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RECOMMENDED GUIDANCE FOR *IN-SITU* MEASUREMENT OF SATURATED HYDRAULIC CONDUCTIVITY BY THE CONSTANT HEAD WELL PERMEAMETER METHOD AND FOR REPORTING RESULTS

The purpose of this document is to assist licensed or registered professionals in the collection and submission of saturated hydraulic conductivity (Ksat) data to local health departments (LHD) and the On-site Water Protection Branch (OSWP). Saturated hydraulic conductivity data should be collected and reported by licensed soil scientists (LSS), licensed geologists (LG), or professional engineers (PE) as required pursuant to G.S. 89C, 89E, or 89F, as applicable. Saturated hydraulic conductivity data for unsaturated soil horizons above the water table are important in the design of on-site wastewater systems. This guidance document is specific to the constant-head well permeameter method (also known as “borehole permeameter method” or “constant-head borehole infiltration test”). The respective procedures contained in the American Society of Testing and Materials (ASTM) Standard D 5126-90 and Methods of Soil Analysis and Drainage Monographs published by Soil Science Society of America (SSSA) have been incorporated into this guidance. Other procedures such as those presented in ASTM D 5126-90 or the aforementioned monographs may also be used for determining soil hydraulic conductivity although they are not discussed in this guidance document.

These recommendations were developed by private and public licensed soil scientists as well as OSWP staff. The recommendations specify minimum procedures and reporting that will expedite review of permit requests and potentially eliminate the need for repeat measurements. Licensed professionals may submit or propose alternative methods of Ksat data collection.

I. Equipment
   a. A commercially available permeameter or similar device for maintaining a constant depth of water in a cylindrical auger hole at a desired depth and measuring the flow rate of water into the soil.
   b. An auger set (including a cutting head, planer or hole cleaner, brush, and extensions) for boring a cylindrical hole.
   c. Any additional equipment specified/recommended in the respective procedure or by the manufacturer of the permeameter. Please describe and justify deviations from the respective procedure or manufacturer’s specifications, as appropriate.

II. Evaluation
   a. Perform all activities (including saturation) according to the respective procedure or manufacturer’s instrument-specific manual.

b. Measurement depths
   i. Measure Ksat at the proposed trench bottom elevation where possible, and at every distinct horizon within and beneath the treatment zone, as applicable.
   ii. Conduct measurements in every horizon at and below the proposed trench bottom elevation to a depth of 48 inches below the ground's surface or to a depth referenced in an associated hydraulic analysis (mounding analysis, lateral flow, etc.).
   iii. Because of potential water flow to the surface, only Ksat measurements at depths greater than six (6) inches from the ground's surface are generally considered valid.
   iv. Where appropriate, conduct measurements within a single horizon. Avoid inclusion of more than one (1) horizon (i.e., straddling two [2] or more horizons) if the thickness of the master (O, A, E, B, or C) horizon under consideration is greater than the required depth of the water in the hole.
   v. Select the depth of water in the hole according to the recommendations outlined in the respective procedures and maintain it constantly throughout the test. For commercial devices, consult the manufacturer's manual for selection of an appropriate water depth.
   vi. Provide a description of any deviation from respective recommendations.
c. Measurement location and replication
   i. General
      1. Field assessment of the variability of soil type, landscape position and proposed system capacity by the LSS determines the appropriate location of measurements and number of replicates necessary to characterize the hydraulic conductivity of the initial drainfield(s) and repair area(s). Please justify the number and locations of the measurements performed.
      2. For the purposes of this guidance document and at a minimum, measure Ksat at the depths set forth in Sections c.ii, c.iii, and c.iv. below.
   ii. Daily design flow ≤ 480 gallons per day (gpd)
      1. Measure Ksat at locations that best characterize the soil and site conditions within each zone and soil type on the site.
      2. OSWP advises measuring Ksat at a minimum of three (3) nests or replicates. A nest represents the soil profile at a particular location. A nest or replicate includes all appropriate depths as indicated in Section II.b.i-iv at one particular location on the site. For example, if there are three (3) horizons in a profile from the trench bottom elevation to 48 inches below the ground's surface, the nest will include one (1) measurement in each of the three (3) horizons for a total of three (3) measurements. Thus, one (1) nest will contain three (3) measurements. The nest will then be replicated at a minimum of two (2) other locations on the site, for a total of nine (9) measurements.
   iii. Daily design flow > 480 gpd but ≤3000 gpd
      1. Measure Ksat at locations that best characterize the soil and site conditions within each zone and soil type on the site.
      2. OSWP advises taking Ksat measurements at a minimum of three (3) Ksat nests per soil type and/or at least two (2) nests per acre of evaluation area. A nest represents the soil profile at a particular location. A nest or replicate includes all appropriate depths as indicated in Section II.b.i-iv at one particular location on the site. For example, for a one-acre evaluation area with one soil type, evaluate a minimum of three (3) replicate Ksat nests in three (3) representative locations; and for a two-acre evaluation area with one soil type, evaluate minimum of four (4) replicate Ksat nests in four (4) different representative locations. For sites with multiple soil types within the evaluation area, evaluate a minimum of three (3) nests per soil type.

iv. Daily design flow > 3000 gpd
1. Due to the increased complexity of siting these systems, OSWP strongly recommends the licensed professional meet with the respective local health department (LHD) representative and regional soil scientist (RSS) to discuss nest locations prior to performing saturated hydraulic conductivity testing.
2. Measure Ksat at locations identified and agreed upon with the RSS and LHD representative to best characterize the soil and site conditions within each zone and soil type in the evaluation area.

v. Please describe and justify deviations from the procedures suggested here.

d. Measurement recording frequency
i. Measure Ksat at time intervals outlined in the respective procedures or manufacturer's instrument-specific manual. In general:
1. For Group II and III soil textures, measure and record at intervals of 15 minutes (or at least 100 cm^3 of water flow into the soil) for a minimum run time of two (2) hours **AND** until steady state is achieved.
2. For Group IV soil textures, measure and record at intervals of 30 minutes (or at least 100 cm^3 of water flow into the soil) for a minimum run time of four (4) hours **AND** until steady state is achieved.

ii. Please describe and justify deviations from the procedures suggested here.

e. Steady state
i. Achieve steady state equilibrium at each test. Provide an explanation if steady state equilibrium is not achieved.
ii. Where the measurement is conducted under a constant depth of water, steady state condition for Ksat can be defined as the time during which the rate of water flow from the hole reaches a constant value (i.e., no longer changes with time). Steady state is achieved when three (3) consecutive flow rate measurements are the same.
iii. Alternately, after allowing saturation of the soil around the hole, flow rate should reach a quasi-steady state condition during which it varies around an average value. To determine this average, it is best to plot the rate of water flow (or the calculated Ksat values) versus time and pass a smooth curve through them using a manually (referred to as fitting a curve by eye) or a mathematically (e.g., statistically) best fitted curve. The steady state flow rate is reached if the tail end of this fitted curve is nearly horizontal without showing an upward or downward trend. Use the arithmetic mean flow rate for the last three (3) to five (5) measurements after reaching steady state to calculate Ksat.
iv. Please describe and justify deviations from the procedures suggested here.

III. Data Reporting

a. At a minimum, a "complete" report includes, but is not limited to:
i. Date, time, and weather conditions when data were collected
ii. Description of methodology
iii. Equipment type used
iv. Soil profile descriptions for all borings including measurement borings prepared by an LSS
v. Locator map showing location of all Ksat measurements and borings
vi. Adequate description of constants and equations used

vii. Report the following for each measurement:
1. Auger hole diameter
2. Depths of measurements

3. Depth of water in the hole under the constant head
4. Saturation start time and steady state time
5. Clock time
6. Reservoir readings
7. Change in time
8. Change in the water level in the permeameter
9. Flow volume
10. Flow rate (flow volume/time)
11. Graph of rate of water flow (or calculated Ksat values) vs. time
12. Ambient temperature, and temperature of water in the hole if temperature correction is needed

b. Note: Recommended calculations using the Glover Equation are as follows:
   i. For $s \geq 2H$:

$$K_{sat} = AQ$$

where:

$$A = \{\sinh^{-1}(H/r) - [(r/H)^2 + 1]^{1/2} + r/H\}/(2\pi H^2)$$

   ii. For $s < 2H$:

$$K_{sat} = BQ$$

where:

$$B = \{3\ln(H/r)/[\pi H(3H + 2s)]\}$$

Q is the steady state rate of water flow from the permeameter
Sinh^{-1} is the inverse hyperbolic sine function
r is the radius of the borehole
H is the depth of water in the hole
s is the distance from the bottom of the hole to an impermeable layer
ln(H/r) is the natural logarithm of H/r.

c. Provide justification from the manufacturer or practitioner if an alternative equation other than Glover Equation is used.
d. OSWP recommends measuring Ksat when ambient temperatures are between 60 degrees F and 110 degrees F. Use temperature correction based on temperature variations in the viscosity of water (as suggested by the respective procedure) when appropriate. Use correction factors based on the temperature of the water in the boring (not ambient temperature). Include a description of temperature correction in the report.
e. In addition to the usual units of length over time (e.g., in/day, cm/hour), report the equivalent value for Ksat in gallons per day per square foot (gpd/ft^2).
f. Complete reports include the date of completion and signature and seal of the LSS, LG, or PE providing the service.

IV. Results

a. Ksat values are used to support a proposed long term acceptance rate (LTAR), perform lateral flow analysis and model groundwater mounding. For untreated effluent (i.e. primary septic tank effluent and NSF-40), OSWP recommends LTARs that do not exceed 10% of the average measured Ksat values. LTAR for TS-I and TS-II treated effluent should not exceed 25% of Ksat.

b. Ksat measurements cannot be used as a means to validate unsuitable soils.
c. Use the geometric mean to support LTAR, lateral flow analysis and groundwater mounding model calculations.

The above guidance is designed to encourage more uniform measurement and reporting of Ksat data. Provide justification for the use of methods, procedures and equipment that vary from the procedures described above.

V. References:

Aardvark Permeameter Operating Instructions. Soilmoisture Equipment Corp. 2012. http://www.soilmoisture.com/PDF%20Files/82840K1%20Aardvark%20Permeameter.pdf

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Amoozegar, A., and G. V. Wilson. 1999. Methods for measuring hydraulic conductivity and drainable porosity. p. 1149-1205. In R. W. Skaggs and J. van Schilfgaarde (ed.) Agricultural Drainage. Agronomy Monograph No. 38, ASA-CSSA-SSSA, Madison, WI.

ASTM Standard D 5126. 2006. Standard guide for comparison of field methods for determining hydraulic conductivity in vadose zone. Annual Book of ASTM Standards, ASTM International, West Conshohocken, PA.

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Process Design Manual for Land Treatment of Municipal Wastewater, Supplement on Rapid Infiltration and Overland Flow. 1984. Center for Environmental research Information, US Environmental Protection Agency, Cincinnati, OH.

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USBR 7300-89. Procedure for Performing Field Permeability Testing by the Well Permeameter Method. Geotechnical Services Branch, code D-3760, Research and Laboratory Services Division, US Department of the Interior, Bureau of Reclamation, Denver Office. Pp. 1227-1236.