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In-Situ Determination of Specific Yield Using Soil Moisture and Water Level Changes in the Riparian Zone of the Arkansas River, Kansas

Sara E. McKay[1], Gerard J. Kluitenberg[2], James J. Butler, Jr.[1], Xiaoyong Zhan[1], Matt S. Aufman[1], and Ralf Brauchler[1]

[1]Kansas Geological Survey, University of Kansas, 1930 Constant Ave, Lawrence, KS 66047; email: mckays@unr.nevada.edu; [2]Department of Agronomy, Kansas State University

Motivation

Specific yield (S_y) is an important parameter for numerous hydrogeologic investigations, but few reliable methods for its in-situ determination exist. At a site in the riparian zone of the Arkansas River in south-central Kansas, the amount and variability of groundwater consumption by phreatophytes is being assessed using small, diurnal water-table fluctuations. The magnitude of these fluctuations is a function of position within the riparian zone (proximity to influential vegetation, Fig. 1), seasonal variability in phreatophyte consumption (Fig. 2), and heterogeneity of the aquifer material, most notably S_y. Specific yield is commonly estimated by saturating and draining soil cores, using soil water characteristics in parametric models, or from pumping tests. However, these methods can introduce large uncertainties. Figure 3 shows a simple model for calculating phreatophyte consumption of groundwater at the site using S_y estimates obtained during a 2002 pumping test at the site. For this test, S_y calculations were done assuming that the aquifer is homogeneous with respect to transmissivity. This assumption is dubious, and results in the pumping-test S_y estimates varying by a factor of two (Fig. 7 – see Schad and Teutsch (1994) for a discussion of this assumption). A more precise method is needed to determine whether differences in water-table fluctuations within the riparian zone are due to variations in plant stresses or in S_y. Our objective was to evaluate the method of Skaggs et al. (1978) for in-situ determination of specific yield, and to obtain more detailed estimates of its magnitude and variability in time and space.

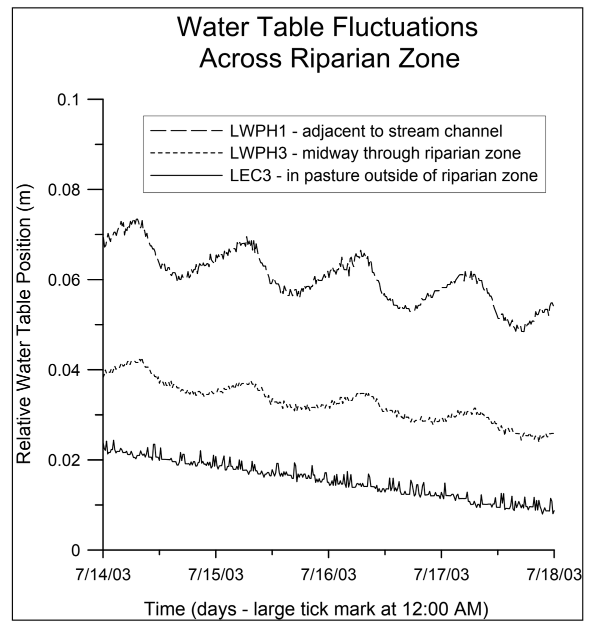

Fig. 1: Water-table fluctuations observed in three observation wells; fluctuation magnitude is clearly dependent on position within the riparian zone.

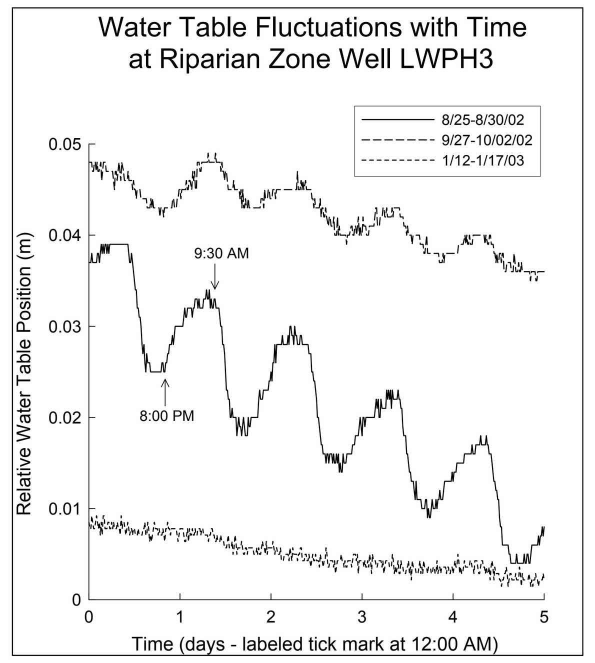

Fig. 2: Water-table fluctuations are large in the summer, decrease during the fall, and disappear altogether after the first killing frost.

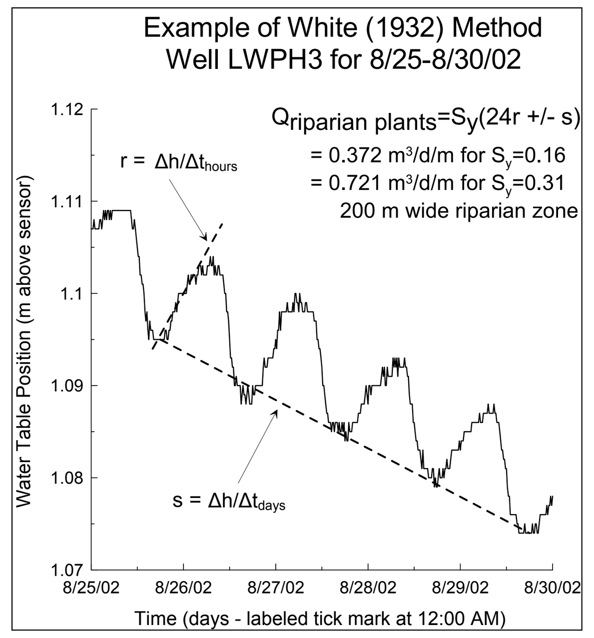

Fig. 3: The White (1932) method for estimating phreatophyte consumption is highly dependent on specific yield, yet estimates from a pumping test vary by a factor of two.

Methods

Seven shallow monitoring wells and eight neutron access tubes (arranged in "nests" with tensiometers) were used to take measurements of water-table and soil-moisture changes over periods of water-table decline following high groundwater levels and flooding in the riparian zone in Sep.-Oct. 2003 and Aug.-Sept. 2004. Water-table measurements were taken every 15 minutes using pressure transducers; these data were then calibrated with electric tape measurements performed periodically throughout the study. Neutron access tubes located near the wells (Figure 6) provided soil moisture profiles across the water table at each location. In 2004, the water-table fell below the bottom of the 4 original access tubes, and 4 additional deeper tubes were installed closer to the wells. The Skaggs method requires that soil moisture profiles remain in equilibrium with the water table (i.e. the vertical hydraulic gradient above the water table is zero). Graphical analysis was used to identify several soil moisture profiles consistent with this criterion; Figure 4 shows three profiles that were chosen from the Sep.-Oct. 2003 period. An attempt was made to quantify the hydraulic gradient using tensiometry, but this failed due to excessive variability in the tensiometer data. At this time, visual inspection is the only method available for selecting appropriate profiles.

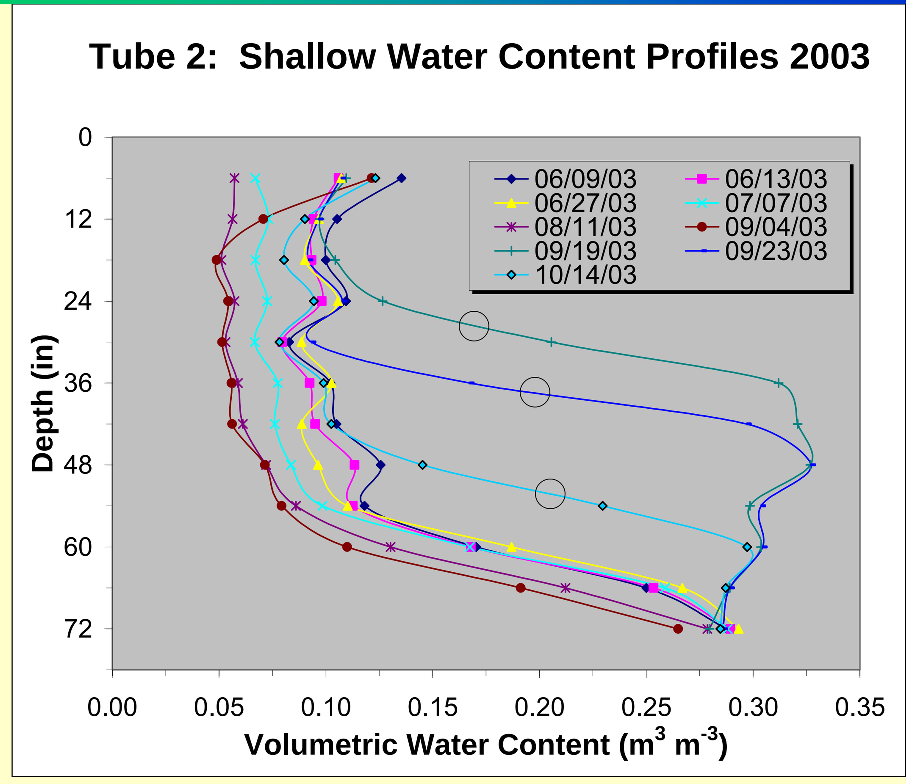

Fig. 4: Circled soil moisture profiles were used in the calculations for S_y.

The Skaggs method uses the difference between the volume of soil moisture (an integral of soil water content over a certain depth interval) at two different water-table positions, to calculate specific yield for that change in water level. This can be expressed by:

$$S_y(y_1) = \frac{V_d(y_1 + \Delta y) - V_d(y_1)}{\Delta y}$$

where:

S_y = Specific yield

V_d = volume of soil moisture

y_1 = initial depth of water table

Δy = change in water-table position (Skaggs et al.,1978)

Field Area

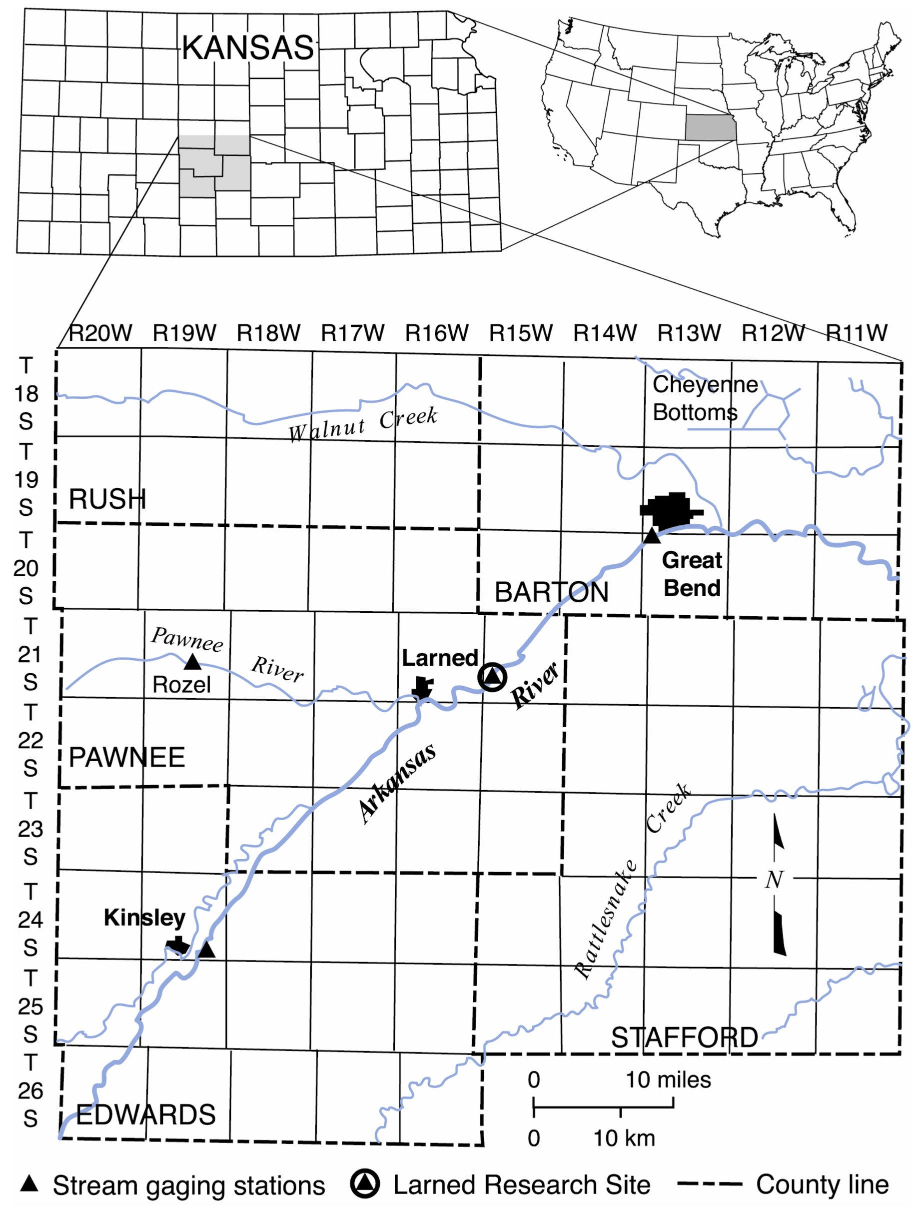

Figure 5: Site Location in south-central Kansas.

The field area, the Larned Research Site, is in the riparian zone of the Arkansas River in south-central Kansas. Vegetation consists mostly of cottonwood, mulberry, and willow trees with low grasses. Observation wells and neutron access tubes were installed with direct-push equipment. Electrical conductivity logging has indicated subsurface sediments consist mostly of sands and silty sands, interbedded with clay layers at greater depths. Access tubes were installed to permit measurement of soil water content with a neutron probe (503 DR Hydroprobe, Campbell Pacific Nuclear) at 6-inch depth intervals every 1-2 weeks during months while trees were actively transpiring. Water-table measurements were taken using programmable, integrated pressure transducers/loggers that were housed within the wells.

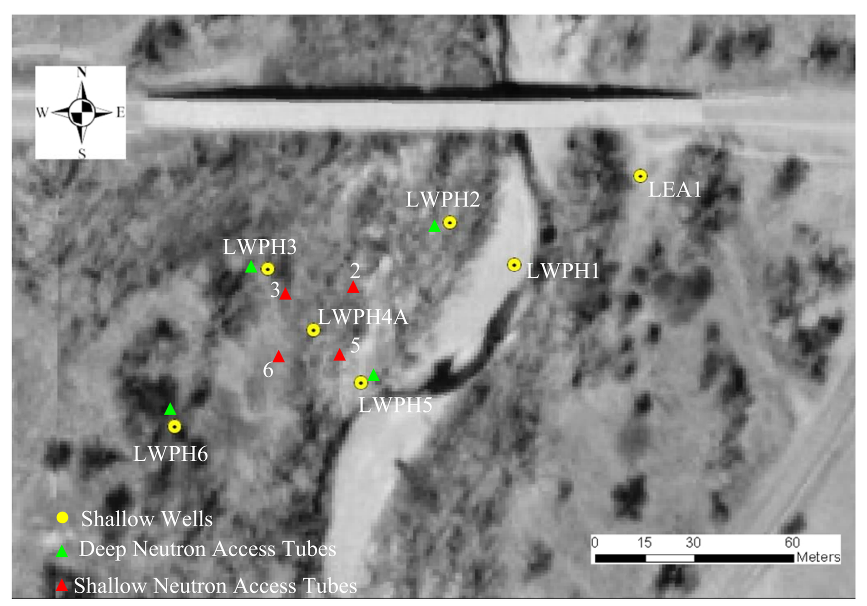

Figure 6: Detailed site map, including locations of shallow groundwater wells and nests of tensiometers/neutron access tubes.

Results

Calculated values of specific yield range from 0.19 to 0.21 for the 2003 data, and from 0.21 to 0.29 for the 2004 data (Table 1). In 2003, no results were calculated for Tube 3, because the water table was below the bottom of the tube for the duration of the analysis. In 2004, no results were calculated for Tube 5, because the water content profile displayed a pronounced leftward shift above the water table, an artifact of phreatophyte soil water uptake. This shift would cause significant overestimation of specific yield.

Figures 8 and 9 show water content profiles for Tubes 3 and 6 in 2004. No prominent leftward shift is evident in either profile, but the S_y estimate for Tube 3 is significantly higher than all other S_y estimates for both years. This is likely due to the large increase in total porosity at the bottom of the depth interval used for making the Tube 3 calculations. Specific yield estimates in both 2003 and 2004 may have been affected by plant water uptake. In general, there is a greater likelihood of plant water uptake artifacts in the 2004 results simply because the water-table drop event occurred earlier than in 2003, while most trees were still actively transpiring. The possibility of water uptake artifacts contributes to the uncertainty introduced by our inability to quantify vertical hydraulic gradients above the water table. These uncertainties represent a significant limitation of our implementation of the Skaggs method.

We observed little variation in S_y across the site in 2003 and, excluding Tube 3, little variation in 2004. The agreement between years is quite good when Tube 3 in 2004 is excluded. Variation in S_y across the site (Table 1) was significantly lower than the variation in specific yield results from the pumping test in 2002 (Fig. 7). All values calculated using the Skaggs method lie within the range found in the pumping test; values for the pumping test ranged from 0.16 to 0.31. However, saturated soil moisture never exceeds 0.34, providing an upper limit for total porosity at the site. It is unlikely that S_y would be as high as 0.31 for these conditions, causing grounds for further doubt in the accuracy of the pumping test S_y estimates. Thus, the Skaggs method values appear to be more appropriate for evaluating the influence of specific yield on phreatophyte consumption.

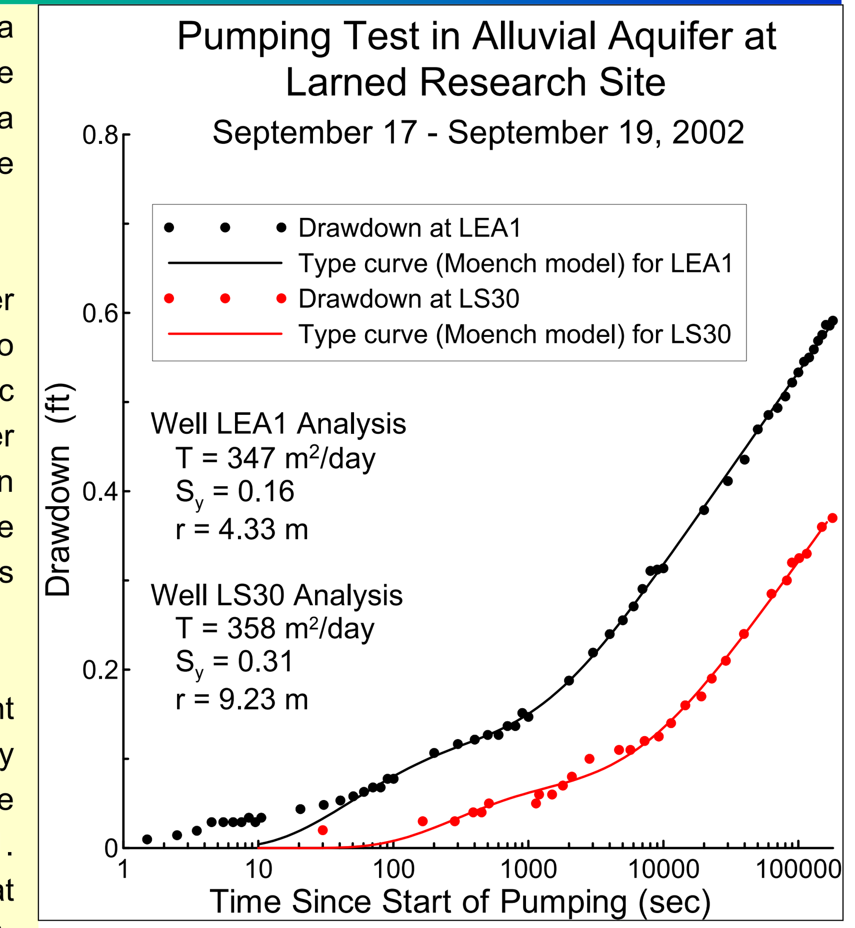

Figure 7: Pumping test analysis using the Moench (1997) model. Sy calculations are done assuming that the transmissivity for the region between the pumping and observation wells is the same as the large-scale average obtained from the linear fit to the late-time drawdown, an assumption that appears highly questionable at this site.

Table 1: Specific Yield Results

	Sep.-Oct. 2003*	Aug.-Sept. 2004**
Tube #2	0.201	0.217
Tube #3	N/A	0.292
Tube #5	0.189	N/A
Tube #6	0.214	0.208

*Shallow tubes; water-level changes averaged from the two nearest wells.

**Deep tubes; water-level changes from single closest well only.

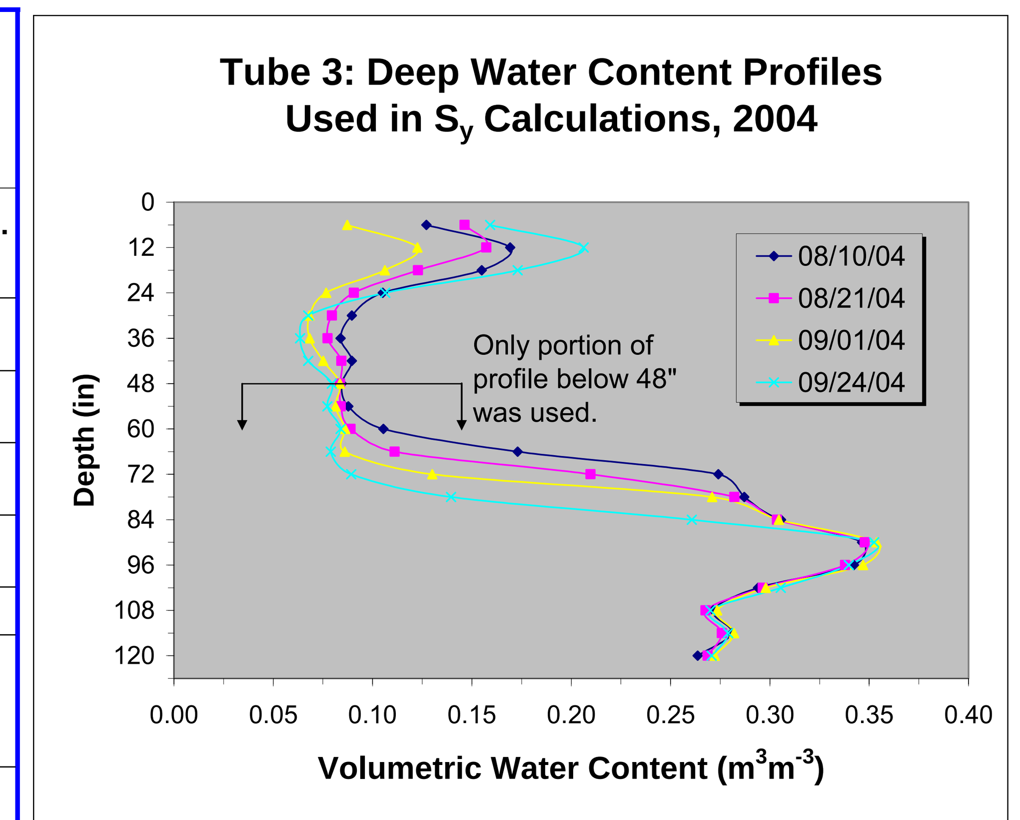

Figure 8: Four water content profiles were used in calculations of specific yield for neutron access tube #6 with the 2004 data.

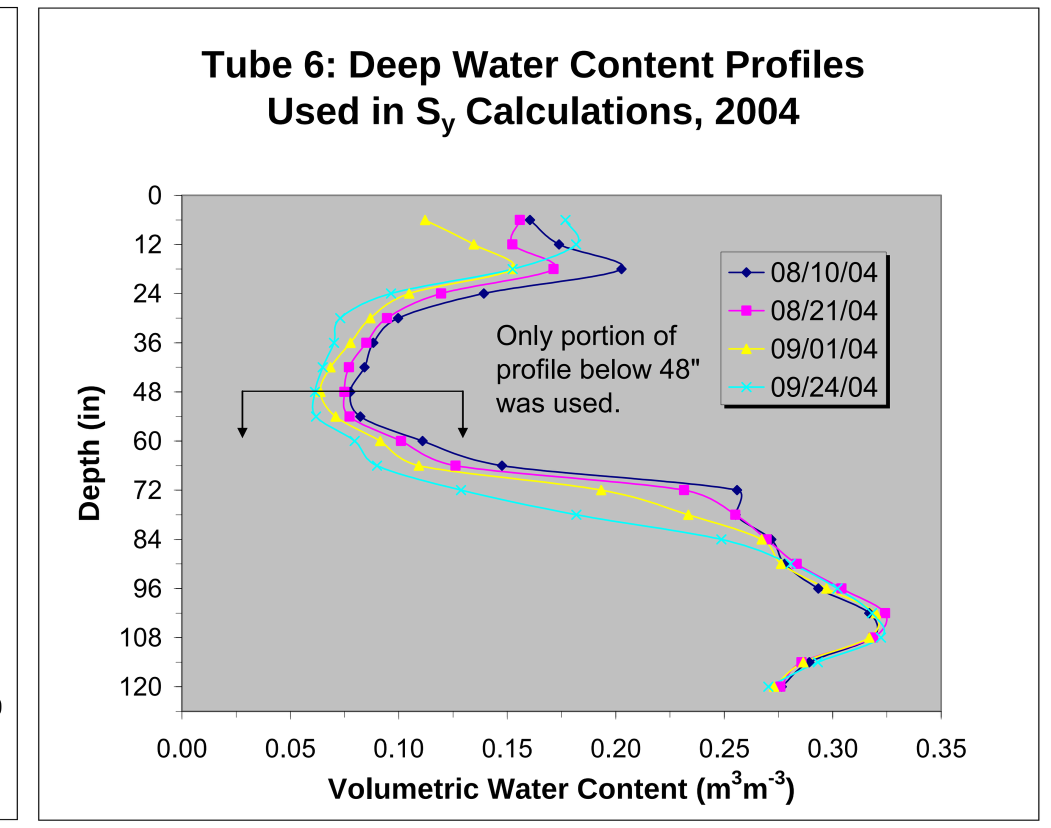

Figure 9: Four water content profiles were used in calculations of specific yield for neutron access tube #3 with the 2004 data.

Conclusions

- In-situ determination of specific yield can provide more defensible estimates than conventional methods.
- The Sy estimates will be useful for estimating consumption of groundwater by phreatophytes in riparian corridors.
- Accuracy of in-situ S_y measurements obtained using the Skaggs method is dependent on selection of soil profiles that are in equilibrium with the water table. The graphical selection method used here should be supplemented with pressure measurements whenever possible.

References

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Acknowledgements

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