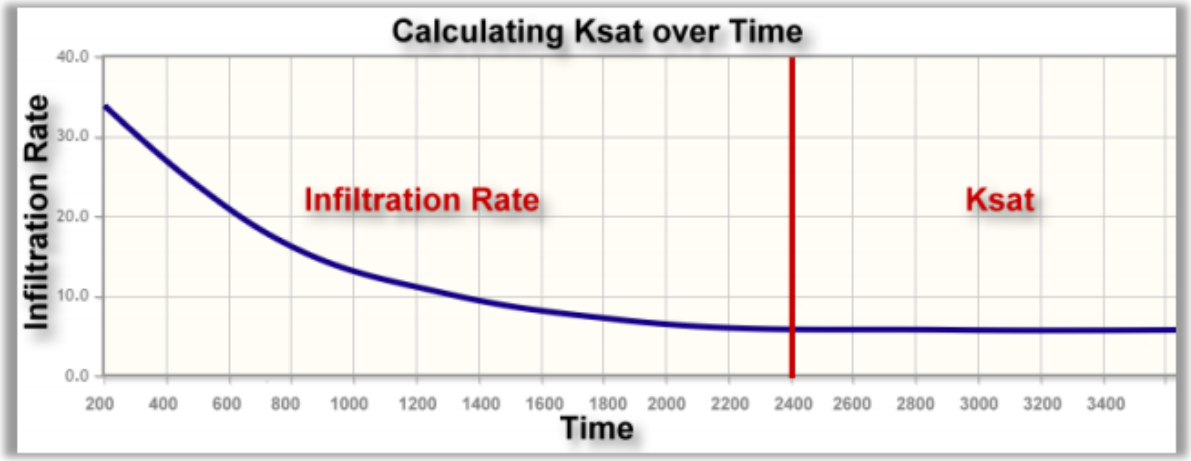
Upstream Technologies Inc.
5201 East River Road, Suite 303
Fridley, MN 55421
651-237-5123
www.upstreamtechnologies.us

U.S. Patent # 11,353,391 B2
U.S. Patent # 10,739,242 B2

MPD – Modified Philip & Dunne and other infiltration test methods

Definitions:

- Infiltration Rate: The height of water drop in a cylinder, divided by time, regardless of the soils saturation level. If the soil is dry, the infiltration rate will be fast. If the soil is wet, the infiltration rate will be slow.
- Ksat (Hydraulic Conductivity of Soil): The infiltration rate when the soil is 100% saturated.
- 100% Saturated Soil: When all the void space between soil particles are occupied with water.
- Steady State Infiltration Rate: The infiltration rate when the soil is 100% Saturated (Ksat)



No mater what device is used, (Double Ring, Percolation, MPD or Turf-Tec) the infiltration rate from each, if plotted over time, would be identical.

As an example: Let's say it has not rained in 6 weeks and the ground is very dry. And an infiltration test is conducted using 5 inches of water in any device and the amount of time is recorded to infiltrate. 5 inches (divided by) Time = Infiltration Rate. This value is plotted on the graph above.

The test is then repeated many times, in the exact same spot, and recorded on the graph. This graph would appear like the image above. As the ground becomes more saturated with each test conducted, the infiltration rate would slow down with each test. At some point in the future, the infiltration rate will no longer slow down. It will have reached a "Steady State" where each test conducted would produce the same rate of infiltration. The ground is 100% saturated. All void space between soil particles are now filled with water. The infiltration rate measured at this point is "Field Hydraulic Conductivity of Soil" or Ksat. This is the worst-case infiltration rate (slowest) for this location of soil.

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Various Devices and Methods:

Percolation Test:

A standard perc test assumes the ground is 100% saturated after so many hours of filling the hole with water. Once that assumption is made, infiltration rate is measured. (Water drop divided by time). If the assumption is correct, and the ground is 100% saturated, then the infiltration rate is assumed to be Ksat and is a very accurate result. (The slowest infiltration rate possible). This test is only subjective to the technician's ability to observe and determine 100% saturation. This test can take many hours to perform and usually requires hundreds of gallons of water.

Double Ring Test:

The Double Ring uses a more refined approach than the perc test and assumes that the outer ring will saturate the ground with more scientific deliberation and force the center ring to infiltrate in a vertical fashion. The double ring is a good method and it produces a useful result that is used to design infiltration practices. The difficulty with the double ring, is the amount of water and time that is needed to ensure 100% saturation before the measurement is performed. Same as the Perc Test.

Turf-Tec:

The Turf-Tec is a miniature double ring test with an integrated measurement scale and built in timer. This device is mostly used by golf courses and agriculture to determine how dry the soil is and if irrigation is required.

Dry soil is indicated by a very fast infiltration and would indicate irrigation is needed. A slow infiltration would indicate wet soil conditions and irrigation is not needed.

Generally, this method works well in this application once the user becomes familiar with their soil type, infiltration rates and irrigation needs.

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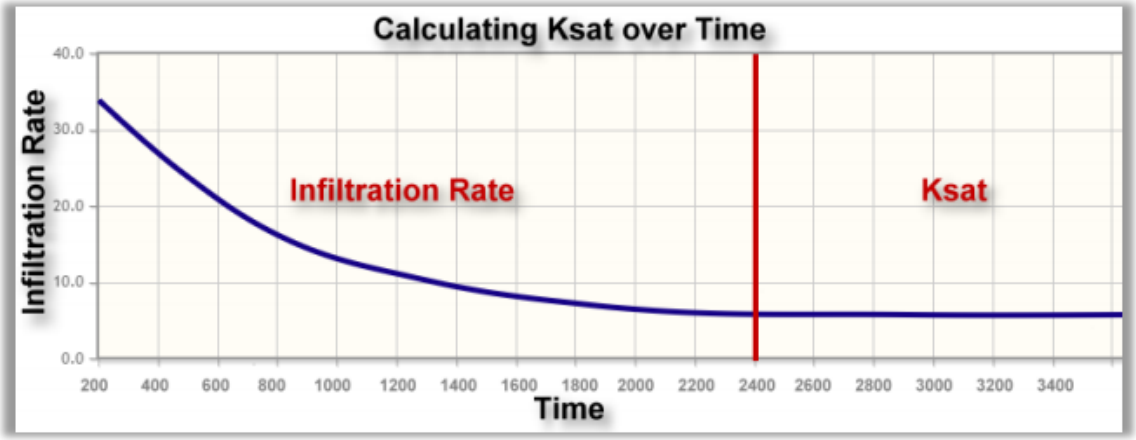
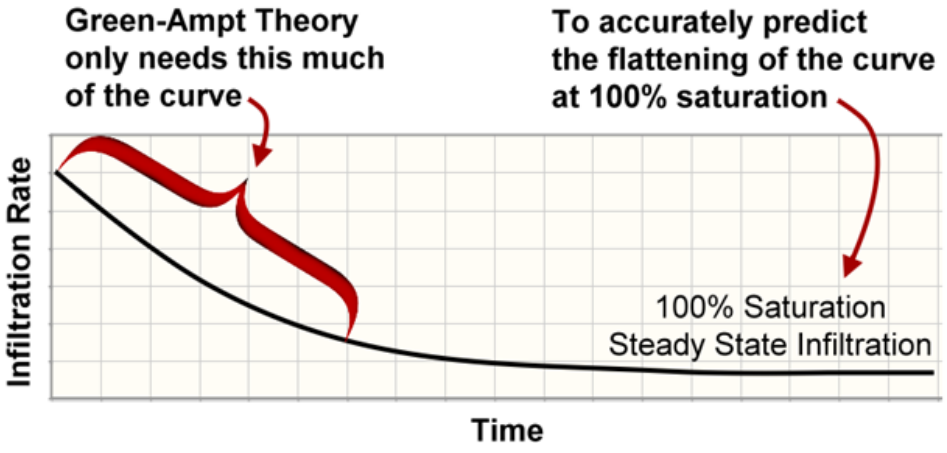
MPD Infiltrometer:

In 1911, the development of the Green-Ampt theory provided a means to take a sample of an exponentially decaying curve and calculate or predict the future of that curve with great accuracy. The Green-Ampt Theory has been academically vetted for over 110 years and is unquestionably accurate.

In the late 1980's, two gentlemen; Philip and Dunne, developed a method for calculating Ksat below the surface of the ground using boring pipes. They used the Green-Ampt theory on infiltration rate data to predict where that decaying curve would be in a steady state saturated condition (Ksat).



Using the exponentially decaying curve we plotted earlier, we can take just 20% of the data on the far left and apply the Green-Ampt theory to predict Ksat on the far right. This saves time, water, and eliminates any subjectivity as to when 100% saturation has been achieved.



Philip & Dunne concluded that infiltration for any device, will occur vertically, horizontally, and diagonally, producing a globular shape of infiltration. The math calculation for the MPD incorporates a sphere, which averages all directions of infiltration.

In the Mid 2000's, the University of Minnesota researched Philip and Dunne's method and modified the equation for surface testing. The University then spent several years field testing to verify accuracy. This method was then renamed the Modified Philip and Dune method, or MPD. The UofM then published their research for peer review. Global academia has peer reviewed and replicated these results and the MPD method has gained world-wide acceptance.

In 2015, Upstream Technologies began working with ASTM to create an ASTM Standard for the manual MPD method. In October of 2018, ASTM D8152 was published for the MPD methodology.

In parallel to that effort, Upstream Technologies automated the MPD method, removing human error from the process and simplifying the task with software and cloud-based reporting.

To further demonstrate the Green-Ampt Theory, Upstream Technologies built the following sand tank for testing purposes:

Each MPD test uses approximately 2.5 liters of water. And it takes about 12.5 liters of water to saturate the sand tank to the point where there is standing water above the sand.

5 MPD tests in a row will use 12.5 liters of water and produce standing water on the sand surface.

Starting with the sand tank completely drained of water, 5 MPD tests were conducted in a row.

- The first test performed, infiltrated the cylinder of water in 8 minutes
- The second test in 10 minutes
- The third test in 13 minutes
- The fourth test in 18 minutes
- The fifth test in 24 minutes

Each test performed produced a slower infiltration rate than the previous test. This is to be expected; As the water saturates the void space between sand particles, it becomes harder and harder for gravity to pull the water into the saturated soil matrix.

Consider the infiltration rate for each of the 5 tests as compared with the MPD calculated Ksat:

Test Number	30cm head drop (Time in minutes)	Infiltration Rate (Inches per Hour)	MPD calculated Ksat (Inches per Hour)
1	8 minutes	225 in/hr	22.85 in/hr
2	10 minutes	180 in/hr	21.32 in/hr
3	13 minutes	138 in/hr	21.42 in/hr
4	18 minutes	100 in/hr	22.90 in/hr
5	24 minutes	75 in/hr	23.26 in/hr

Ksat was then calculated on all 5 tests using the MPD ASTM Method and all 5 Ksat results were within 8.7% of each other. Total Range for Ksat was 1.94 inches per hour. Whereas the total range for infiltration rate was 150 inches per hour, a 104% deviation.

Statistics	Infiltration Rate	Ksat
Min	75	21.32
Max	225	23.26
Average	144	22.35
Range	150	1.94
Percent of Deviation:	104%	8.7%

Conclusion: Infiltration rate changes depending on how dry the soil is, where Ksat does not significantly change, regardless of how wet or dry the soil is. This also demonstrates the effectiveness of the MPD using the Green-Ampt Theory.