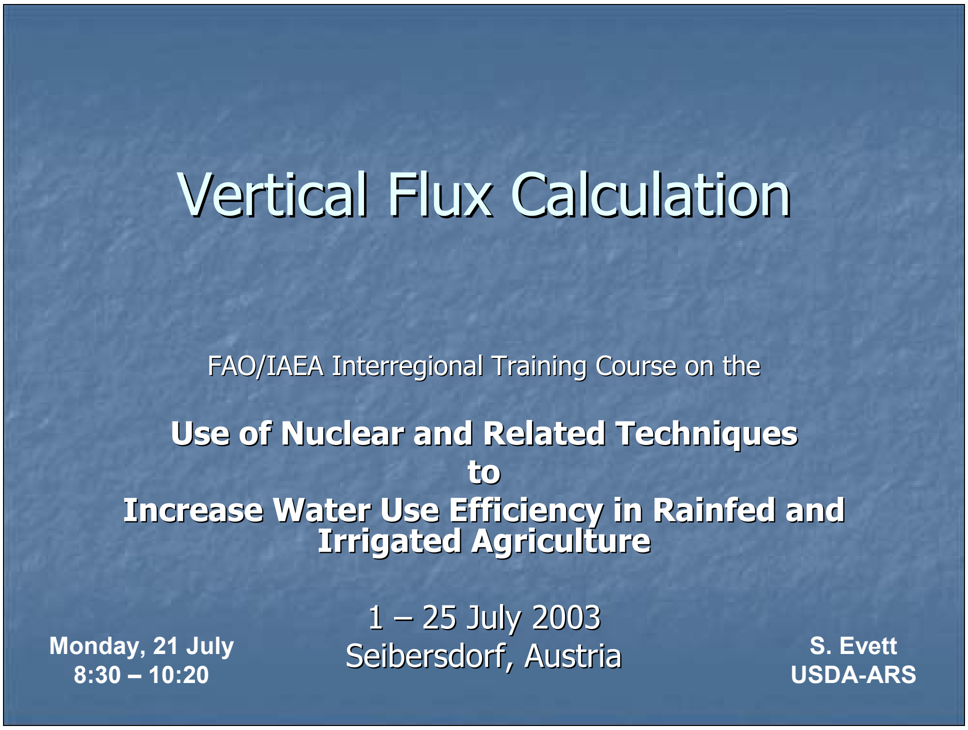


Quality Assurance in Soil Water Measurement

FAO/IAEA Interregional Training Course on the

Use of Nuclear and Related Techniques To Increase Water Use Efficiency in Rainfed and Irrigated Agriculture

1 – 25 July 2003

Seibersdorf, Austria

S. Evett, USDA-ARS

Vertical Flux Calculation

- Use soil water potential measurements to establish potential gradient at depth z_f:

  $\Delta\Psi_f = \Psi_{f+1} - \Psi_{f-1}$

  Or, infer potential gradient from soil water content measurements (beware hysteresis)
- Infer hydraulic conductivity at z_f from $K(\theta)$ or $K(\Psi)$ functions.
- Calculate the flux rate, $q_f = -K_f\,(\Delta\Psi_f/\Delta z)$
- Calculate the total flux, Q_f, over the period from t_0 to t_1 as: $Q_f = \int_{t_0}^{t_1} q_f \partial t$

Vertical flux calculations involve several steps:

•Use soil water potential measurements to establish potential gradient at depth z_f:

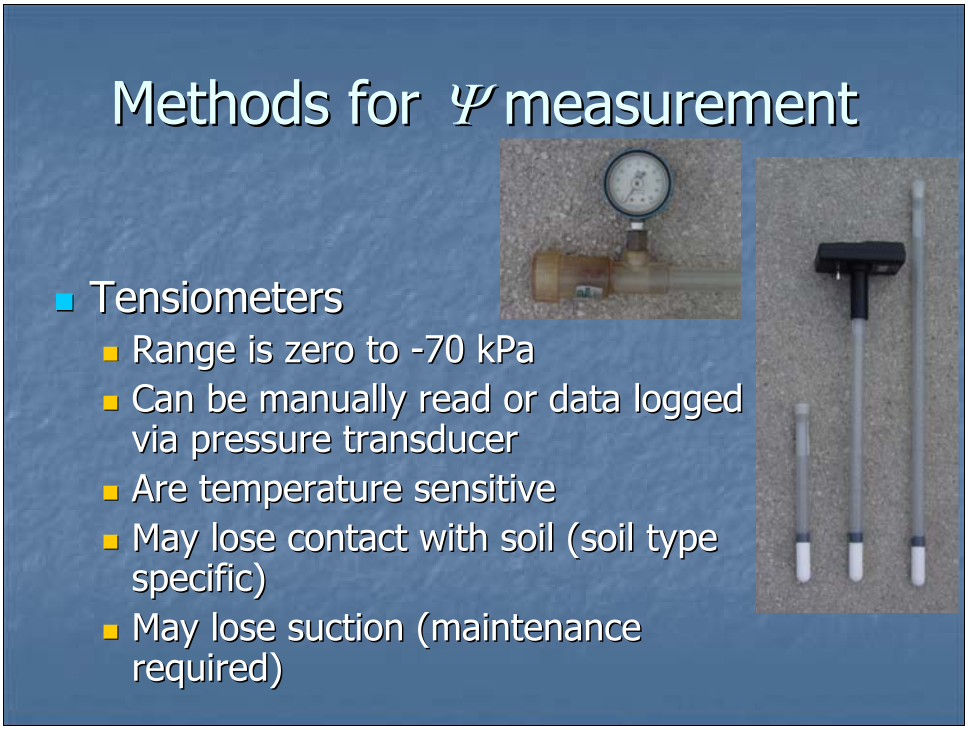
$$\Delta\Psi_f = \Psi_{f+1} - \Psi_{f-1}$$

Or, infer potential gradient from soil water content measurements (beware hysteresis)

•Infer hydraulic conductivity K_f at z_f from $K(\theta)$ or $K(\Psi)$ functions.

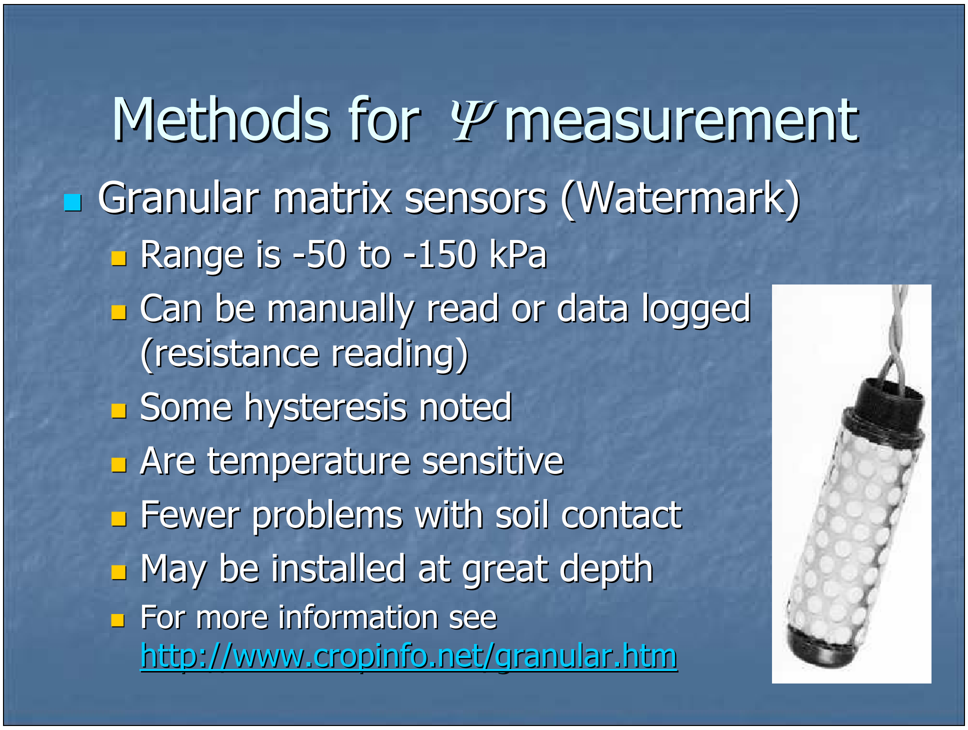
•Calculate the flux rate, $q_f = -K_f\,(\Delta\Psi_f/\Delta z)$, using Darcy's law, given here in finite difference form.

•Calculate the total flux, Q_f, over the period from t_0 to t_1 by integration.



Among the several methods for measuring soil water potential, the tensiometer is the oldest, dating to 1908 at least (Or and Wraith, 2002). The tensiometer consists of a cup of porous material, usually ceramic, and often connected to a thick-walled plastic tube, filled with water, and attached for reading to a device for measuring the differential pressure between the water inside the tensiometer and the atmosphere. The pore size in the cup determines both its bubbling pressure and its hydraulic conductivity. Tensiometers tend to fail at about 70 kPa tension due to air passage through the cup. The upper limit of use is 100 kPa, at which tension the water inside would boil at room temperature. Boiling the water before filling the tensiometer removes most of the dissolved air and decreases the tendency for bubble formation at tensions below 100 kPa. Because soil air will diffuse through the cup and dissolve in the water inside, this is not a permanent fix. Tensiometers require periodic refilling.

Installation of tensiometers involves augering a hole to the depth of measurement, placing loose soil in the hole to ensure good contact between the cup and soil, and pressing the cup into the soil, then backfilling the hole. In coarse soils, a finer textured material may be placed in the bottom of the hole to establish good contact. Typically, the plastic tube extends to above the soil surface for measurements. The vertical distance between the height of measurement must be subtracted from the reading to account for gravitational potential and arrive at the matric potential. Calibration is of the pressure sensing system.

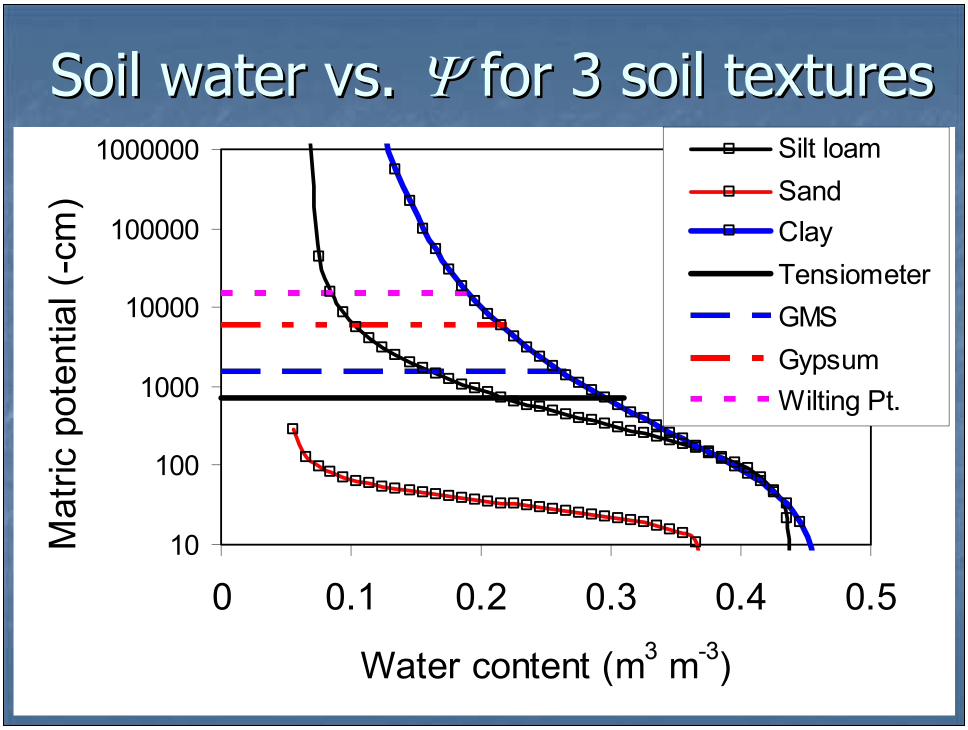


Several types of granular matrix sensors or GMS have been invented and are on the market. The sensor consists of a porous medium in which are embedded two wires, often connected to porous plates of wire mesh inside the sensor. The reading is of the electrical resistance in the medium between the wires or mesh electrodes. Often, a quantity of gypsum (calcium sulfate) is included to buffer the soil water solution and decrease effects of salinity on the resistance. The greater the soil water tension, the less water is in the porous medium, and the greater the electrical resistance. Calibration may be done in a porous medium covering a pressure plate, which is subjected to several values of pressure in a pressure chamber. It is wise to use the soil to be measured as the porous medium. Installation and contact problems are similar to those for a tensiometer. Reading requires an alternating current to minimize effects of capacitive charge build up. Lack of precision and calibration drift over time may limit use of GMS for determining soil water potential gradients. See Clint Shock's interesting web site for more information on granular matrix sensors: http://www.cropinfo.net/granular.htm

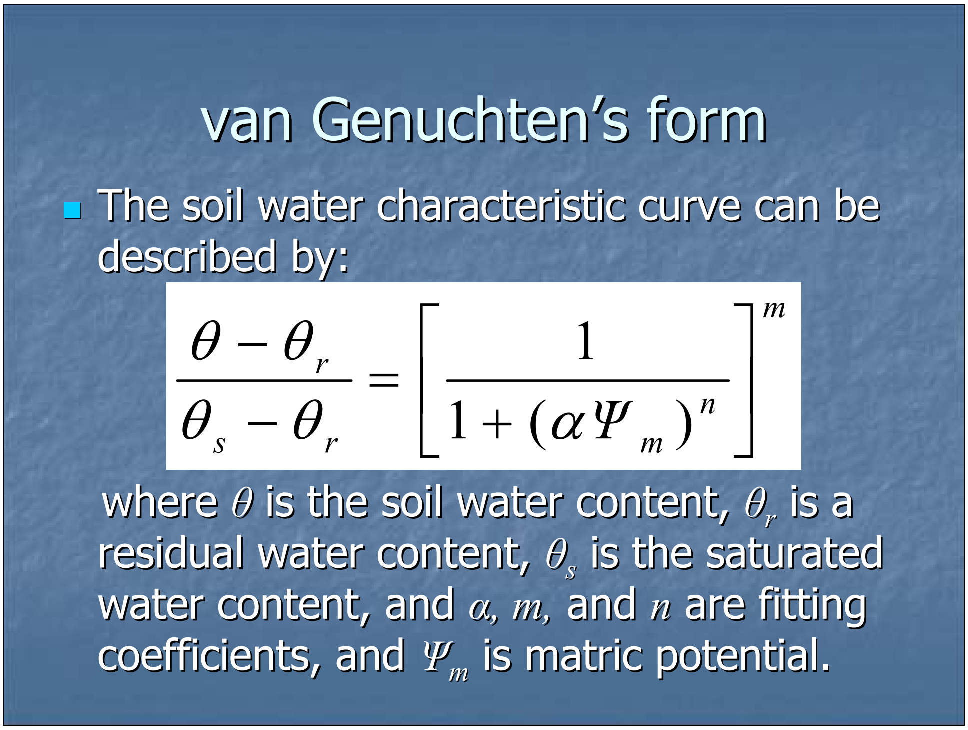
Methods for Ψ measurement

- Gypsum blocks (various manufacturers)
  - Range is -150 to -600 kPa
  - Can be manually read or data logged (resistance reading)
  - Problems with soil contact loss in some soils
  - Are temperature sensitive
  - May be installed at great depth
  - Wide variance in sensor calibration, and calibration changes over time
  - Used for irrigation scheduling but not for accurate work

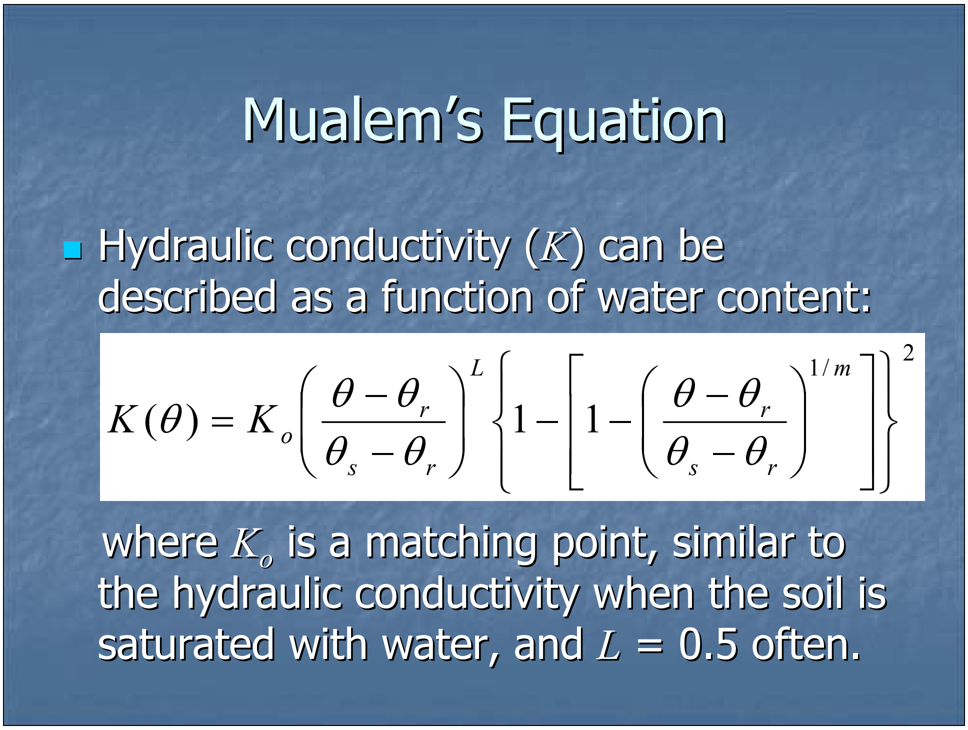
Gypsum blocks are just that, a block of calcium sulfate (gypsum), usually formed by mixing plaster of Paris with water and pouring into a mold. Embedded in the block are two wires, often connected to metal mesh electrodes. The porosity of the solidified plaster of Paris is such that the block will take up water from wet soil and release it as the soil dries. Because the gypsum buffers the water in the block, the effects of soil water salinity on the electrical resistance measured are minimized. Gypsum blocks are highly variable in output from one block to the other, and must be calibrated. However, the calibration drifts over time as the block dissolves and its porosity changes. Gypsum blocks are temperature sensitive, which may or may not be problematic depending on the depth of installation. While they have their place in irrigation scheduling, gypsum blocks are not accurate enough to determine the soil water potential gradient for soil water flux calculations.



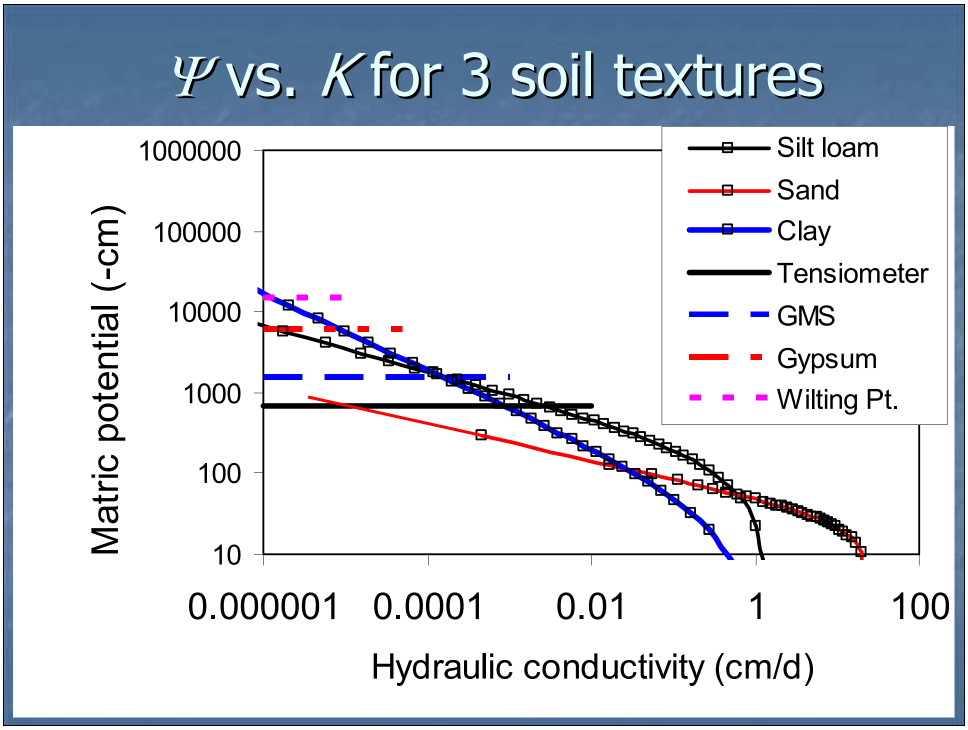
Soil water vs. matric potential curves plotted using data from the van Genuchten equation parameterized with values from the Rosetta computer program for three soil texture classes. Also plotted are the upper limits of measurement of granular matrix sensors (GMS), gypsum blocks, and tensiometers. Also plotted is the permanent wilting point, taken as 1500 kPa.



The soil water characteristic curve can be described by the equation above, where θ is the soil water content, θ_r is a residual water content, θ_s is the saturated water content, α, m, and n are fitting coefficients, and Ψ_m is matric potential.



The van Genuchten-Mualem (van Genuchten, 1980) model of unsaturated hydraulic conductivity is given as an equation above, where $K(\theta)$ is the unsaturated hydraulic conductivity at soil water content θ, K_o is a matching point (for fitting data), that has a value similar to the saturated hydraulic conductivity, and L is a tortuosity/connectivity parameter that may be fitted to data, but is usually taken to be 0.5. Also, often it is assumed that m = 1 – 1/n.



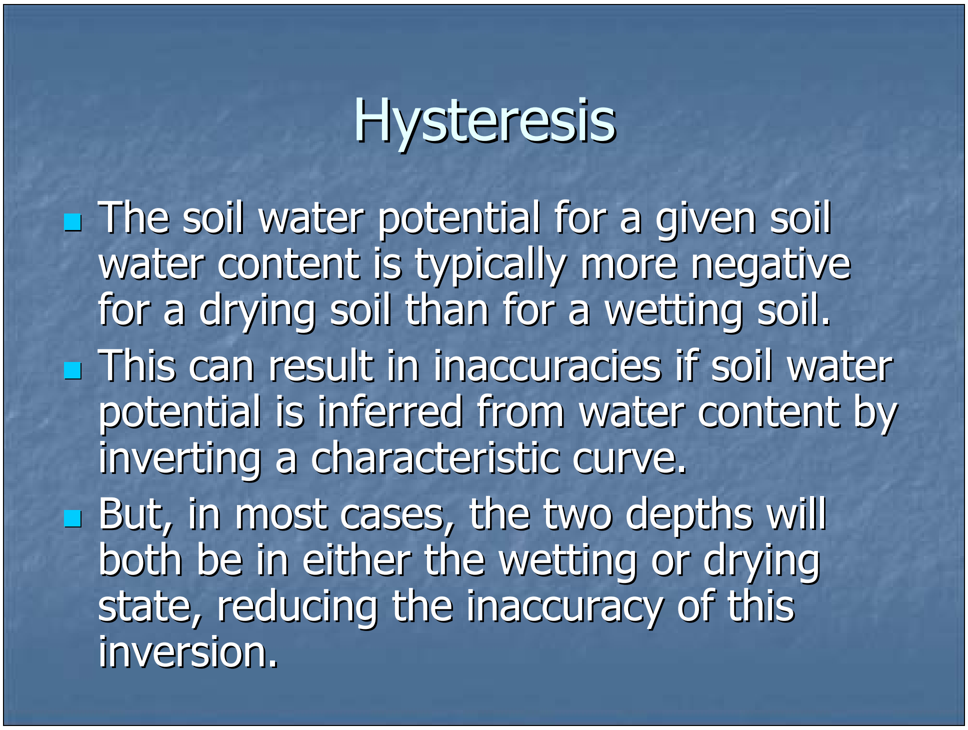
Soil water potential (*Ψ*) vs. hydraulic conductivity (*K*) curves plotted using data from the van Genuchten equation parameterized with values from the Rosetta computer program for three soil texture classes. Also plotted are the upper limits of measurement of granular matrix sensors (GMS), gypsum blocks, and tensiometers. Also plotted is the permanent wilting point, taken as 1500 kPa. If unit hydraulic gradient exists at the bottom of the control volume, a conductivity of 0.01 cm/d would lead to a flux of 10 mm over a 100 d growing season. We see that the tensiometer is capable of measuring soil water tension to a large enough value to be within the range of conductivities >0.01 cm/d. A GMS gives a better range of conductivities, but could easily lead to more inaccuracy. This is because multiple tensiometers can be read with the same calibrated pressure transducer (e.g. Tensimeter from Soil Measurement Systems, Inc.), thus canceling most calibration error in the vertical soil water potential gradient calculated from tensiometer readings at two depths. For the GMS, the electrical resistance meter may be used on multiple GMS units, but the calibration difference inherent in the different GMS units remains.

Estimating Ψ_m from θ_v

- We can invert van Genuchten's equation to estimate the matric potential (Ψ_m) from the water content:

$$\Psi_m = \frac{\left[\left(\dfrac{\theta - \theta_r}{\theta_s - \theta_r}\right)^{-1/m} - 1\right]^{1/n}}{\alpha}$$

We can invert van Genuchten's equation to estimate the matric potential (Ψ_m) from the water content (see equation above). Hysteretic behaviour in the soil water retention curve (different curves for wetting soil and drying soil) can cause errors in estimation of θ as a function of Ψ_m or in estimation of Ψ_m as a function of θ.



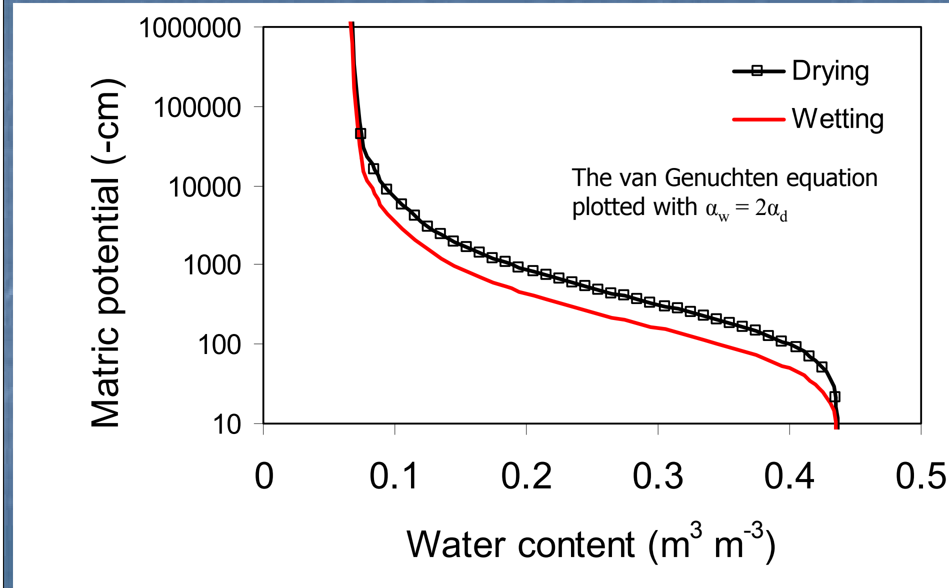
Hysteresis

The soil water potential for a given soil water content is typically more negative for a drying soil than for a wetting soil.

This can result in inaccuracies if soil water potential is inferred from water content by inverting a characteristic curve.

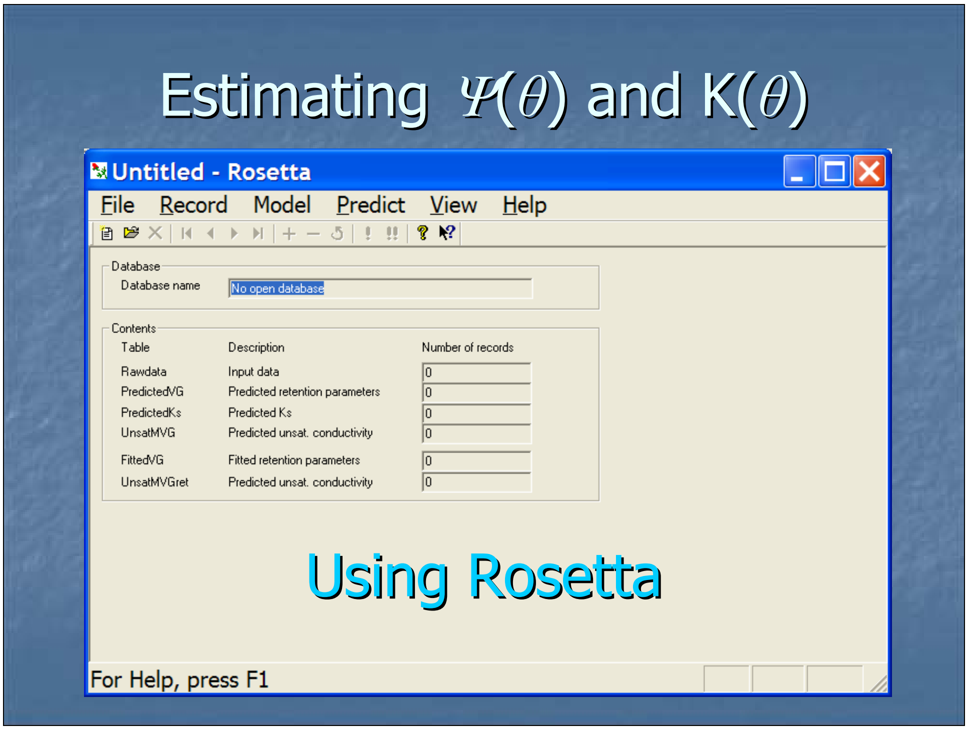
But, in most cases, the two depths will both be in either the wetting or drying state, reducing the inaccuracy of this inversion.

Hysteresis in a silt loam



Plotting the van Genuchten equation with $\alpha_w = 2\alpha_d$ is a first approximation to reproducing the boundary wetting and drying curves if only one is known (Warrick, 2003).

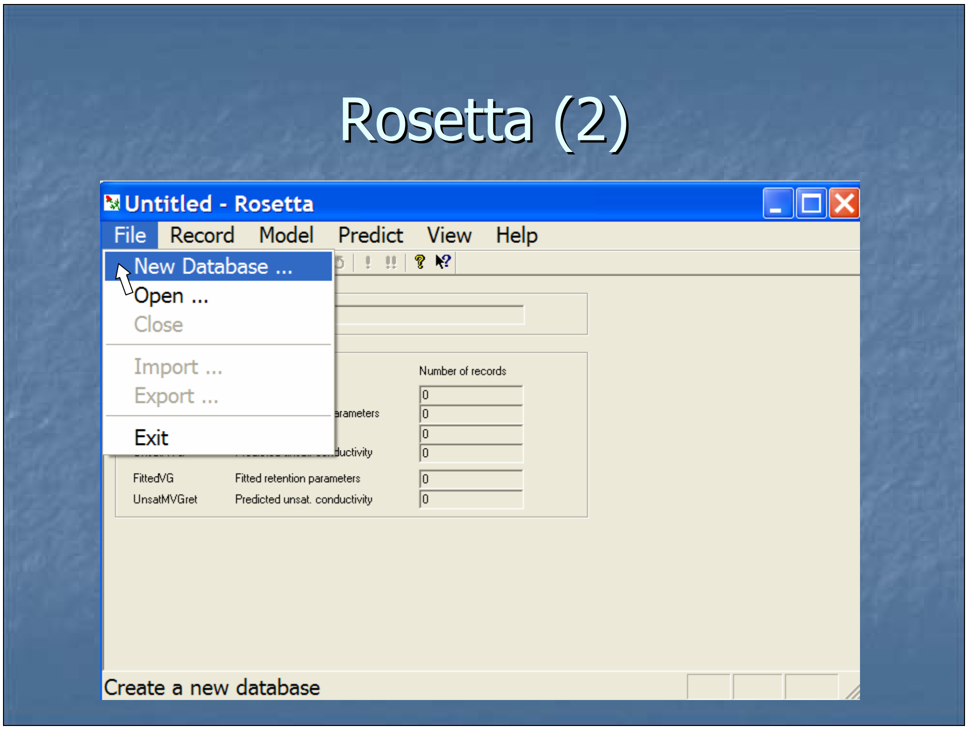
Warrick, A.W. 2003. Soil Water Dynamics. Oxford University Press. New York, New York. ISBN 0-19-512605-X. http://www.oup.com



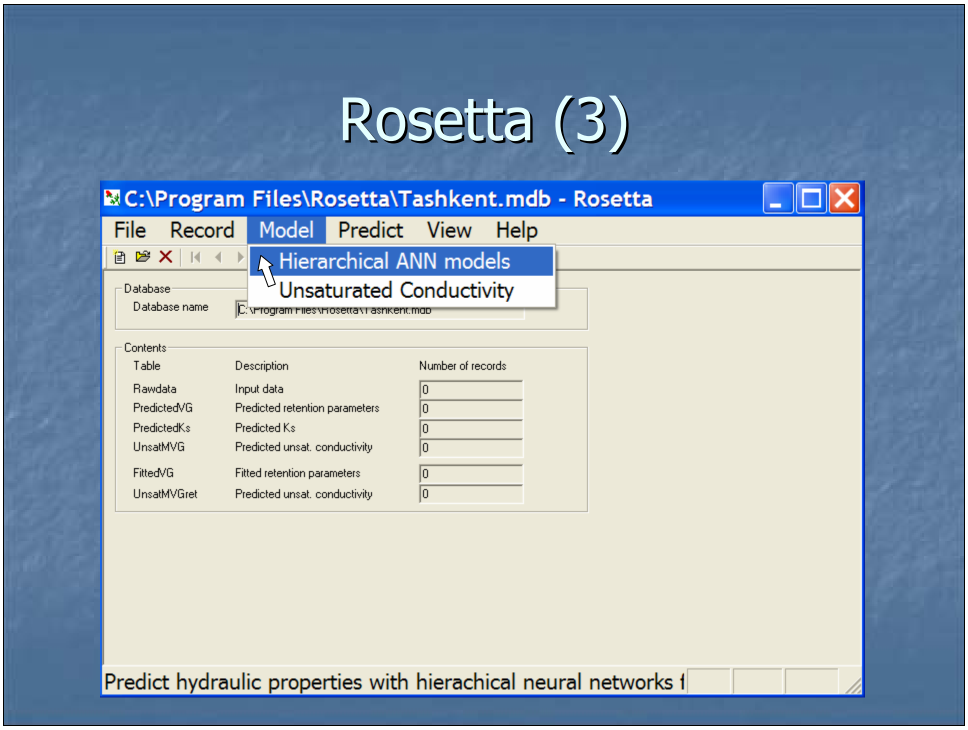
The Rosetta computer program is the embodiment of five pedotransfer functions (PTFs) that estimate the parameters of the van Genuchten-Mualem equations for soil water retention and hydraulic conductivity. Each PTF requires a different degree of information, with the simplest requirement being soil texture (clay, loam, silt, silty clay loam, sandy loam, etc.). The requirements for the five PTFs are:

1) Texture
2) Sand, silt, and clay percentages (USDA definitions of particle sizes)
3) Sand, silt, and clay percentages; and bulk density
4) Sand, silt, and clay percentages; bulk density; and water content at -0.33 kPa soil water potential
5) Sand, silt, and clay percentages; bulk density; and water contents at -0.33 and -1500 kPa soil water potentials

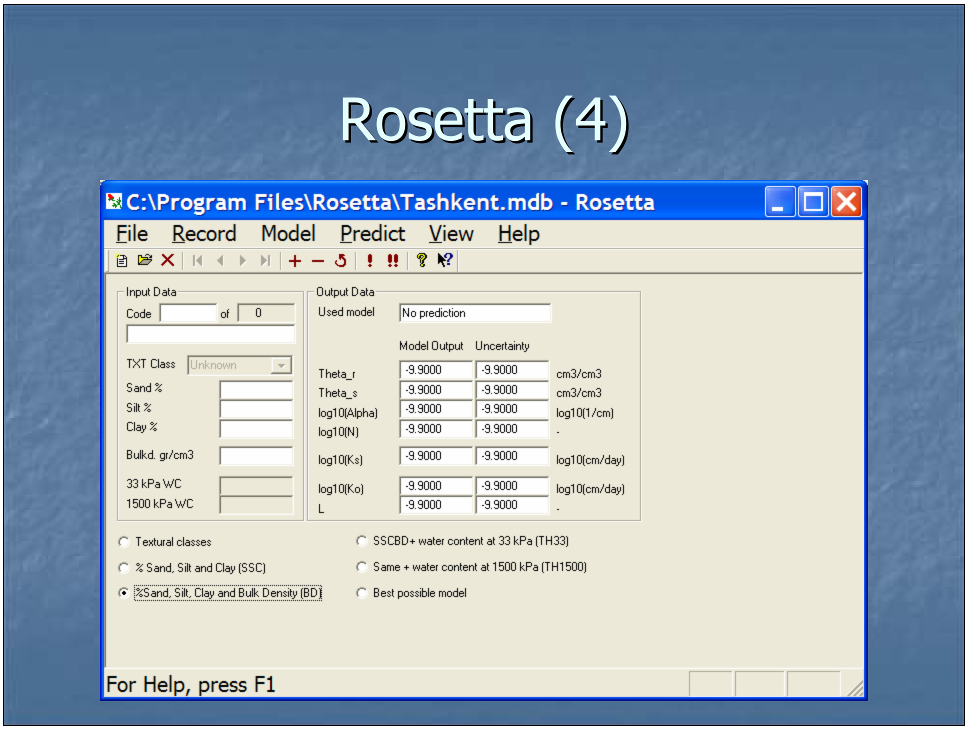
The more input information is available, the better the predictions of the van Genuchten-Mualem parameters.



After opening Rosetta, we create a new database title. This is as simple as providing a file name.



To estimate the van Genuchten parameters based on our input data, we click on “Model” and “Hierarchical ANN models”



The parameters that are estimated are (from the Rosetta documentation):

θ_r Residual water content (cm^3 cm^{-3})

θ_s Saturated water content (cm^3 cm^{-3})

log(α) log10(Alpha) curve shape parameter in log10(1/cm)

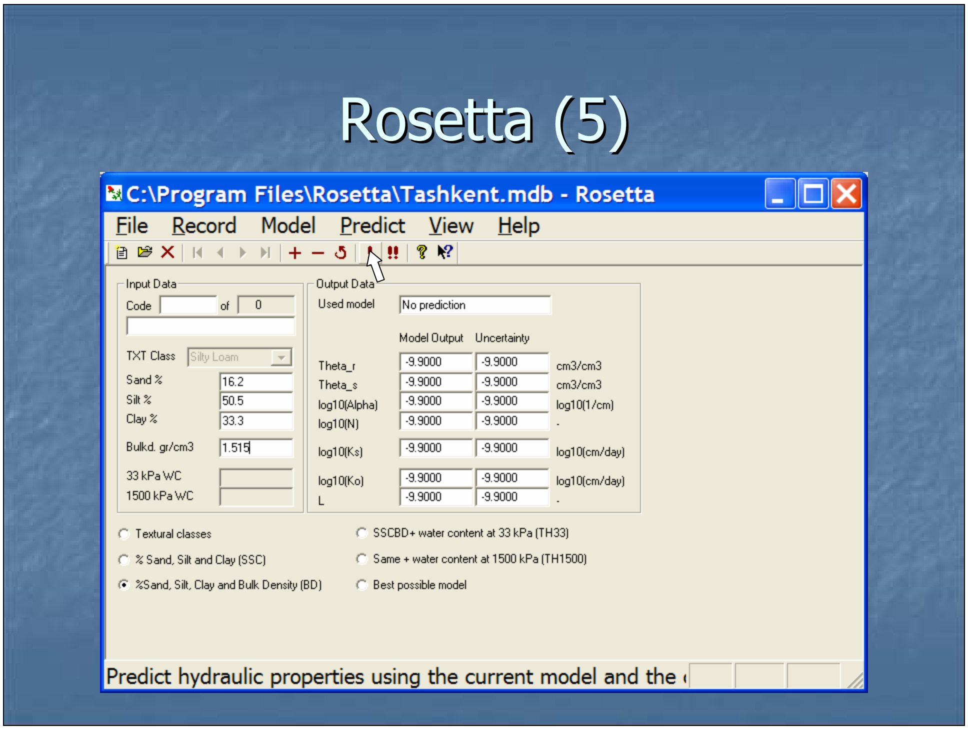
log(n) log10(n) curve shape parameter (-)

log(K_s) log10 of saturated hydraulic conductivity in log10(cm/day)

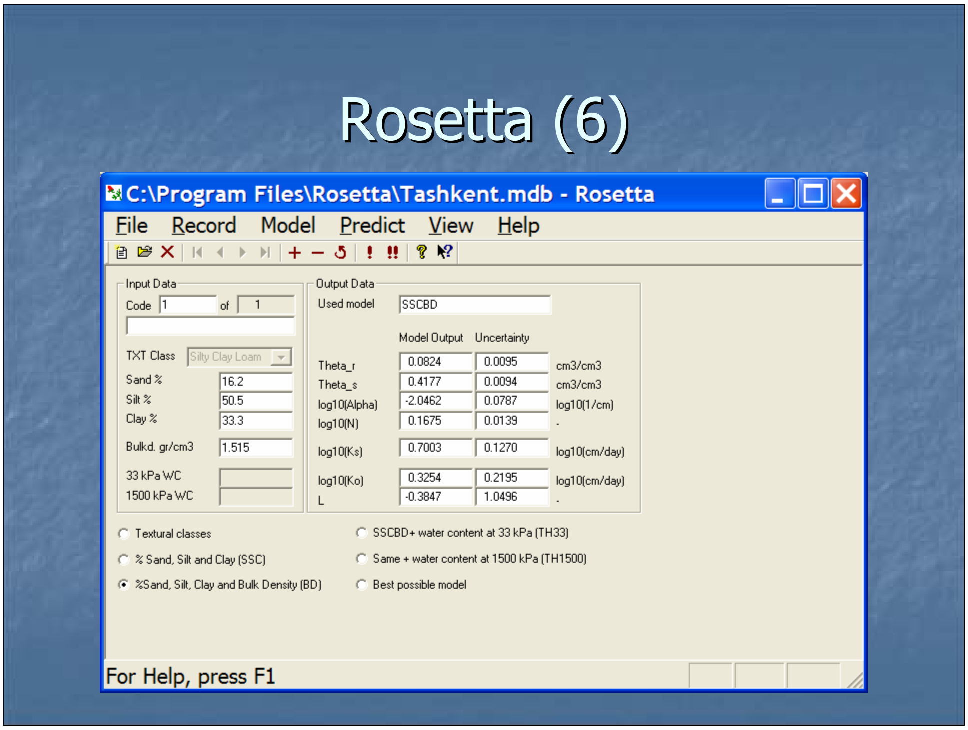
Log(K_o) log10 of matching point at saturation in the van Genuchten-Mualem model (cm/day)

L Tortuosity/connectivity parameter in the van Genuchten-Mualem model (-)

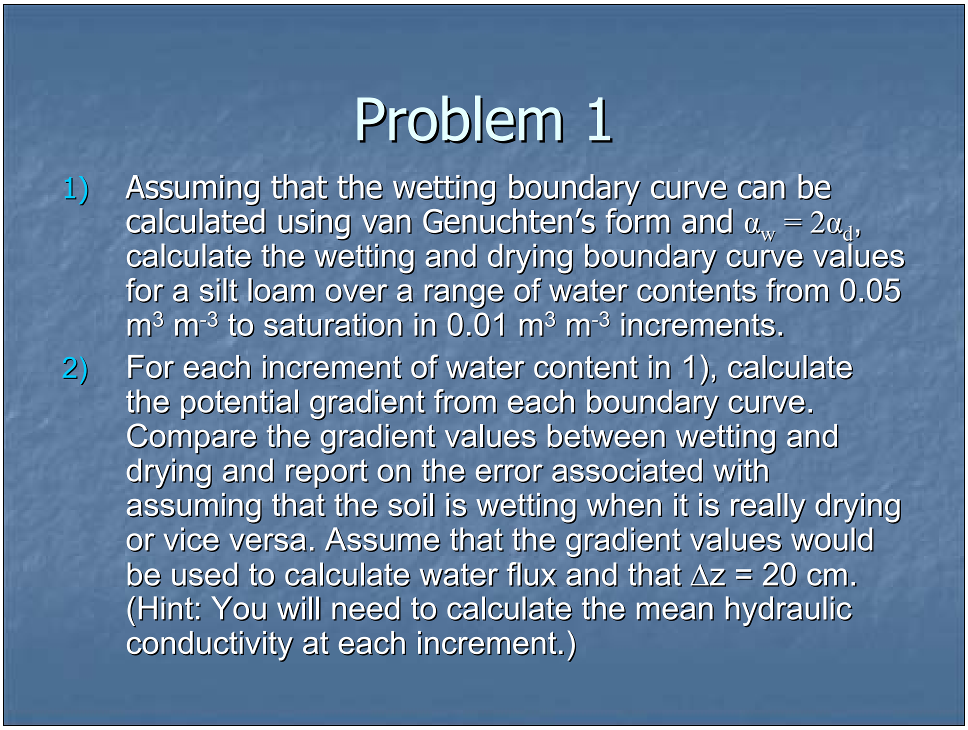
Note that m is not estimated. This is because the assumption is made that $m = 1 - 1/n$



We click on the icon that is a single exclamation mark in order to make the estimates.



Example estimates are shown above for given data on sand, silt, and clay percentages, and the soil bulk density.



Problem

1) Assuming that the wetting scanning curve can be calculated using van Genuchten's form and $\alpha_w = 2\alpha_d$, calculate the wetting and drying boundary curve values for a silt loam over a range of water contents from 0.05 $m^3\ m^{-3}$ to saturation in 0.01 $m^3\ m^{-3}$ increments.
2) For each increment of water content in 1, calculate the potential gradient from each boundary curve. Compare the gradient values between wetting and drying and report on the error associated with assuming that the soil is wetting when it is really drying or vice versa . Assume that the gradient values would be used to calculate water flux and that Δz = 40 cm. (Hint: You will need to calculate the mean hydraulic conductivity at each increment.)

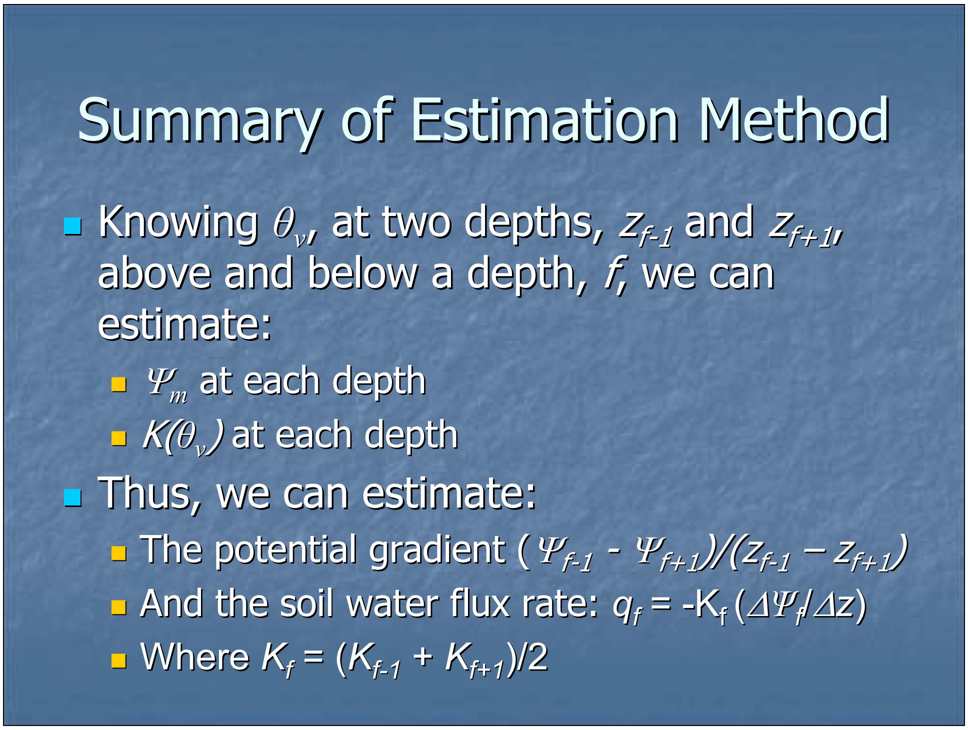
Problem continued

3) The calculation for 2 was done for water content increments of 0.01 $m^3\ m^{-3}$. This is tantamount to assuming that the measurements at z_{f-1} and z_{f+1} differed by that amount. Assume that the water contents at these two depths differed by 0.05 $m^3\ m^{-3}$ and discuss the associated error.
4) Calculations of $K(\theta)$ and $\Psi(\theta)$ using the van Genuchten/Mualem equations are discussed and examples given in the Excel spreadsheet: Vert Flux Calc.xls

Problem (continued)

- The calculation for 2 was done for water content increments of 0.01 $m^3\ m^{-3}$. This is tantamount to assuming that the measurements at z_{f-1} and z_{f+1} differed by that amount. Assume that the water contents at these two depths differed by 0.05 $m^3\ m^{-3}$ and discuss the associated error.
- Calculations of $K(\theta)$ and $\Psi(\theta)$ using the van Genuchten/Mualem equations are discussed and examples given in the Excel spreadsheet:

  Vert Flux Calc.xls



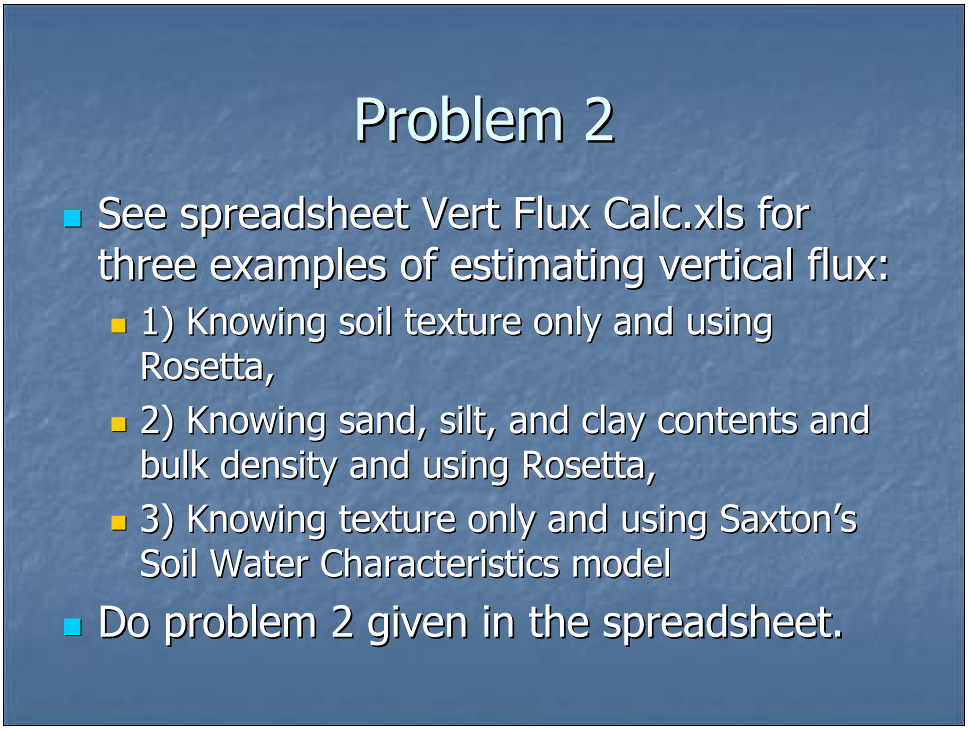
Summary of Estimation Method

Knowing θ_v, at two depths, z_{f-1} and z_{f+1}, above and below a depth, *f*, we can estimate:

- Ψ_m at each depth
- $K(\theta_v)$ at each depth

Thus, we can estimate:

- The potential gradient $(\Psi_{f-1} - \Psi_{f+1})/(z_{f-1} – z_{f+1})$
- And the soil water flux rate: $q_f = -K_f\,(\Delta\Psi_f/\Delta z)$
- Where $K_f = (K_{f-1} + K_{f+1})/2$



Problem 2

See spreadsheet Vert Flux Calc.xls for three examples of estimating vertical flux:

1) Knowing soil texture only and using Rosetta,

2) Knowing sand, silt, and clay contents and bulk density and using Rosetta,

3) Knowing texture only and using Saxton's Soil Water Characteristics model

Do problem 2 given in the spreadsheet to estimate vertical flux at the bottom of a soil profile.