The Stevens Hydra Probe Inorganic Soil Calibrations

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Introduction

The Stevens Hydra Probe can be calibrated to accommodate almost any inorganic soil regardless of clay content or organic mater. While the default calibrations are suitable for most soils, other published calibrations can be used to obtain a higher level of accuracy if specific textural information about the soil is available.

Starting in the early 1980s with the early work of Topp (Topp 19), there has been a large amount of work addressing the relationship between complex dielectric permittivity and volumetric soil moisture content. Bulk density, organic mater, ionic conductivity, and mineralogy are all factors that can influence a volumetric soil moisture calibration curve. (Seyfried 2005).

Because many soil geomorphological trends can be correlated to soil texture (Birkland 1999), soil texture has been a reliable method for selecting an appropriate calibration curve and for making predictions about soil water holding capacities. Figure 1 shows the soil texture triangle that classifies texture base on the gravimetric sand, silt and clay fractions.

Calibrations

The relationship between soil water fraction by volume and the real dielectric permittivity can be expressed by equations [1] through [4]. Note that equations [1] and [3] use the temperature corrected real dielectric permittivity and equations [2] and [4] use the temperature uncorrected real dielectric permittivity. Table 1 defines the variables in equations [1] through [4].

θ	Soil Moisture in units of water fraction by volume (m^3m^{-3})
$\varepsilon_{R,TC}$	Temperature Corrected Real dielectric Permittivity
ε_R	Real Dielectric Permittivity
A, B, C, D	Coefficients see table 2.

Table 1, Variable definitions

Table 2 shows the suitable coefficients to the corresponding soil textures.

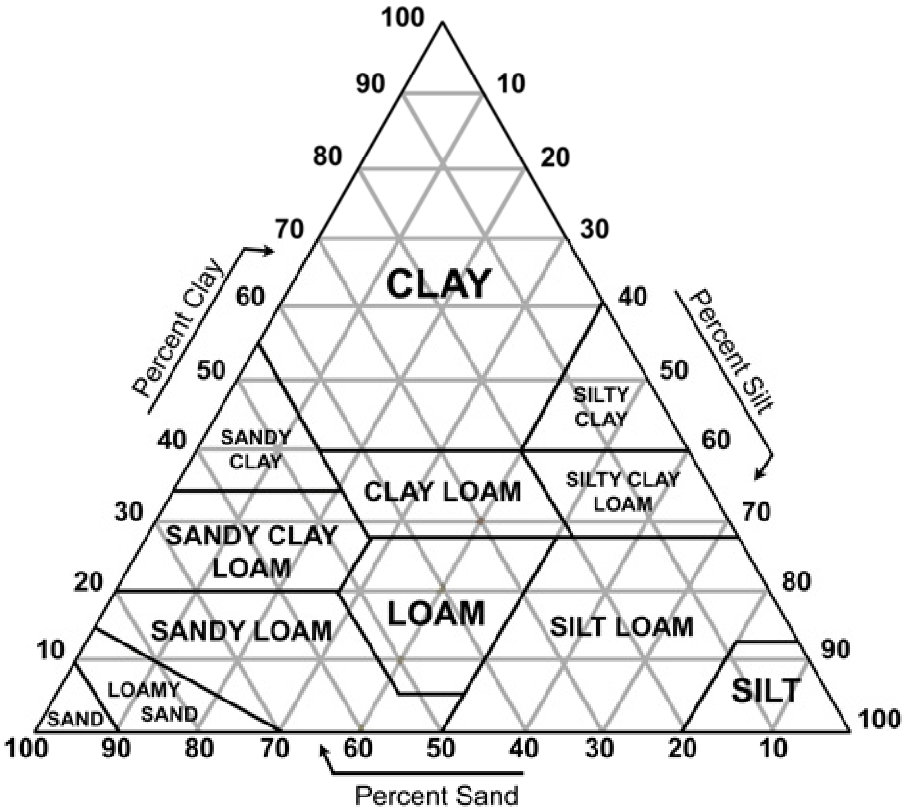

Figure 1 Soil texture Triangle

$$\theta = A + B\varepsilon_{R,TC} + C\varepsilon_{R,TC}^2 + D\varepsilon_{R,TC}^3 \qquad [1]$$

$$\theta = A + B\varepsilon_R + C\varepsilon_R^2 + D\varepsilon_R^3 \qquad [2]$$

$$\theta = A\sqrt{\varepsilon_{R,TC}} + B \qquad [3]$$

$$\theta = A\sqrt{\varepsilon_R} + B \qquad [4]$$

Soil Texture	Equa-tion	A	B	C	D	Pedology/Mineralogy
Sand (1)	1	-8.63	3.216	-9.54 E-2	1.579 E-3	Most Sands (Default)
Silt (1)	1	-13.04	3.819	-9.129 E-2	7.342E-4	(Default)
Clay (1)	2	-20.93	6.553	-0.2464	3.2414E-3	(Default)
Loam (1)	4	0.109	-0.179			Suitable for Most Soils (Default)
Silt Loam (1)	3	0.1226	-0.1903			A Horizon
Sandy Loam (1)	4	0.1017	-0.1786			A Horizon
Sandy Clay Loam (1)	4	0.1132	-0.1989			Bk Horizon
Loam (2)	4					Bk Horizon
Sandy Loam (2)	3	0.1251	-0.2065			Ap Horizon/Kaolinite
Clay (2)	4	0.1111	-0.1725			Bt Horizon/Kaolinite, Gibbsite
Sandy Loam (3)	4	0.1070	-0.1825			A Horizon
Loam (3)	3	0.1170	-0.1847			Ap Horizon/ Kaolinite, Vermiculite
Loam (4)	3	0.1161	-0.1909			E Horizon
Silty Loam (2)	3	0.1031	-0.1648			Ap Horizon/Montmorillonite
Silty Clay Loam (2)	4	0.0967	-0.1613			Bg Horizon
Silty Loam (3)	3	0.0958	-0.1610			Bw Horizon
Clay Loam	4	0.1033	-0.1768			A Horizon/Montmorillonite
Silty Clay	4	0.1088	-0.1738			Bg Horizon Montmorillonite
Silty Loam (4)	4	0.1004	-0.1588			
Loamy Sand	3	0.1204	-0.2025			Ap Horizon
Sandy Loam (4)	3	0.1105	-0.1725			Ap Horizon
Sandy Clay Loam (3)	3	0.1078	-0.1723			Bt Horizon
Silty Clay Loam (4)	4	0.1033	-0.1702			A Horizon

Table 2, calibration coefficients according to texture and mineralogy

The values in table 2 can be used with equations 1 through 4 to obtain soil moisture values for various soil textures (Seyfried 2005).

If the user has an andisol or a soil that has an porosity greater than 60%, the user of the Hydra Probe may decide to generate their own calibration. The Hydra Probe provides the dielectric permittivities for this purpose. In order to generate a custom calibration the user will need to calculate the volumetric soil moisture content from the gravimetric values and the bulk densities. The user will then need to compare the calculated soil moisture values to either the documented calibration curves or the real dielectric permittivities to construct a new calibration.

Temperature Effects

Both the real and the imaginary dielectric permittivities can be influenced by temperature (Yuanshi 2003). In general, as molecular vibration increases with temperature the real dielectric permittivity decreases. The relationship between imaginary dielectric permittivity and temperature mirrors the temperature effects of soil DC electrical conductivity. Equations 5 and 6 shows the dielectric temperature corrections used by the Hydra Probe for water at 50 MHz.

$$\varepsilon_{R,TC} = \varepsilon_R * 1.011/(1.045-0.00225 * T) \qquad [5]$$

$$\varepsilon_{i,TC} = \varepsilon_i * 1.0755/(0.693 +0.0153 * T) \qquad [6]$$

ε_i is the imaginary dielectric permittivity and T is temperature in Celsius.

Clay and Cation Polarization due to Temperature Affects

The real dielectric permittivity of water will decrease as the temperature increases. This phenomenon can be explained by molecular vibration. As the temperature of water increases, the molecular vibration of water molecules will increase. This increased vibration will inhibit the molecular orientation associated with the real dielectric permittivity. A quantitative expression for the temperature affects on the dielectric permittivity can described by the Debye-Langevin equation (Levine 1993).

Based on the correlations found in the literature, the Hydra Probe provides temperature corrections for both the real and imaginary dielectric permittivities. The temperature correction for the imagery dielectric permittivities are used for the temperature corrected soil electrical conductivity. It follows the trend that the increased molecular vibration due to increased temperature impedes electrical conductivity. In most applications, the temperature corrected soil electrical conductivity is used in order to make temperature independent comparisons.

The temperature effect on the real dielectric permittivity of soil are very complex and is still an area of research. The effects are related to soil mineralogy, ion valence, and the amount of clay. In general, the dielectric properties of water behave in sand the way in would as a liquid. In other words, because temperature/dielectric affects of sand and some silts are predicable, the temperature corrected real dielectric permittivity is used for the sand and silt calibrations.

The temperature/dielectric properties of clay are not well understood and are highly dependent on the type of clay and the amount of cations present. The real dielectric permittivity of some clays go up with temperature because molecular vibrations of cations bound to negative receptor sites increases thus increasing the polarization of the clay with temperature. In other words, with some clays, the dielectric permittivity will increase with temperature while the dielectric permittivity of water will decrease with temperature. This is why dielectric temperature correction works better for sand.

If you are calibrating the Hydra Probe in a clay rich soil with large diurnal temperature fluctuations, we recommend the temperature uncorrected real dielectric permittivity.

Conclusion

Knowledge about soil texture is useful for selecting a calibration curve for the Hydra Probe. The default Loam (1) calibration uses equation [4] and are the averages of the coefficients from 20 soils. The Loam (1) default calibration is reliable and suitable for most users. When a higher level of accuracy is required for known soil textures, the user may use an alternative calibration described here or construct there own calibration.

References

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