(Ri),\left(\frac{z}{h_c}\right),\left(\frac{z^2}{t*D}\right),(Re),\left(\frac{z}{S*t^{0.5}}\right)\right)$$ where the terms, definitions and dimensions of $(\gamma, z, t, q, Sh, v_z, Sc, \mu, \psi, \rho_s, Ri, h_c, D, Re, S)$ are presented in detail in the below terminology (Table A8) of the **Appendix**. For clarification purposes, (q) refers to infiltration rate and (S) refers to the sorptivity. Rayleigh's method of indices was deployed along with the echelon matrix procedure as an additional confirmation method.
5	5	$ASTM_{5,5}$	[6]	Thermal diffusivity	$PP_{4,1}$	Soil mass density (ρ_s) *depends on* thermal diffusivity (D_{th}), according to implicit function: $$\rho_s=\left(\left(\frac{\lambda*T^3}{D_{th}^3*\left(\frac{dT}{dz}\right)^2}\right)*f\left(\left(\frac{D_{th}^2*\left(\frac{dT}{dz}\right)^2}{C*T^3}\right),\left(\frac{T^2}{t*D_{th}*\left(\frac{dT}{dz}\right)^2}\right),\left(\frac{T^3}{V_s*\left(\frac{dT}{dz}\right)^3}\right),\left(\frac{\lambda*T^6}{D_{th}^3*M_s*\left(\frac{dT}{dz}\right)^5}\right),\left(\frac{\lambda*T}{D_{th}*\left(\frac{dT}{dz}\right)*k_{th}}\right),\Phi,n\right)\right)$$ where the terms, definitions and dimensions of $(\rho_s, \lambda, T, D_{th}, z, C, v_s, M_s, k_{th}, \Phi, n)$ are presented in detail in the below terminology (Table A8) of the **Appendix**. For clarification purposes, (Φ) is the total porosity and (n) is pore size distribution index. Rayleigh's method of indices was deployed along with the echelon matrix procedure as an additional confirmation method.

[2]No model/function or quantitative path exists, interconnecting the concepts.
[3]No model/function or quantitative path exists, interconnecting the concepts.

Table A6. Description of all nodes (see **Figure A1**) under the form of Standards or published papers and the corresponding concepts (see **Figure A2**) which are included in the sixth generation.

6th Generation						
Row	**Column**	**Node**	**Appendix references**	**Concept**	**Depends on/ Related to**	**Contribution**
6	1	$PP_{6,1}$	[47]	Soil organic matter	$PP_{5,1}$	Results show that soil water retention is *related to* soil organic matter (SOM) (page 3086). Soil organic matter affects soil water retention because of its affinity to water and its influence on soil structure and bulk density (page 3087)[4]
6	2	$PP_{6,2}$	[18]	Type of rock of soil parent material	$PP_{5,2}$	The soil texture heterogeneity is controlled by the type of rock that constitutes the soil parent material (pages 157, 163). Consequently, soil texture is *related to* type of rock of soil parent material[5]
6	3	$PP_{6,3}$	[39]	Total Porosity	$PP_{5,3}$	The capillary pressure (P_c) *depends on* the porosity (Φ), (equation 3.4.1.14, page 58). $P_c = \left(\frac{\Phi}{K}\right)^{0,5} * \sigma * J(s)$, where the terms, definitions and dimensions of $\left(P_c, \Phi, K, \sigma, J(s), s\right)$ are presented in detail in the below terminology (**Table A8**) of the **Appendix**.
6	4	$PP_{6,4}$	[30]	Pore size distribution	$ASTM_{5,4}$	In van Genuchten's model, the capillary pressure (P_c) is *depended on* the pore size distribution (n), (eq. 2, page 3619): $P_c = a^{-1} * \left(S_e^{\left(-\frac{1}{m}\right)} - 1\right)^{\frac{1}{n}}$, where the terms, definitions and dimensions of $\left(P_c, a, S_e, m, n\right)$ are presented in detail in the below terminology (**Table A8**) of the **Appendix**.
6	5	$ASTM_{6,5}$	[1]	Thermal conductivity	$ASTM_{5,5}$	Thermal diffusivity (D_{th}) *depends on* thermal conductivity (λ), according to the implicit function: $D_{th} = \left(\frac{V_s^{\frac{2}{3}}}{t}\right) f\left(\left(\frac{V_s^{\frac{1}{3}} * M_s}{\lambda * t^3 * T}\right), \left(\frac{V_s^{\frac{2}{3}}}{C * t^2 * T}\right), \left(\frac{M_s}{\rho_s * V_s}\right), \left(\frac{T}{V_s^{\frac{1}{3}} * \left(\frac{dT}{dz}\right)}\right), \left(\frac{M_s}{t^2 * T * k_{th}}\right), \Phi, n\right)$ where the terms, definitions and dimensions of $\left(D_{th}, V_s, t, M_s, \lambda, T, C, \rho_s, z, k_{th}, \Phi, n\right)$ are presented in detail in the below terminology (**Table A8**) of the **Appendix**. For clarification purposes, (Φ) is the total porosity and (n) is pore size distribution index. Rayleigh's method of indices was deployed along with the echelon matrix procedure as an additional confirmation method.

[4]No model/function or quantitative path exists, interconnecting the concepts.
[5]No model/function or quantitative path exists, interconnecting the concepts.

Continued

6	6	$ASTM_{6,6}$	[12]	Heat transfer rate	$ASTM_{5,5}$	Thermal diffusivity (D_{th}) *depends on* heat transfer rate (q_H), according to the implicit function: $D_{th} = \alpha_s = \left(\frac{z^2}{t}\right) * f\left(\left(\frac{\rho_s * z^4}{\lambda_s * T_i * t^3}\right), \left(\frac{z^2}{C_s * t^2 * T_i}\right), \left(\frac{z^3}{V_s}\right), \left(\frac{T_i}{\left(\frac{dT}{dz}\right) * z}\right), (Bi), \left(\frac{z^2}{A}\right), \left(\frac{\rho_s * z^5}{t^2 * q_H}\right)\right)$ Where the terms, definitions and dimensions of $\left(D_{th}, z, t, \rho_s, \lambda_s, T_i, C_s, V_s, Bi, A, q_H\right)$ are presented in detail in the below terminology (Table A8) of the **Appendix**. For clarification purposes, (A) refers to specimen sectional area. Rayleigh's method of indices was deployed along with the echelon matrix procedure as an additional confirmation method.

Table A7. Description of all nodes (see **Figure A1**) under the form of Standards or published papers and the corresponding concepts (see **Figure A2**) which are included in the seventh generation.

7th Generation						
Row	**Column**	**Node**	**Appendix references**	**Concept**	**Depends on/ Related to**	**Contribution**
7	1	$PP_{7,1}$	[44]	Soil temperature	$PP_{6,1}$	Results show that soil organic matter (SOM) is *related to* soil temperature. Soil temperature is an important factor which affects soil organic matter (SOM) decomposition rate (pages 399, 403, 404)[6]
7	2	$PP_{7,2}$	[16]	Effective porosity	$PP_{6,3}$	Effective porosity (Φ_e) *depends on* the porosity (Φ) according to the (equation 19, page 23). $\Phi_e = (1 - S_r) * \Phi$ where the terms, definitions and dimensions of (Φ_e, S_r, Φ) are presented in detail in the below terminology (**Table A8**) of the **Appendix**.
7	3	$PP_{7,3}$	[27]	Soil water retention	$PP_{6,4}$	Statistics of the soil pore radius distribution function $g(r)$, is *related to* the water retention curve of Kosugi's further modified water retention model in which two parameters with physical significance are involved (page 1).[7]
7	4	$ASTM_{7,4}$	[9]	Soil temperature	$ASTM_{6,5}$	Thermal conductivity (λ_s) *depends on* soil temperature (T), according to the implicit function: $$\lambda_s = \left(\frac{\rho_s * z^4}{t^3 * T_i}\right) * f\left(\left(\frac{z^2}{C_s * t^2 * T_i}\right), \left(\frac{z^2}{t * a_s}\right), \left(\frac{z^3}{V_s}\right), \left(\frac{T_i}{\left(\frac{dT}{dz}\right) * z}\right), \left(\frac{\rho_s * z^3}{t^3 * T_i * k_{th(s)}}\right), \left(\frac{\rho_s * z^3}{t^3 * T_i * k_{th(w)}}\right), \left(\frac{\rho_s * z^4}{t^3 * T_i * \lambda_w}\right), (Pr), (St), \left(\frac{z^2}{t^2 * T_i * C_w}\right), \left(\frac{z^2}{A}\right), \left(\frac{z}{t * v_z}\right), \left(\frac{z^3}{V}\right), \left(\frac{\rho_s * z^2}{t * \mu}\right), \Phi, n, i\right)$$ where the terms, definitions and dimensions of $\left(\lambda_s, \rho_s, z, t, \lambda_w, T_i, z, C_s, C_w, k_{th(w)}, k_{th(s)}, V, \frac{dT}{dz}, \mu, v_z, A, K_{th}, \Phi, n, i\right)$ are presented in detail in the terminology (**Table A8**) of the **Appendix**. For clarification purposes, (Φ) is the total porosity and (n) is pore size distribution index. Rayleigh's method of indices was deployed along with the echelon matrix procedure as an additional confirmation method.
7	5	$ASTM_{7,5}$	[13]	Specific heat capacity	$ASTM_{6,5}$	Thermal conductivity (λ_s) *depends on* specific heat capacity (C), according to the implicit function: $$\lambda_s = \left(\frac{V_s^{\frac{1}{3}} * M_s}{t^3 * (\Delta T)}\right) * f\left(\left(\frac{V_s^{\frac{2}{3}}}{C * t^2 * \Delta T}\right), \left(\frac{M_s}{\rho_s * V_s}\right), \left(\frac{V_s^{\frac{2}{3}}}{t * a_s}\right), \left(\frac{\Delta T}{V_s^{\frac{1}{3}} * \left(\frac{dT}{dz}\right)}\right), \left(\frac{M_s}{t^3 * (\Delta T) * k_{th}}\right), \left(\frac{V_s^{\frac{2}{3}}}{A}\right), \Phi, n\right)$$ where the terms, definitions and dimensions of $(\lambda_s, V_s, M_s, t, T, C, \rho_s, a_s, k_{th}, A, \Phi, n)$ are presented in detail in the terminology (**Table A8**) of the **Appendix**. Where (C) refers to mean specific heat capacity, (Φ) is the total porosity and (n) is pore size distribution index. Rayleigh's method of indices was deployed along with the echelon matrix procedure as an additional confirmation method.

[4]No model/function or quantitative path exists, interconnecting the concepts.
[5]No model/function or quantitative path exists, interconnecting the concepts.

Continued

7	6	$PP_{7,6}$	[45]	Ground thermal/heat flux	$ASTM_{6,6}$	The heat transfer rate *depends on* ground heat/thermal flux (G_o), according to the equation 1, page 214: $R_n = H + LE + G_o$ where the terms, definitions and dimensions of (R_n, H, LE, G_o) are presented in detail in the below terminology (Table A8) of the **Appendix**.

Terminology Table—SI Units

Table A8. All the term and the soil/water physicochemical & biological properties that are being used in the above **Appendix** tables, including their symbols and dimensions.

Parent material *defined as* the reference to unconsolidated mass from which the solum is developed by pedogenic processes (soil survey manual)	
Particle size distribution is the fractions of the various soil separates in a soil sample, often expressed as mass percentages.	[1]
Soil organic matter (SOM) is the organic matter component of soil, consisting of plant and animal detritus at various stages of decomposition, cells and tissues of soil microbes, and substances that soil microbes synthesize	
Soil texture is a classification instrument used both in the field and laboratory to determine soil classes based on their physical texture	[1]

Latin Symbols

($\mathcal{A}$)	**Permeability coefficient** or **gravity term** *defined* ad hoc by (Jaynes & Gifford, 1981) *as* given in [25]	$[LT^{-1}]$
(A)	**Constant** *defined* ad hoc by Lassabatere et al., 2010, as given in [28]	$[L^{-1}]$
(a)	**Parameter** *defined* ad hoc by Van Genuchten, 1980 as given in [42], inverse of air entry pressure in soils	$[L^{-1}]$
(A_{infl}), (A)	**Cross section** of the infiltrometer cylinder/control volume **cross section**	$[L^2]$
(B)	**Constant** *defined* ad hoc by Lassabatere et al., 2010, as given in [28]	[1]
(b)	**Parameter** *defined* ad hoc by Van Genuchten, 1980 as given in [42]	[1]
(Bi)	**Biot number,** where $Bi = \frac{k_{th(s)} * V_s}{\lambda_s * A}$ heat transfer phenomena dimensionless quantity	[1]
(C)	**Specific capacity** in Richards' equation, as given in [37]	$[L^{-1}]$
(C), (C_s), (C_w)	**Specific heat capacity** (mean) *defined as* the ability of a given substance's mass to store enthalpy while undergoing a given temperature change without undergoing a phase change. ($_s$) denotes the bulk soil and ($_w$) denotes 'as regards the water'	$[M{\cdot}L^{-1}{\cdot}T^{-2}{\cdot}\Theta^{-1}]$
(c)	**Constant** *defined* ad hoc by Brooks & Corey, 1964 as given in [16]	$[M{\cdot}L^{-1}{\cdot}T^{-2}]$
(c)	**Parameter** *defined* ad hoc by Van Genuchten, 1980 as given in [42]	[1]
(Ca)	**Capillary number**, where $Ca = \frac{\mu * v_z}{\gamma}$ (Schluberger Oil Field Glossary)	[1]
(C_i)	**Concentration molecular** initial	$[L^{-3}{\cdot}mol]$
(c_{44})	**Shear modulus/elastic tensor** *defined as* the frequency-dependent elastic moduli by which a compressible viscous fluid is characterized	$[M{\cdot}L^{-1}{\cdot}T^{-2}]$
(D)	**Diffusivity/Hydraulic diffusivity** *defined as* the ratio of transmissivity divided by the storage coefficient (storativity) or the hydraulic conductivity divided by the specific storage (Lohman, 1972) as given in [31] and (United States Geological Survey—USGS, Glossary of Hydrologic Terms), as given in [50]	$[L^2{\cdot}T^{-1}]$
(D_{th})	See **thermal diffusivity**	$[L^2{\cdot}T^{-1}]$
($\frac{dC_i}{dt}$)	**Chemical reaction rate** *defined as* the speed at which reactants are converted into products	$[L^{-3}{\cdot}T^{-1}{\cdot}mol]$

Continued

(d_{grain})	**Mean soil grain diameter** *defined as* the average estimated value of the grained soil diameter	[L]
(d_{inner})	**Diameter** of the inner ring of a double ring infiltrometer	[L]
(d_{pore})	**Diameter mean pore size**	[L]
(d_{ring})	**Diameter** of the ring of the infiltrometer	[L]
($\frac{dT}{dz}$)	**Temperature/thermal gradient** vertical direction, within boundaries	[$L^{-1}\cdot\Theta$]
$f(r)$	**Volume frequency** *defined* ad hoc by Pereira & Arson, 2017 as given in [35]	[1]
(g)	**Gravitational acceleration/gravitational constant** *defined as* the acceleration on an object caused by the force of gravitation	[$L\cdot T^{-2}$]
(G_o)	**Ground heat flux** *defined as* energy received by the soil to heat it per unit of surface and time	[$M\cdot T^{-3}$]
$g(r)$	**Pore radius distribution function** by Kosugi, 1997, *as* given in [27]	[1]
(H)	**Sensible heat** (flux) *defined as* the energy moving from one system to another that changes its temperature rather than changing its phase	[$M\cdot T^{-3}$]
(H)	**Head of ponding** *defined as* the depth of the ponded water above the surface	[L]
(h)	**Soil water pressure head/Hydrostatic pressure** defined by the hydrostatic pressure expressed as the height of a column of water that the pressure can support at the point of measurement United States Geological Survey—USGS, Glossary of Hydrologic Terms, given in [50]. Hydrostatic pressure is the pressure exerted by the weight of water at any given point in a body of water at rest (American Geosciences Institute—AGI, Glossary of Geology), given in [48]. See also matric suction	[L]
(h_c)	**Capillary pressure head** *defined as* the pressure difference between a fluid of a higher pressure and another fluid of a lower. It is common practice to express the pressure as an equivalent of a water height Encyclopedia of Soil Science	[L]
($h_{c(e)}$)	**Capillary (entry) pressure head** *defined as* the pressure (in column height) to enter the non-wetting phase to the largest size of the pores of a porous medium Liu et al., 2014, as referred in [30]	[L]
(i)	**Hydraulic gradient/Darcy slope** *defined as* the inclination of the line joining different pressure heads. A line joining the points of highest elevation of water in a series of vertical open pipes rising from a pipeline in which water flows under pressure (ASCE)	[1]
$J(s)$	**Capillary pressure function** *defined* ad hoc by (Leverett, 1941) *as* the relationship between the capillary pressure and the pore structure, as given in [29]	[1]
(K)	**Hydraulic conductivity/Coefficient of permeability** *defined as* a proportionality constant (in Darcy's Law), relating hydraulic gradient to specific discharge which for an isotropic medium and homogeneous fluid, equals the volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow	[$L\cdot T^{-1}$]
(k_i), (k_{intr}), ($\boldsymbol{K}$)	**Intrinsic permeability/absolute permeability/specific permeability** *defined as* the measure of the relative ease with which a porous medium can transmit a fluid under a potential gradient and is a property of the medium alone Lohman, 1972, as given in [31] and United States Geological Survey—USGS, Glossary of Hydrologic Terms, given in [50] the measurement of the permeability, or ability to flow or transmit fluids through a rock, conducted when a single fluid, or phase, is present in the rock Schluberger Oil Field Glossary, as given in [49]	[L^2]
(K_i)	**Initial unsaturated hydraulic conductivity** *defined as* a quantitative measure of an unsaturated soil's ability to transmit water when subjected to a hydraulic gradient at the initial stage of wetting	[$L\cdot T^{-1}$]
(K_r)	**Relative hydraulic conductivity** *defined* ad hoc by Mualem's 1976 *as* given in [32], by the given equation (K_r) = $(\theta-\theta_r)/(\theta_s-\theta_r)$	[1]
(K_s)	**Fluid solubility** *defined as* the property of a fluid substance called solute to dissolve in a solid, liquid or gaseous solvent	[1]
(K_s)	**Saturated hydraulic conductivity** *defined as* a quantitative measure of a saturated soil's ability to transmit water when subjected to a hydraulic gradient or the easiness with which pores of a saturated soil permit water movement.	[$L\cdot T^{-1}$]

Continued

(k_{th}), ($k_{th(s)}$), ($k_{th(w)}$)	**Heat transfer coefficient/coefficient of convection** the proportionality constant between the heat flux and the thermodynamic driving force for the flow of heat (i.e., the temperature difference, ΔT). ($_s$) denotes the coefficient of the bulk soil and ($_w$) denotes "as regards the water"	[$M \cdot T^{-2.5} \cdot \Theta^{-1}$]
(l)	**Pore connectivity** empirical **parameter** of Mualem's equation with the value 0.5 commonly used *defined* ad hoc by Di Prima, 2016 *as* given in [20] and by (Oh et al., 2015) *as* given in [34]	[1]
(LE)	**Latent heat** *defined as* the flux of heat from the Earth's surface to the atmosphere and is associated with evaporation or transpiration	[$M \cdot T^{-3}$]
(M)	**Initial liquid mass** *defined as* the mass of our interest before the progress of a physical phenomenon	[M]
(M_s)	**Soil mass/Mass of the bulk soil** of our interest (control mass)	[M]
(m)	**Parameter** *defined* ad hoc by (Liu, et al., 2014) as given in [30]	[1]
(m)	**Calculated value** *defined* ad hoc by Di Prima, 2016 *as* the equal of the numerical quantity 1-(1/n) *as* given in [20], (eq. 15b)	[1]
(n)	**Shape parameter** *defined* ad hoc by Xu et al., 2012 as given in [46]	[1]
(n)	**Pore size distribution index** *defined* ad hoc by Mualem, 1976 & Van Genuchten, 1980 *as* given in [32] & [42]	[1]
(n)	**Parameter** *defined* ad hoc by Liu, et al., 2014 *as* given in [30]	[$M^{-1} \cdot L \cdot T^2$]
(p)	**Matric suction** *defined* ad hoc by Oh et al., 2015 *as* the pressure difference between the air and the water in soil pores [34]	[L]
(P_c)	**Capillary pressure** *defined as* the difference in pressure across the interface between two immiscible fluid phases jointly occupying the interstices of a porous medium caused by interfacial tension between the two phases American Geosciences Institute—AGI, Glossary of Geology, *as* given in [48]	[$M \cdot L^{-1} \cdot T^{-2}$]
$q(t)$, (q)	**Infiltration rate** *defined as* the volume flux of water entering through a unit soil surface area. Alternative symbols (f), $i(t)$	[$L \cdot T^{-1}$]
(q_H)	**Heat flux/heat transfer rate** *defined* ad hoc by Wang & Bou-Zeid, 2012, *as* given in [45]	[$M \cdot L^2 \cdot T^{-3}$]
(r)	**Average pore space** *defined as* the average space diameter among soil particles	[L]
(r)	**Radius** of natural pores *defined as* the radius of, for simplicity purposes, spherical shaped pores	[L]
(Re)	**Reynolds** number, where $Re = \frac{\rho_w * v_z * z}{\mu}$ introduced by Sommerfeld, 1909, *as* given in [40]	[1]
(Ri)	**Richardson number**, where $Ri = \frac{g * z}{v_z^2}$ dimensionless quantity in fluid mechanics	[1]
(R_n)	**Net radiation** see **Heat flux/heat transfer rate/** *defined as* the radiative flux transported towards the earth's surface	[$M \cdot T^{-3}$]
(s)	**Liquid saturation** *defined as* the volume of the liquid phase per unit void volume in the packed column	[1]
(S)	**Sorptivity/soil sorptivity** *defined* ad hoc by Philips, 1957 *as* the measure of the capacity of the medium to absorb or desorb liquid by capillarity, *as* given in [36]	[$L \cdot T^{-0.5}$]
(Sc)	**Schmidt number**, where $Sc = \frac{\mu}{\rho * D}$ dimensionless quantity in fluids mechanics	[1]
(S_e)	**Effective saturation/Degree of saturation/Percent saturation/Normalize water content** terms used equally, *defined as* the ratio expressed as a percentage of the volume of water to the total volume of intergranular space (voids) in a given porous medium regarding Van Genuchten, 1980, *as given* in [42]. Alternative symbol (Θ)	[1]
(S_o)	**Sorptivity** in state ($_o$) as regards Haverkamp, 1994 equation, *as* given in [24]	[$L \cdot T^{-0.5}$]
(Sh)	**Sherwood number**, where $Sh = \frac{K * z}{D}$ dimensionless quantity in diffusion mass transport	[1]
(S_{max})	**Maximum Sorptivity** *defined as* the maximum capacity of a medium (dry state) to absorb or desorb liquid by capillarity	[$L \cdot T^{-0.5}$]

Continued

(S_r)	**Residual saturation** *defined* ad hoc by Brooks & Corey, 1964 as given in [16]	[1]
(t)	**Time** elapsed	[T]
(t_f)	**Time** at the final stage of percolation	[T]
(T), (T_i)	**Temperature,** ($_i$) denotes the initial phase	[Θ]
(t_i)	**Time** at the initial stage of percolation	[T]
(t_p)	**Time** at the beginning of the ponding stage of percolation	[T]
(z)	**Percolation depth** (vertical)/wetting front/**heat transfer** length (vertical)/membranes **penetration depth**	[L]
(V)	**Water volume**	[L^3]
(V_s)	**Volume** of the bulk soil or massive **soil** (control volume)	[L^3]]
(v_z)	**Vertical percolation velocity** *defined as* the percolation that occurs in the vertical direction	[$L \cdot T^{-1}$]
(z)	**Vertical distance/**penetration depth/wetting depth/penetration depth at saturation state	[L]

Greek Symbols

(a)	**Parameter** *defined* ad hoc by Van Genuchten, 1980 as given in [42] as the reciprocal of capillary pressure	[$M^{-1} \cdot L\ T^2$]
(α)	**Total porosity** also given as (Φ), the complement of the ratio (ρ_s/ρ_p).	[1]
(α), (a_s), (a_w)	**Thermal diffusivity** *defined* as the ratio of the thermal conductivity to the volumetric heat capacity. Where ($_s$) denotes the bulk soil and ($_w$) denotes "as regards the water". It has the SI derived unit of ($m^2 \cdot s^{-1}$).	[$L^2 \cdot T^{-1}$]
(β_o)	**Brutsaert equation parameter** *defined* ad hoc by Brutsaert [17], as given in Assouline, 2013, *as* given in [15]	[1]
(β)	**Shape constant** in Haverkamp, 1994 equation, *as* given in [24]	
(γ)	**Vapour-liquid/Interfacial tension/Surface tension** *defined as* the elastic tendency of a fluid surface which makes it acquire the least surface area possible Speight, 2020, *as* given in [41]	[$M \cdot T^{-2}$]
(γ)	Proportionality **constant** in Haverkamp, 1994 equation, *as* given in [24]	
(ΔT)	**Initial temperature difference**	[T]
(δ).	**Interpolation parameter** of Haverkamp, 1990 equation, *as* given in [23]	
(η)	**Dynamic** or **absolute viscosity** *defined as* a measure of water's internal resistance	[$M \cdot L^{-1} \cdot T^{-1}$]
(Θ)	**Degree of saturation** (see also effective saturation)	[1]
(θ)	**Moisture content/soil-water content/water retention** *defined as* the ratio of the mass of water contained in the pore spaces of soil or rock material, to the solid mass of particles in that material, expressed as a percentage ASTM D653-20, given in [4]	[$L^3 \cdot L^{-3}$]
(θ_i)	**Initial moisture content** *defined as* the moisture volume percentage in soils before irrigation or raining	[$L^3 \cdot L^{-3}$]
(θ_m)	**Maximum moisture content** *defined as* the maximum value of the liquid content as given above	[$L^3 \cdot L^{-3}$]
(θ_o), (θ_n)	**Volumetric water content** in final & initial states according to Haverkamp, 1994 equation, as given in [24]	[$L^3 \cdot L^{-3}$]
(θ_r)	**Residual moisture content** is the quantity of water retained in a residual soil (as percent)	[$L^3 \cdot L^{-3}$]
(θ_s)	**Saturated moisture content** *defined as* the liquid content value in a saturated soil	[$L^3 \cdot L^{-3}$]
(λ)	**Thermal conductivity** *defined* as the proportionality factor in Fourier's Law that represents the ability of soil to conduct heat and is equivalent to the thermal flux per unit temperature gradient. In SI units, thermal conductivity is measured in watts per meter-kelvin ($W \cdot m^{-1} \cdot K^{-1}$). Thermal conductivity often denoted, λ, or κ). (λ) is referring to the liquid of our interest.	[$M \cdot L \cdot T^{-3} \cdot \Theta^{-1}$]
(λ_s)	**Thermal conductivity** where ($_s$) denotes the bulk soil	[$M \cdot L \cdot T^{-3} \cdot \Theta^{-1}$]

Continued

(λ_w)	**Thermal conductivity** where ($_w$) denotes the water phase	[M·L·T^{-3}·Θ^{-1}]
(μ)	See **Dynamic** or **absolute viscosity**	[M·L^{-1}·T^{-1}]
(ρ)	**Liquid's density** *defined as* a liquid is its mass per unit volume	[M·L^{-3}]
(ρ_p)	**Soil mass density** or **particle density**	M·L^{-3}]
(ρ_s)	**Soil bulk density/average bulk density** *defined as* for mostly powders and granules, the mass of many particles of the material divided by the total volume they occupy/the average density value of the control volume material	[M·L^{-3}]
(ρ_w)	**Water density** *defined as* water is its mass per unit volume	[M·L^{-3}]
(σ)	**Vapour-liquid Interfacial tension/Surface tension** *defined as* the elastic tendency of a fluid surface which makes it acquire the least surface area possible	[M·T^{-2}]
(Φ)	**Total porosity** also given *as* (**α**)	[L^3·L^{-3}]
(φ)	**Average contact angle** of the liquid-air interface	[1]
(Φ_e)	**Effective porosity** *defined as* the ratio of the volume of the voids of a soil or rock mass that can be drained by gravity to the total volume of the mass (ASTM D653-20), *as* given in [4]	[1]
(ψ)	**Soil water potential/water potential** *defined as* the quantification of the tendency of water to move from one area to another due to osmosis, gravity, mechanical pressure or matrix effects such as capillary action (which is caused by surface tension)	[M·L^{-1}·T^{-2}] or [L]
(ψ_f)	**Matric pressure/matric potential** at the wetting front *defined as* the difference between the applied air pressure and the water pressure. The pressure of the water in a pore of the medium relative to the pressure of the air United States Geological Survey—USGS, Glossary of Hydrologic Terms, *as* given in [50]	[M·L^{-1}·T^{-2}] or [L]
(ω_1)	**Angular relaxation frequency** *defined as* the oscillation frequency	[T^{-1}]

Appendix References

ASTM Standards

[1] ASTM C714-17, Standard Test Method for Thermal Diffusivity of Carbon and Graphite by Thermal Pulse Method.

[2] ASTM C1585-20, Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes.

[3] ASTM C1792-14, Standard Test Method for Measurement of Mass Loss versus Time for One-Dimensional Drying of Saturated Concretes.

[4] ASTM D653-20, Standard Terminology Relating to Soil, Rock, and Contained Fluids.

[5] ASTM D3385-18, Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer.

[6] ASTM D4612-16, Standard Test Method for Calculating Thermal Diffusivity of Rock and Soil.

[7] ASTM D5093-15e1, Standard Test Method for Field Measurement of Infiltration Rate Using Double-Ring Infiltrometer with Sealed-Inner Ring.

[8] ASTM D5126-16e1, Standard Guide for Comparison of Field Methods for Determining Hydraulic Conductivity in Vadose Zone.

[9] ASTM D5334-14, Standard Test Method for Determination of Thermal Conductivity of Soil and Soft Rock by Thermal Needle Probe Procedure.

[10] ASTM D5856-15, Standard Test Method for Measurement of Hydraulic Conductivity of Porous Material Using a Rigid-Wall, Compaction-Mold Permeameter.

[11] ASTM D7100-11 (2020) Standard Test Method for Hydraulic Conductivity Compatibility Testing of Soils with Aqueous Solutions.

[12] ASTM E1461-13, Standard Test Method for Thermal Diffusivity by the Flash Method.

[13] ASTM E2585-09 (2015) Standard Practice for Thermal Diffusivity by the Flash Method.

[14] ASTM F316-03 (2019) Standard Test Methods for Pore Size Characteristics of Membrane Filters by Bubble Point and Mean Flow Pore Test.

Scientific published papers

[15] Assouline, S. (2013) Infiltration into Soils: Conceptual Approaches and Solutions. *Water Resources Research*, **49**, 1755-1772. https://doi.org/10.1002/wrcr.20155

[16] Brooks, R.H. and Corey, A.T. (1964) Hydraulic Properties of Porous Media. Hydrology Papers, Colorado State University, Fort Collins.

[17] Brutsaert, W. (1977) Vertical Infiltration in Dry Soil. *Water Resources Research*, **13**, 363-368. https://doi.org/10.1029/WR013i002p00363

[18] Camara, J., *et al.* (2017) Lithologic Control on Soil Texture Heterogeneity. *Geoderma*, **287**, 157-163. https://doi.org/10.1016/j.geoderma.2016.09.006

[19] Culligan, P.J., *et al.* (2005) Sorptivity and Liquid Infiltration into Dry Soil. *Advances in Water Resources*, **28**, 1010-1020. https://doi.org/10.1016/j.advwatres.2005.04.003

[20] Di Prima, S. (2016) Testing a New Automated Single Ring Infiltrometer for Beerkan Infiltration Experiments. *Geoderma*, **262**, 20-34. https://doi.org/10.1016/j.geoderma.2015.08.006

[21] Drotz, S.H., *et al.* (2010) Effects of Soil Organic Matter Composition on Unfrozen Water Content and Heterotrophic CO2 Production of Frozen Soils. *Geochimica et Cosmochimica Acta*, **74**, 2281-2290. https://doi.org/10.1016/j.gca.2010.01.026

[22] Fu, W.S. and Shieh, W.J. (1990) A Transient Natural Convection in a Uniformly Heated Enclosure under Time—Dependent Gravitational Acceleration Field. *International Communications in Heat and Mass Transfer*, **17**, 501-510. https://doi.org/10.1016/0735-1933(90)90068-U

[23] Haverkamp, R., Parlange, J.Y., Starr, Y.L., Schmitz, G. and Fuentes, C. (1990) Infiltration under Ponded Conditions. 3. A Predictive Equation Based on Physical Parameters. *Soil Science*, **149**, 292-300. https://doi.org/10.1097/00010694-199005000-00006

[24] Haverkamp, R., Ross, P.J., Smetten, K.R.J and Parlange, J.Y. (1994) Three-Dimensional Analysis of Infiltration from the Disc Infiltrometer: 2. Physically Based Infiltration Equation. *Water Resources Research*, **30**, 2931-2935. https://doi.org/10.1029/94WR01788

[25] Jaynes, R.A. and Gifford, G.F. (1981) An In-Depth Examination of the Philip Equation for Cataloging Infiltration Characteristics in Rangeland Environments. *Journal of Range Management*, **34**, 285-296. https://doi.org/10.2307/3897853

[26] Jindaluang, W., *et al.* (2013) Influence of Soil Texture and Mineralogy on Organic Matter Content and Composition in Physically Separated Fractions Soils of Thailand. *Geoderma*, **195-196**, 207-219. https://doi.org/10.1016/j.geoderma.2012.12.003

[27] Kosugi, K. (1997) A New Model to Analyze Water Retention Characteristics of Forest Soils Based on Soil Pore Radius Distribution. *Journal of Forest Research*, **2**, 1-8. https://doi.org/10.1007/BF02348255

[28] Lassabatere, L., *et al.* (2010) Effect of the Settlement of Sediments on Water Infiltra-

tion in Two Urban Infiltration Basins. *Geoderma*, **156**, 316-325.
https://doi.org/10.1016/j.geoderma.2010.02.031

[29] Leverett, M.C. (1941) Capillary Behavior in Porous Solids. *Transactions of the AIME,* **142**, 159-172. https://doi.org/10.2118/941152-G

[30] Liu, Y., *et al.* (2014) Effects of Capillary Pressure—Fluid Saturation—Relative Permeability Relationships on Predicting Carbon Dioxide Migration during Injection into Saline Aquifers. *Energy Procedia*, **63**, 3616-3631.
https://doi.org/10.1016/j.egypro.2014.11.392

[31] Lohman, S.W. (1972) Ground-Water Hydraulics. U.S. Geological Survey, Report: viii, 70 p., 9 Plates.

[32] Mualem, Y. (1976) A New Model for Predicting the Hydraulic Conductivity of Unsaturated Porous Media. *Water Resources Research*, **12**, 513-522.
https://doi.org/10.1029/WR012i003p00513

[33] Nimmo, J.R. (2004) Porosity and Pore Size Distribution. In: *Encyclopedia of Soils in the Environment*, Elsevier, London, Vol. 3, 295-303.
https://doi.org/10.1016/B0-12-348530-4/00404-5

[34] Oh, S., *et al.* (2015) A Modified van Genuchten-Mualem Model of Hydraulic Conductivity in Korean Residual Soils. *Water*, **7**, 5487-5502.
https://doi.org/10.3390/w7105487

[35] Pereira, J.M. and Arson, C. (2013) Retention and Permeability Properties of Damaged Porous Rocks. *Computers and Geotechnics*, **48**, 272-282.
https://doi.org/10.1016/j.compgeo.2012.08.003

[36] Philips, J.R. (1957) The Theory of Infiltration: 4. Sorptivity and Algebraic Infiltration Equations. *Soil Science,* **84**, 257-264.
https://doi.org/10.1097/00010694-195709000-00010

[37] Richards, L.A. (1931) Capillary Conduction of Liquids through Porous Mediums. *Physics*, **1**, 318-333. https://doi.org/10.1063/1.1745010

[38] Saenger, E.H., *et al.* (2011) Digital Rock Physics: Effect of Fluid Viscosity on Effective Elastic Properties. *Journal of Applied Geophysics,* **74**, 236-241.
https://doi.org/10.1016/j.jappgeo.2011.06.001

[39] Scheidegger, A.E. (1957) The Physics of Flow through Porous Media. 3rd Edition, University of Toronto Press, Toronto. https://doi.org/10.3138/9781487583750

[40] Sommerfeld, A. (1909) Ein Beitrag zur hydrodynamischen Erklärung der turbulenten Flüssigkeitsbewegungen (A Contribution to Hydrodynamic Explanation of Turbulent Fluid Motions). *International Congress of Mathematicians*, Vol. 3, 116-124.
https://docplayer.org/65491852-A-sommerfeld-ein-beitrag-zur-hydrodynamischen-der-turbulenten-fluessigkeitsbeweguengen-uebersicht-ueber-die-litteratur-des-gegenstandes.html

[41] Speight, G.J. (2020) Natural Water Remediation, Chemistry and Technology.
https://doi.org/10.1016/B978-0-12-803810-9.00003-6

[42] Van Genuchten, M.T. (1980) A Closed-Form Equation for Predicting the Hydraulic Conductivity of Unsaturated Soils. *Soil Science Society of America Journal*, **44**, 892-898. https://doi.org/10.2136/sssaj1980.03615995004400050002x

[43] Vereecken, H. (1995) Estimating the Unsaturated Hydraulic Conductivity from Theoretical Models Using Simple Soil Properties. *Geoderma*, **65**, 81-92.
https://doi.org/10.1016/0016-7061(95)92543-X

[44] Wang, D., *et al.* (2016) Effects of Temperature and Moisture on Soil Organic Matter

Decomposition along Elevation Gradients on the Changbai Mountains, Northeast China. *Pedosphere*, **26**, 399-407. https://doi.org/10.1016/S1002-0160(15)60052-2

[45] Wang, Z.H. and Bou-Zeid, E. (2012) A Novel Approach for the Estimation of Soil Ground Heat Flux. *Agricultural and Forest Meteorology*, **154**-**155**, 214-221. https://doi.org/10.1016/j.agrformet.2011.12.001

[46] Xu, X., *et al*. (2012) Analysis of Single-Ring Infiltrometer Data for Soil Hydraulic Properties Estimation: Comparison of BEST and Wu Methods. *Agricultural Water Management*, **107**, 34-41. https://doi.org/10.1016/j.agwat.2012.01.004

[47] Yang, F., *et al*. (2014) Organic Matter Controls of Soil Water Retention in an Alpine Grassland and Its Significance for Hydrological Processes. *Journal of Hydrology*, **519**, 3086-3093. https://doi.org/10.1016/j.jhydrol.2014.10.054

Glossary and Terms

[48] American Geosciences Institute AGI (2020) Glossary of Geology. Fifth Edition, Revised. https://www.americangeosciences.org/pubs/glossary

[49] Schluberger Oil Field (2020) The Oilfield Glossary. https://www.glossary.oilfield.slb.com

[50] United States Geological Survey USGS (2020) Glossary of Hydrologic Terms. https://or.water.usgs.gov/projs_dir/willgw/glossary.html