PREDICTING SOIL SUCTION PROFILES USING PREVAILING WEATHER

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Abstract

Suction profiles are useful in evaluation of many aspects of unsaturated soil behavior, to include strength and prediction of movement. Typically, profiles are obtained at a point in time of sampling. Evaluating potential change in soil properties with suction requires an understanding of the time variation in the suction profile.

Modeling of daily weather patterns using a modified Thornthwaite Index procedure is used to "predict" the suction profile for five measured profiles. The procedure consists of plotting deficit/storage values from the Thornthwaite calculations using the yearly pattern of moisture with specific emphasis on three to five months immediately preceding the sampling event.

The technique appears to reasonably predict the suction profile on sites where the major influence on the profile is climate. Profiles on sites with heavy growth of mature trees also exhibit muted variations with changes in prevailing weather.

Introduction

The measurement and use of suction to model unsaturated soil behavior has increased rapidly within the last 10 years. Numerous methods are available to reasonably measure suction. Two of the relatively easy methods are the filter paper technique and the psychrometer.

Suction profiles have been extensively used to evaluate slope failures, the performance of landfill covers and liners, and both heave and collapse of unsaturated soils. The current edition of the PTI design manual has extended the use of suction as a stress variable to predict the magnitude of surface movement, with an assumption that all profiles follow a "trumpet" shape.

The purpose of this study has been to evaluate if various observed suction profiles can be "predicted" based on historical patterns of weather. Logically, drier (wetter) profiles would be anticipated considering patterns of drier (wetter) weather; however, the specific depth of drying (wetting) is of importance if suction is to be used as a stress variable for prediction of movement. It will also be critical to have some understanding of the potential change in the profile if this method will be used in design, since construction rarely occurs immediately after the initial geotechnical investigation.

The Thornthwaite Index[1] is one method for evaluating regional climates. The procedure consists of a yearly summation of the potential for evapotranspiration versus available infiltration and/or runoff of rainfall. A negative Index indicates that there is a greater potential for evapotranspiration than there is available rainfall. A positive Index indicates there is more rainfall than the magnitude of potential evapotranspiration. Climatic areas exhibiting a positive Index generally will have shallow ground water and relatively moist profiles.

The Dallas/Fort Worth (D/FW) regional area straddles an average Thornthwaite Index of 0, although wide variation in the actual index is common. The calculated Index using weather information from the D/FW Airport reporting station for an "average" soil profile is shown in Figure 1.

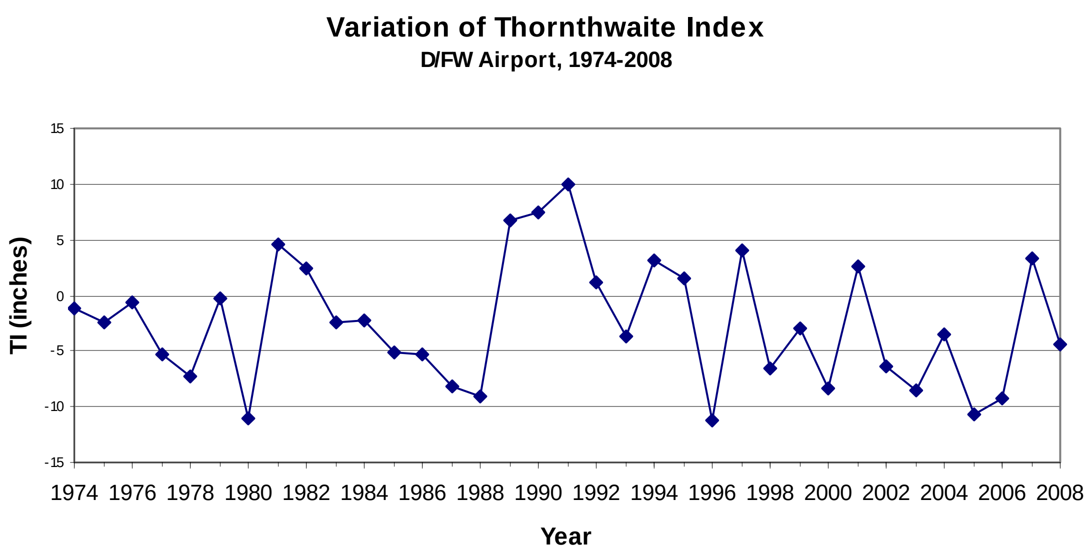

Figure 1. Thornthwaite Index 1974 - 2008 (inches).

[1] Thornthwaite, C.W. (1948). "An Approach Toward a Rational Classification of Climate." Geographical Review, 38(1), 54-94.

Determination of the Index involves calculation of the monthly average of deficit and/or storage. A plot of the average monthly moisture deficit/storage for 1996 is provided in Figure 2.

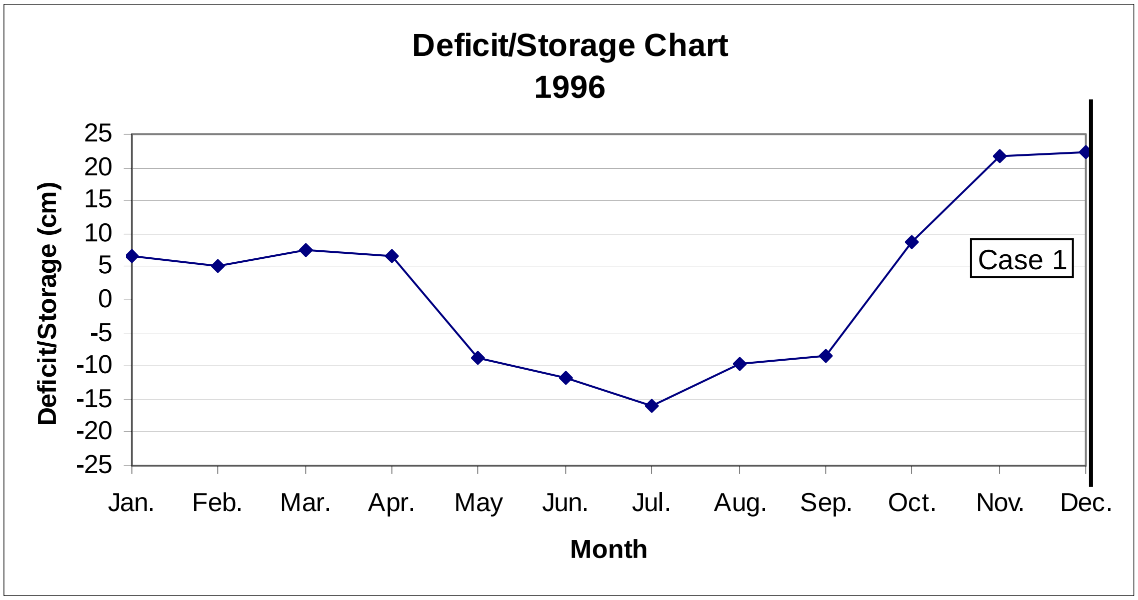

Figure 2. Plot of calculated deficit or storage values in cm for 1996. The vertical line on the right side indicates the approximate sampling date for Case Study 1.

Analysis of Figure 2 indicates that 1996 began the year with approximately 6 cm of stored water and prevailing dry weather as indicated by the Thornthwaite Index of approximately 2 inches in 1995. Sufficient rainfall occurred during February through April to effectively balance the evapotranspiration through the end of April. An increase in temperature in May and June resulted in an increase in the evapotranspiration which exceeded the available rainfall, thus the observed development of a calculated deficit from May through September. An increase in rainfall, coupled with cooler weather, resulted in development of theoretical storage through the end of December. The effect of this pattern on the measured suction profile will be discussed in the following section.

Five case studies are presented in the following section. For each study, the deficit/storage graph is provided along with the measured suction profile. Additional information on each profile to include actual rainfall and average temperatures was previously discussed by Reed[2]. To allow the reader to review previous information on each study, the case studies are numbered consistently with the previous paper. Case Study 3 was deleted from the current paper for brevity.

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[2] Reed, Ronald F. (2009). "Observed Soil Suction Profiles with North Texas". Spring Meeting, Texas Section ASCE, South Padre Island.

Case Studies

Five case studies are presented in the following paragraphs. Each case study consists of a deficit/storage graph and measure suction profile. Suction tests were performed using the filter paper, non-contact method.

Case Study 1. - This study is located on relatively deep alluvial CH clay deposits. The clays are generally dark brown becoming brown to yellowish-brown below depths of 8 to 12 feet. Ground water was not encountered during the study, although typically, it is present at depths of 25 to 30 feet, varying with seasonal and yearly rainfall.

The measured storage/deficit plot for 1996 was provided in Figure 2. The suction profile was measured in mid-December 1996 and is shown in Figure 3.

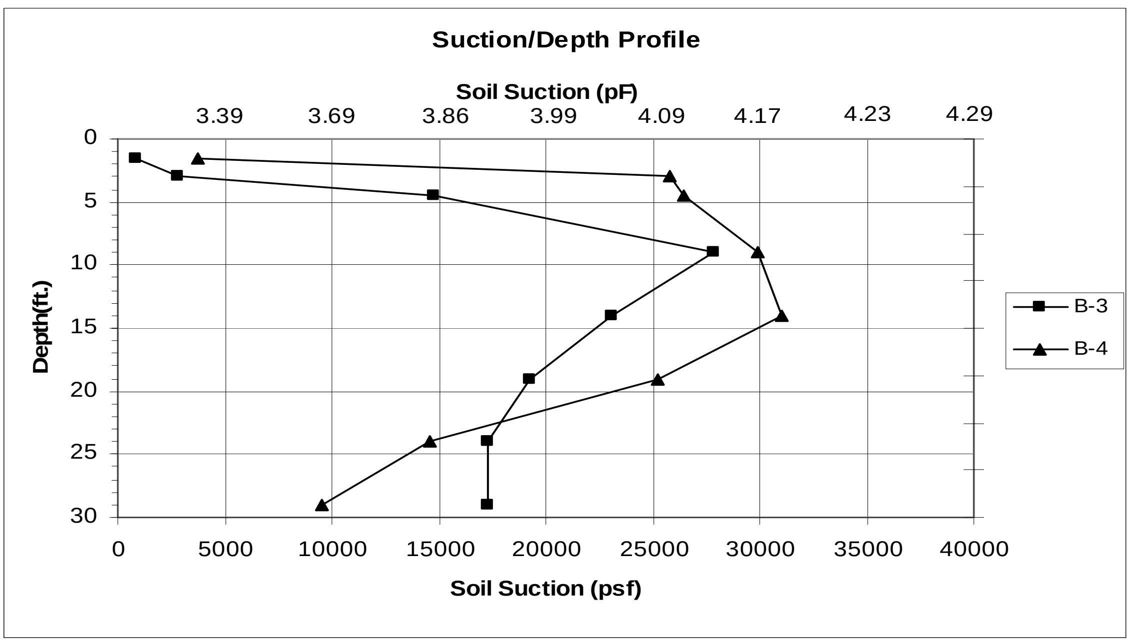

Figure 3. Suction Profile, Case 1.

As noted in Figure 3, the profile indicates relatively moist conditions to approximately five feet, then relatively dry conditions to approximately 25 feet. Analysis of the storage/deficit graph in Figure 2 indicates that the early part of 1996 was relatively dry, with limited storage of moisture in the soil going into the drier part of the year. Analysis of the prevailing Thornthwaite Index for 1995 indicates that the previous year was also relatively dry.

Rainfall which occurred in the later part of 1996, as indicated by the increased values of storage in Figure 2 resulted in surface infiltration and a corresponding reduction in suction. Approximately three months of calculated "storage" appears to have resulted in approximately five feet of infiltration.

Case Study 2. - The site is underlain by CH clay derived from the Marlbrook Marl Formation. The clay is generally dark brown near the surface becoming olive to olive-gray with depth. Soils below a depth of approximately five feet have iron-stained joints and fissures characteristic of weathered marl. Ground water was located at an approximate depth of 12 feet. Based on experience, ground water in the vicinity is generally encountered at depths of 10 to 15 feet throughout the year.

The calculated storage/deficit for 1997 is provided in Figure 4.

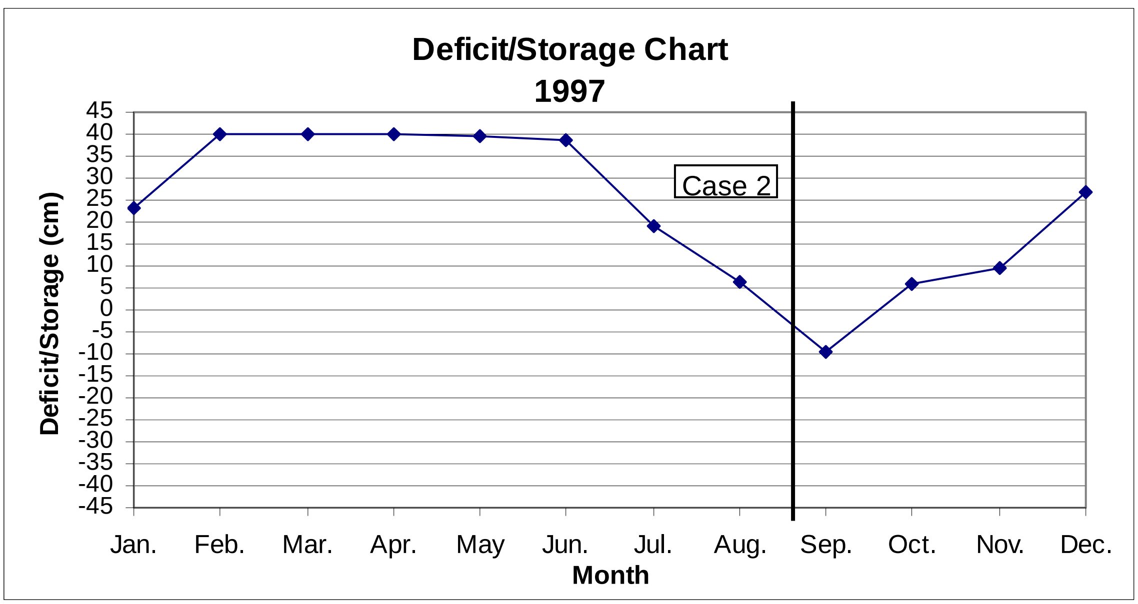

Figure 4. Storage/Deficit Graph for 1997 (Case Study 2).

Analysis of Figure 4 indicates that storage reached a maximum peak at the end of January 1997 of approximately 40 cm, continuing through the last part of May. Drier weather coupled with increased temperatures and plant growth resulted in development of a moderate deficit by the first part of September of approximately 10 cm.

Note that the "peak" storage value is based on an "average" soil profile which was used to calculate the yearly Thornthwaite Index values shown in Figure 1. For calculation of the Index, any rainfall occurring when maximum storage is recorded is calculated to be runoff. The actual storage would have to be evaluated based on site-specific weather and soil profile.

Sampling was performed in early August 1997. The measured suction profile is shown in Figure 5.

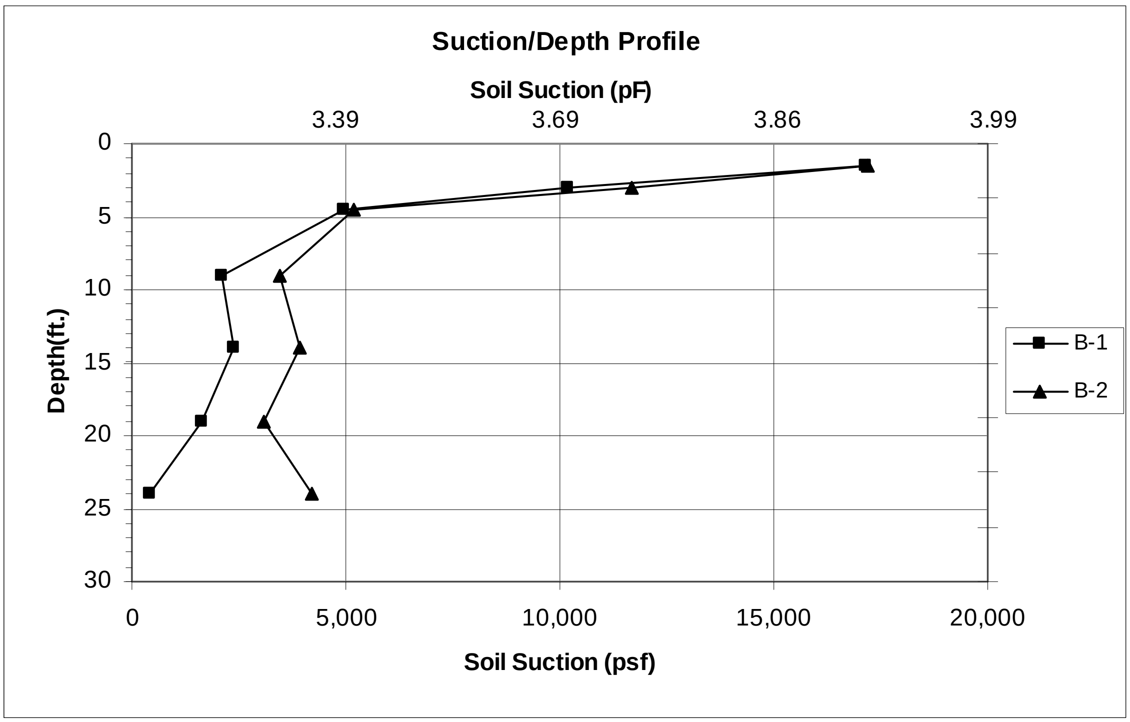

Figure 5. Suction Profiles for Case Study 2.

As noted in Figure 5, the suction is relatively dry to approximately 5 feet, then moist to the 25-foot completion depth. This profile is consistent with the drying indicated by the storage/deficit plot which was occurring during June, July and August.

Case Study 4. - This study is an example of relatively dry conditions within residual soils of the Eagle Ford Group. Subsurface conditions consist of approximately three to five feet of alluvial sandy clay over severely weathered shale dual classified as olive to olive-yellow CH clay. The clay (severely weathered shale) is hard and has extensive secondary joints and fissures that are iron-stained. Ground water was not present at the time of the investigation and is generally not present in any appreciable quantities. The site was also heavily covered with mature mesquite trees.

The site was sampled in early July 2005. The storage/deficit plot for 2005 is provided in Figure 6.

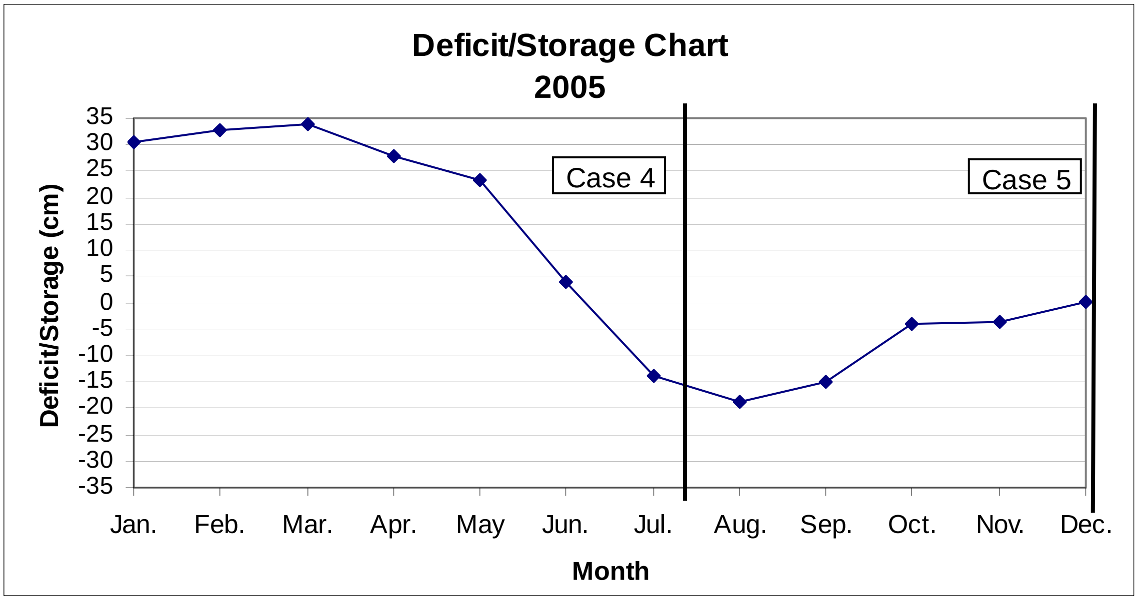

Figure 6. Deficit/storage chart for 2005.

The deficit/storage chart for 2005 is similar to the one for 1997 (Figure 4) in that approximately 30 to 35 cm of storage was available into May. Drying during June and July resulted in a calculated deficit of 20 cm at the time the site was sampled. This compares to a deficit for the 1997 study (Case Study 2) of 5 cm.

The suction profile is provided in Figure 7.

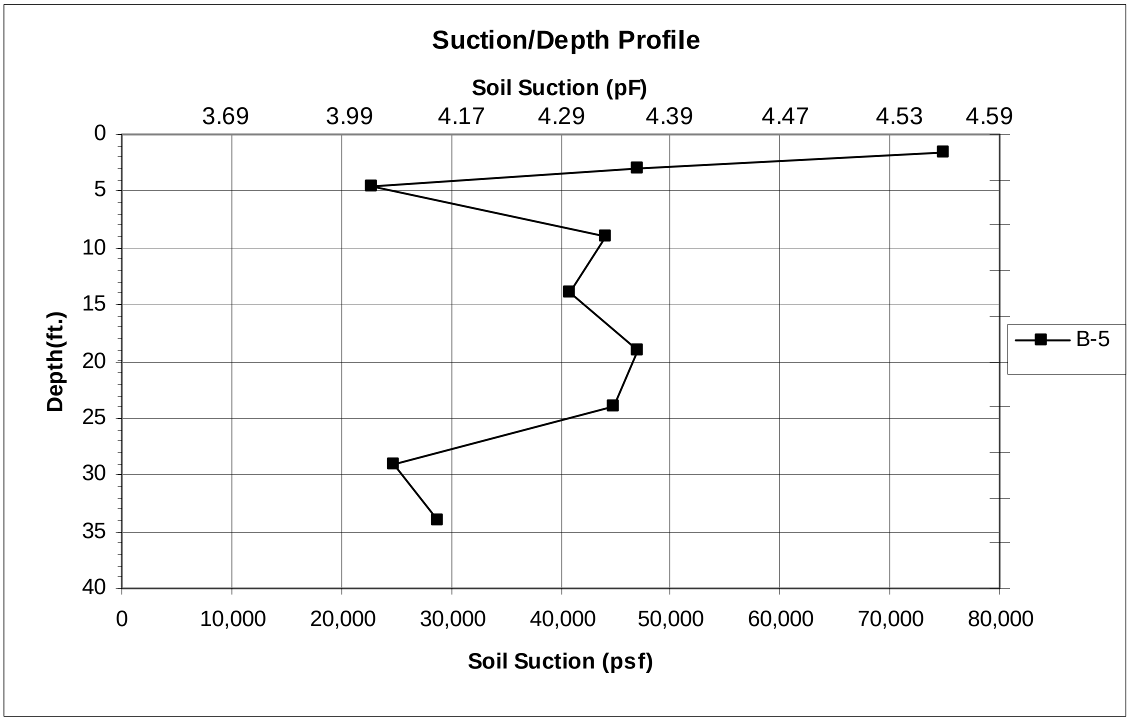

Figure 7. Suction Profile for Case Study 4.

The suction profile in Figure 7 indicates relatively dry conditions through the 35-foot sampling depth, with extremely dry conditions in the upper 5 feet. This compares with Case Study 2 where drying extended to a depth of approximately 5 feet. It is unknown if the deeper drying is associated with the lower deficit, -20 cm of water in 2005 versus -5 cm in 1997, or if the drier conditions are associated with the extensive growth of mesquite trees present on the site prior to sampling.

Case Study 5. - Subsurface conditions consisted of 9 to 11 feet of CH clay over weathered grading to unweathered limestone. The clay was dark brown to dark grayish-brown to the top of the weathered limestone. Ground water was encountered at a depth of approximately 13 feet, within joints and fractures of the weathered limestone.

The site was sampled in December 2005. The deficit/storage graph for this year was provided in Figure 6.

At the beginning of 2005, the Thornthwaite calculations indicated an approximate storage of 25 to 35 cm through April, dropping to a deficit of -18 cm of water by August. Moderate rainfall and cooler temperatures resulted in infiltration and a gradual rise in water in the profile to approximately 0 by December.

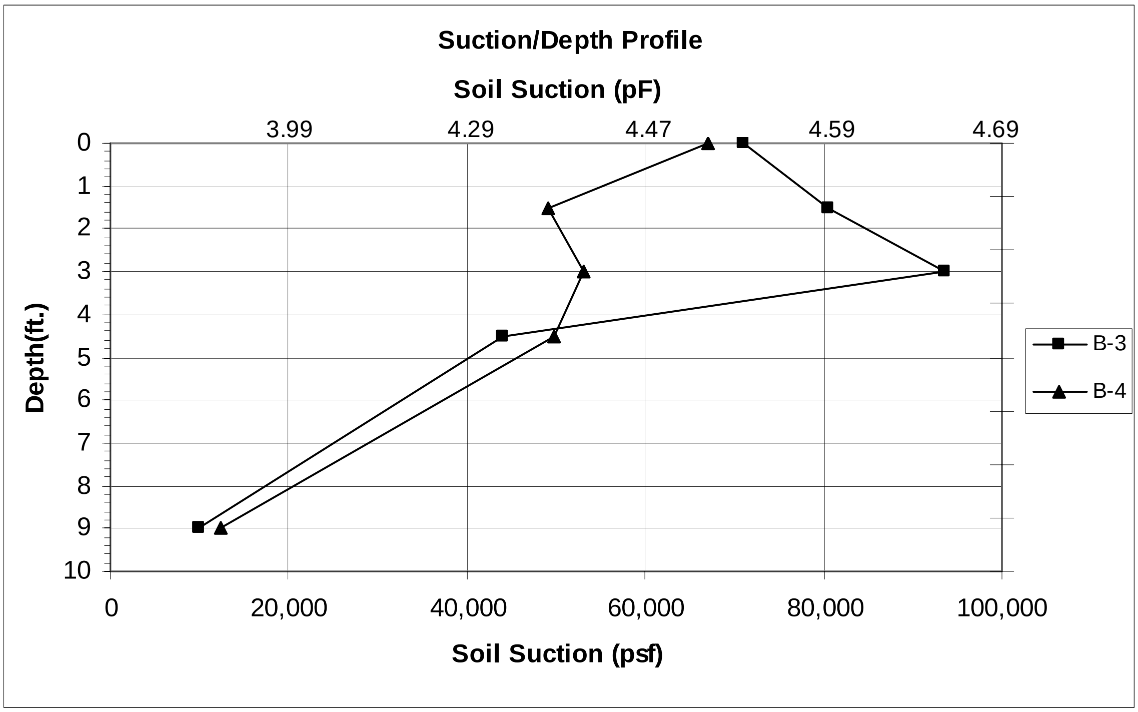

Figure 8. Suction profile for Case Study 5.

Analysis of the suction profile shown in Figure 8, indicates relatively dry conditions to the top of weathered limestone at approximately nine feet. The general trend is to be drier near the surface, which would be expected. The measured suction values at Boring B-3 appear to also reflect some wetting of the surface soils to approximately three feet, relative to the highest measured suction. The profile remains, however, dry throughout the depth of the clay.

Case Study 6. - Subsurface conditions consisted of dark brown to dark grayish-brown clay becoming yellowish-brown and light gray below depths of seven to eight feet. The clay exhibited extensive jointing and fracturing characteristic of severely weathered calcareous shale below a depth of 13 feet. Ground water was noted at a depth of 12 feet at the time of the field investigation which was conducted in mid-September 2007.

The deficit/storage graph for 2007 is provided in Figure 9.

Analysis of Figure 8 indicates that the maximum storage of 40 cm was obtained by June, dropping with seasonal drying to approximately 10 cm of storage by August. However, because of the weather pattern in 2007, significant drying apparently did not occur as calculations indicate that a deficit condition was never achieved. By December, the estimate of storage had rebounded to approximately 23 cm.

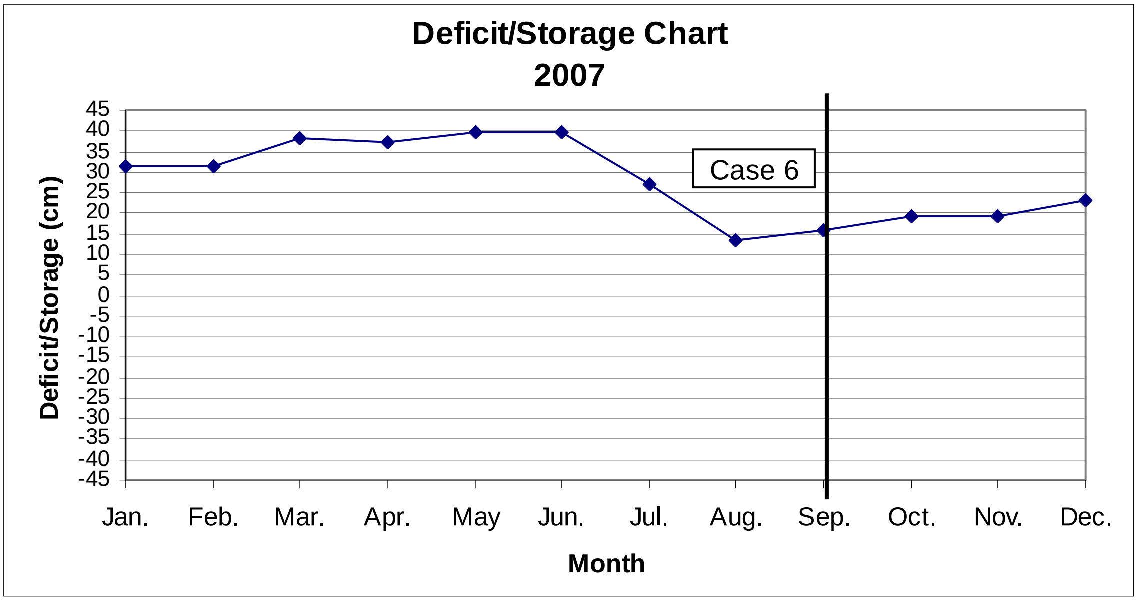

Figure 9. Moisture Storage/Deficit Profile for Case Study 6.

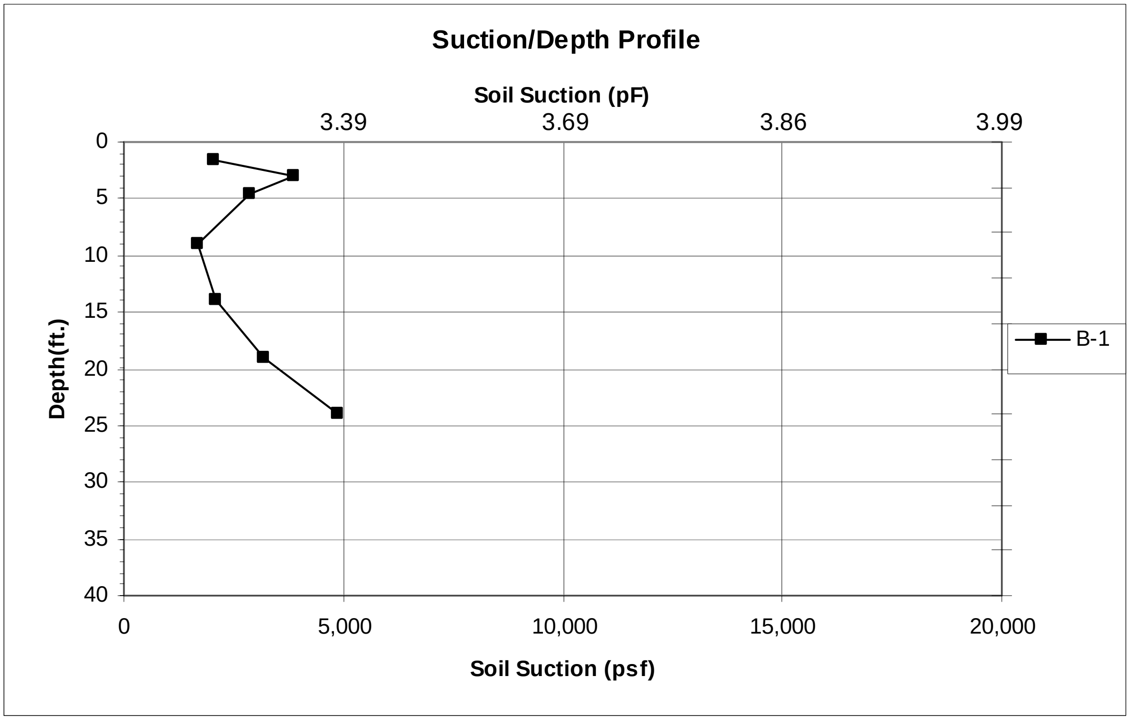

Figure 10. Suction Profile for Case Study 6.

The measured suction profile is provided in Figure 10. The suction values are low, indicating relatively moist conditions. This is consistent with the storage/deficit profile in that no net deficit in soil moisture was calculated for 2007.

Summary and Conclusions

The above studies indicate a strong correlation between graphs of the Thornthwaite storage/deficit calculations and the observed suction profiles. One limitation of the Thornthwaite procedure is that it does not account for specific site slopes or ground cover, which would impact both infiltration and rainfall runoff.

As observed in Case Study 4, the presence of an extensive growth of mature mesquite trees (or other types of trees) may significantly impact the suction profile. Different geologic conditions may also impact the observed correlation.

Additional studies are being conducted to evaluate the impact of a particular deficit/storage profile on various geologic and soil conditions. It is anticipated this information may be useful in both forensic studies and design where the project has been delayed and climatic conditions have changed from initial design.