4 ADDITIONAL INDICATORS OF WATER MANAGEMENT

4.13 Measured infiltration rate and capacity

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Author/s and affiliations: Laura Wendling[1], Ville Rinta-Hiiro[1], Maria Dubovik[1], Arto Laikari[1], Johannes Jermakka[1], Zarrin Fatima[1], Malin zu-Castell Rüdenhausen[1], Peter Roebeling[2], Ricardo Martins[2], Rita Mendonça[2]

[1] *VTT Technical Research Centre Ltd, P.O. Box 1000 FI-02044 VTT, Finland*

[2] *CESAM – Department of Environment and Planning, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal*

Infiltration rate **Infiltration capacity**	**Water Management**
Description and justification	Surface imperviousness is characteristic of urban areas and an important environmental indicator (Arnold & Gibbons, 1996; Strohbach et al., 2019). As surface imperviousness increases, the volume and velocity of surface runoff increases and there is a corresponding decrease in water infiltration. A high proportion of surfaces in urban areas are impermeable and the impermeability of surfaces in the cities is increasing as cities become more densely populated. The impermeability of urban surfaces originates from constructing buildings, roads, parking areas, etc., with materials that are not permeable to water.
Definition	Infiltration capacity (%; change in precipitation infiltration capacity measured using ring infiltrometer & extrapolated/modelled for full unsealed area)
Strengths and weaknesses	+ Straightforward assessment of infiltration capabilities of soil + Fairly easy to run the experiments - Several measurement locations may not represent the situation holistically - Potential sources of errors during the measurement procedure
Measurement procedure and tool	When measuring water flow parameters in the field (field-saturated parameters), the measurements in the unsaturated or vadose zone (above the water table), are typically conducted using various ring infiltrometer and borehole or well permeameter methods. In the saturated zone (below the water table), water flow parameters (saturated parameters) are usually measured using auger hole methods, and at greater depths using piezometer methods.

Measurements of water flow parameters of the soil in the vadose zone using ring infiltrometers can be conducted with the following steps (Reynolds et al., 2002):

1. The cylinder is inserted 3-10 cm into the soil. The contact between the soil and the inside cylinder should be lightly tamped to prevent flow or leakage around the cylinder walls.

2. A constant depth of water is ponded inside the measuring cylinder and also inside the buffer cylinder if the concentric-ring infiltrometer is used. The ponding depth is usually 5-20 cm depending on the circumstances.

3. The water infiltration rate through the measuring cylinder is measured. The infiltration rate through the buffer cylinder can also be measured if single-ring and concentric-ring infiltration rate results are compared. Quasi-steady flow in the near-surface soil under the measuring cylinder is assumed to occur when the discharge becomes effectively constant. The field-saturated hydraulic conductivity, K_{fs}, can be calculated using the Equation 1.

$$q_s/K_{fs} = Q/(\pi a^2 K_{fs}) = [H/(C_1 d + C_2 a)] + \{1/[\alpha^*(C_1 d + C_2 a]\} + 1 \quad (1)$$

where q_s (L T^{-1}) is quasi-steady infiltration rate, K_{fs} (L T^{-1}) is the field-saturated hydraulic conductivity, Q (L^3 T^{-1}) is the corresponding quasi-steady flow rate, a (L) is the ring radius, H (L) is the steady depth of ponded water in the ring, d (L) is the depth of ring insertion into the soil, C_1=0.316π and C_2=0.184π are dimensionless quasi-empirical constants that apply for d ≥3 cm and H ≥5 cm (Reynolds & Elrick, 1990; Youngs, Leeds-Harrison, & Elrick, 1995). The macroscopic capillary length, α (L^{-1}), can be estimated from soil structure and texture or measured using independent methodology. Some values for α:

Table 1: Soil texture-structure categories for site-estimation of the parameter "α" (Reynolds et al., 2002, adapted from Elrick, Reynolds & Tan, 1989).

Soil texture and structure category	**α* (cm^{-1})**
Compacted, structureless, clayey or silty materials such as landfill caps and liners, lacustrine or marine sediments	0.01
Soils that are both fine textured (clayey or silty) and unstructured; may also include some fine sands.	0.04

Most structured soils from clays through loams; also includes unstructured medium and fine sands. The category most frequently applicable for agricultural soils.	0.12
Coarse and gravelly sands; may also include highly structured or aggregated soils, as well as soils with large and/or numerous cracks, macropores.	0.36

The following instructions for measuring infiltration of a water permeable pavement are based on the ASTM C1701/C1701M-09 (infiltration rate of in situ pervious concrete). More detailed instructions are provided in the standard.

• Install the infiltration ring. The joint between the ring and the pavements should be made watertight using, e.g., plumber’s putty.

• Conduct pre-wetting. Pour a total of 3.60 ± 0.05 kg of water inside the ring so that the head maintains between lines marked inside the ring. The timing starts when the water hits the surface and it stops when there is no free water left on the surface.

• Conduct the test. The test shall start within 2 min after the completion of the pre-wetting. Similar procedure for the test is used than in the pre-wetting. However, if the elapsed time in the pre-wetting was less than 30 s, a total of 18.00 ± 0.05 kg of water is used in the test.

Scale of measurement	Plot scale to street scale
Data source	
Required data	Soil texture and structure category, infiltration rate of soil
Data input type	Quantitative
Data collection frequency	Annually, and before and after NBS implementation
Level of expertise required	Moderate – requires ability to perform the experiment High – for executing the calculations
Synergies with other indicators	Indirect relation to the whole *Water Management* indicator group
Connection with SDGs	SDG 11 Sustainable cities and communities, SDG 13 Climate action
Opportunities for participatory data collection	Participatory data collection is feasible through conducting an infiltration rate experiment under supervision

Additional information	
References	Arnold, C.L., Jr., & Gibbons, C.J. (1996). Impervious surface coverage: The emergence of a key environmental indicator. Journal of the American Planning Association, 62(2), 243-258. ASTM C1701/C1701M-09. Standard test method for infiltration rate of in place pervious concrete. Reynolds, W.D., Elrick, D.E., & Youngs, E.G. (2002). Ring or Cylinder Infiltrometers (Vadose Zone). In J.H. Dane & G.C. Topp (Eds.), Methods of Soil Analysis. Part 4 Physical Methods. Madison, Wisconsin: Soil Science Society of America, Inc. Strohbach, M.W., Döring, A.O., Möck, M., Sedrez, M., Mumm, O., Schneider, A.-K., … Schröder, B. (2019). The “hidden urbanization”: Trends of impervious surface in low-density housing developments and resulting impacts on the water balance. Frontiers in Environmental Science, 7, 29. Youngs, E.G., Leeds-Harrison, P.B., & Elrick, D.E. (1995). The hydraulic conductivity of low permeability wet soils used as landfill lining and capping material: analysis of pressure infiltrometer measurements. Journal of Soil Technology, 8, 153-160.

4.14 Calculated infiltration rate and capacity

Project Name: OPERANDUM (Grant Agreement no. 776848)

Author/s and affiliations: Alejandro Gonzalez-Ollauri[1] , Slobodan B. Mickovski[1]

[1] *Built Environment Asset Management Centre, Glasgow Caledonian University, Glasgow, Scotland, UK*

Infiltration rate **Infiltration capacity**	**Water Management**
Description and justification	It refers to the speed at which water moves into and through the soil profile. It is normally expressed as the volume of water (measured in terms of water column) infiltrating within a given soil area per unit of time. It is related to the soil’s ability to allow water movement within the soil profile, to the storage of water in the soil, the water available to plants, or the generation of runoff. Calculated infiltration rate can be derived from classic soil infiltration models, from pedotransfer functions, or from simple soil water mass balances.
Definition	Volume of water infiltrating a soil volume per unit of time