# MODELING VEGETATION (AND OTHER) EFFECTS USING VOLFLO SOFTWARE

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# PART I

## UNSATURATED SOIL MECHANICS (USM) THEORY

# Unsaturated Soil Mechanics

$$\text{SHRINK OR SWELL} = \sum \left( \frac{\Delta H}{H} \right)_i (\Delta Z)$$

$\frac{\Delta H}{H}$ =Vertical volume change per element

$\Delta Z$ =Element thickness

$$\frac{\Delta H}{H} = f\left( \frac{\Delta V}{V} \right)$$

$\frac{\Delta V}{V}$ =Percent volume change per element

$f$ =vertical volume change coefficient

(f = 0.5 shrink, f = 0.8 swell)

# Unsaturated Soil Mechanics

## Percent Volume Change Per Element

### SWELL

$$\frac{\Delta V}{V} = (-\gamma_h)(\log_{10}\left(\frac{h_f}{h_i}\right)) - (\gamma_\sigma)(\log_{10}\left(\frac{\sigma_f}{\sigma_i}\right)) - (\gamma_o)(\log_{10}\left(\frac{\pi_f}{\pi_i}\right))$$

### SHRINK

$$\frac{\Delta V}{V} = (-\gamma_h)(\log_{10}\left(\frac{h_f}{h_i}\right)) + (\gamma_\sigma)(\log_{10}\left(\frac{\sigma_f}{\sigma_i}\right)) - (\gamma_o)(\log_{10}\left(\frac{\pi_f}{\pi_i}\right))$$

**Note: sign change**

# Unsaturated Soil Mechanics

$$\frac{\Delta V}{V} = (-\gamma_h)(\log_{10}\left(\frac{h_f}{h_i}\right)) - (\gamma_\sigma)(\log_{10}\left(\frac{\sigma_f}{\sigma_i}\right)) - (\gamma_o)(\log_{10}\left(\frac{\pi_f}{\pi_i}\right))$$

**Matrix Suction component**

**Overburden component**

**Osmotic Suction component**

# Unsaturated Soil Mechanics

## Matrix Suction component

**Suction Compression Index corrected for fine clay and coarse grained components**

**Δ SUCTION**

$$\frac{\Delta V}{V} = (-\gamma_h)(\log_{10}\left(\frac{h_f}{h_i}\right))\ldots\ldots$$

# Unsaturated Soil Mechanics

$$(\log_{10}\left(\frac{h_f}{h_i}\right))$$ **really is a CHANGE**

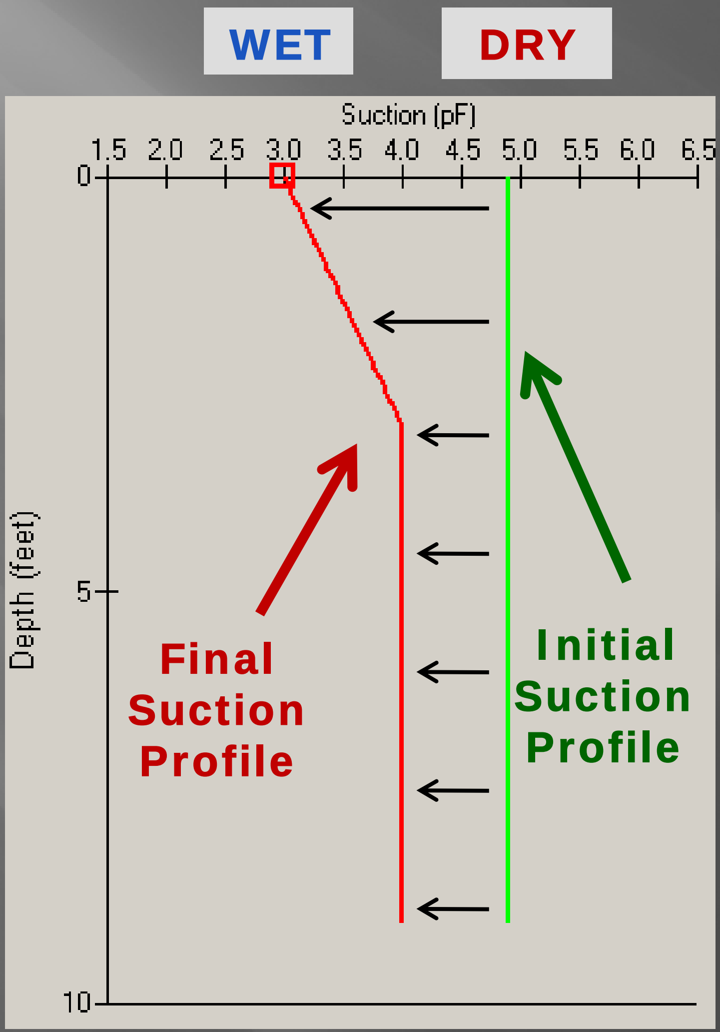
**Final suction**

**Initial Suction**

$$(\log_{10}\left(\frac{h_f}{h_i}\right)) \Rightarrow \log_{10}(h_f) - \log_{10}(h_i)$$

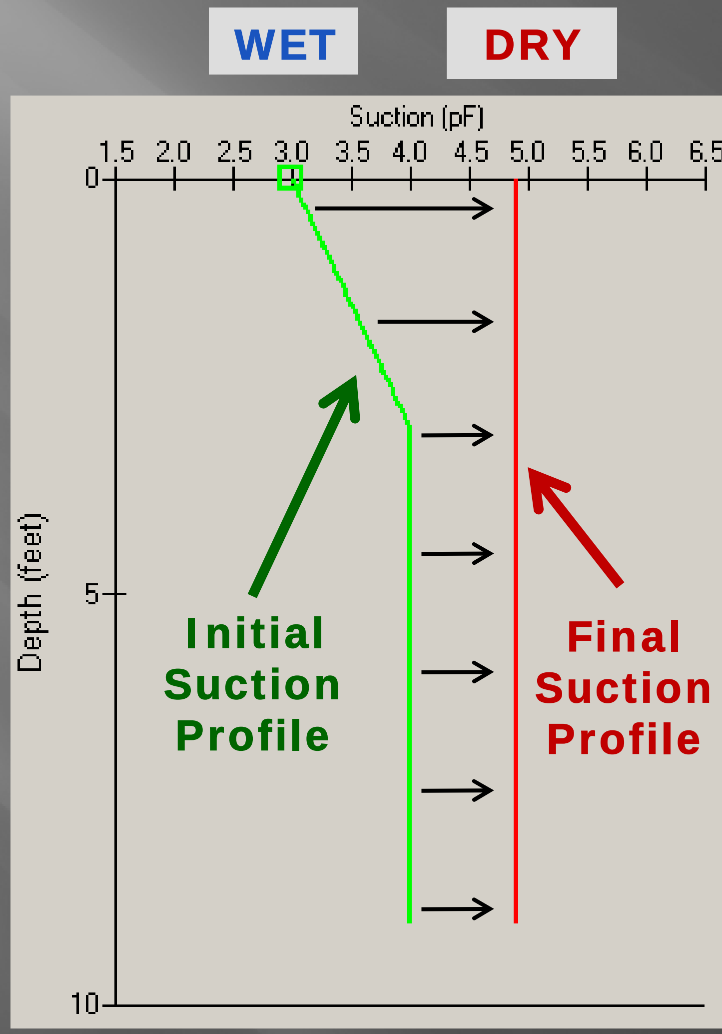
# Suction Change

A suction change from dry (higher suction) to wet (lower suction) results in swell ($y_{m\ edge}$).



# Suction Change

A suction change from wet (lower suction) to dry (higher suction) results in shrink ($y_{m\ center}$).



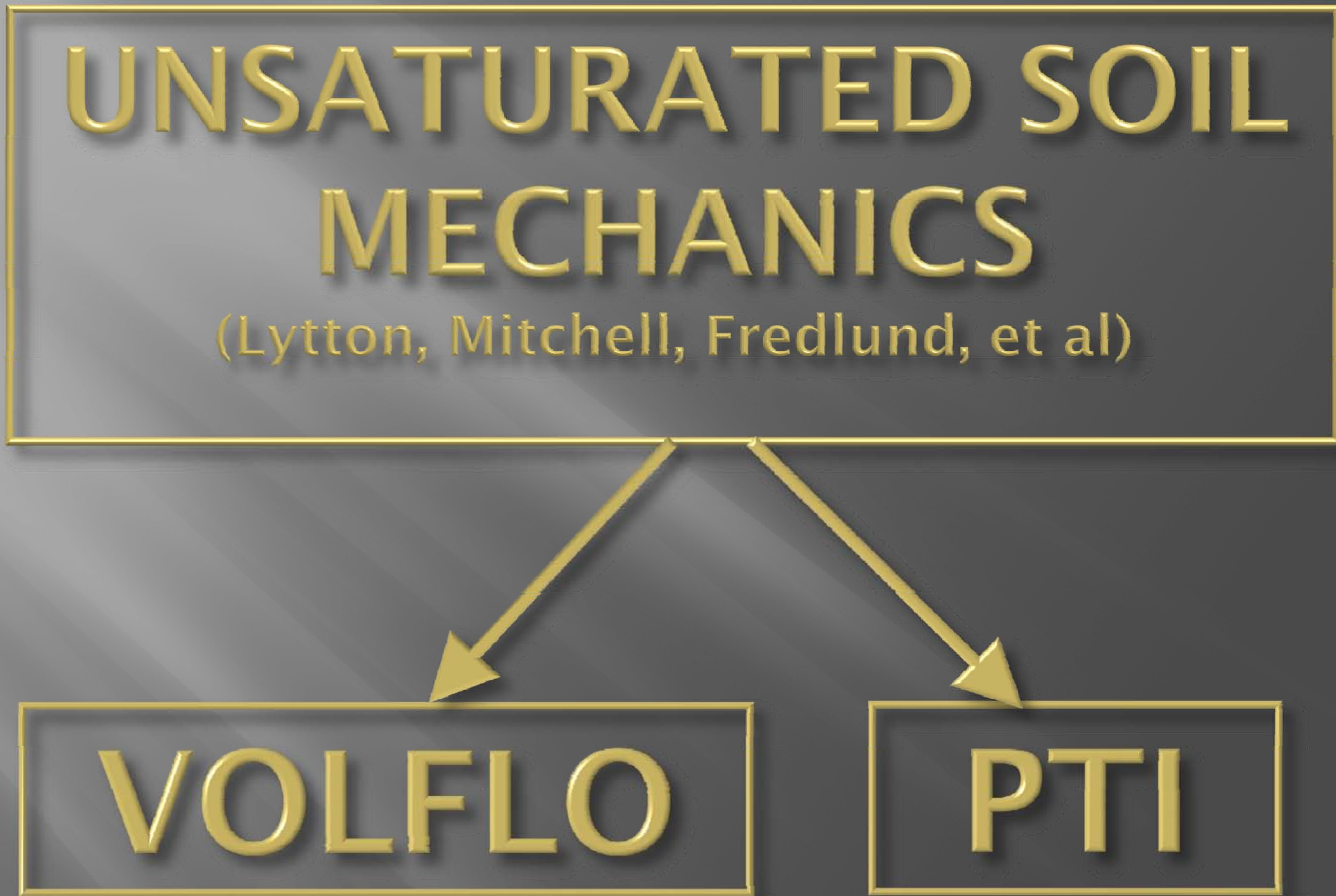
# Unsaturated Soil Mechanics

**The Suction Compression Index ($\gamma_h$) defines how much a soil will shrink or swell for a change in suction**

# Unsaturated Soil Mechanics

**The volume change due to change in suction is similar to consolidation due to effective pressure change**

| Consolidation Theory | Shrink / Swell Theory |
| --- | --- |
| Consolidation Index **Cs** | Suction Compression Index - $\gamma_h$ |
| Effective Pressure Change - $\Delta$**p** | Suction Change - $\Delta$**pF** |


UNSATURATED SOIL MECHANICS
(Lytton, Mitchell, Fredlund, et al)
VOLFLO
PTI

**PTI didn’t develop unsaturated soil mechanics (USM).**

**PTI adopted USM to define their soil / structure interaction model. As a result, the modeling of simple and complex cases are possible.**
**(Is this possible for other design procedures?)**

**PTI made simplifying assumptions, provided boundary conditions for use in design and techniques to determine certain variables.**

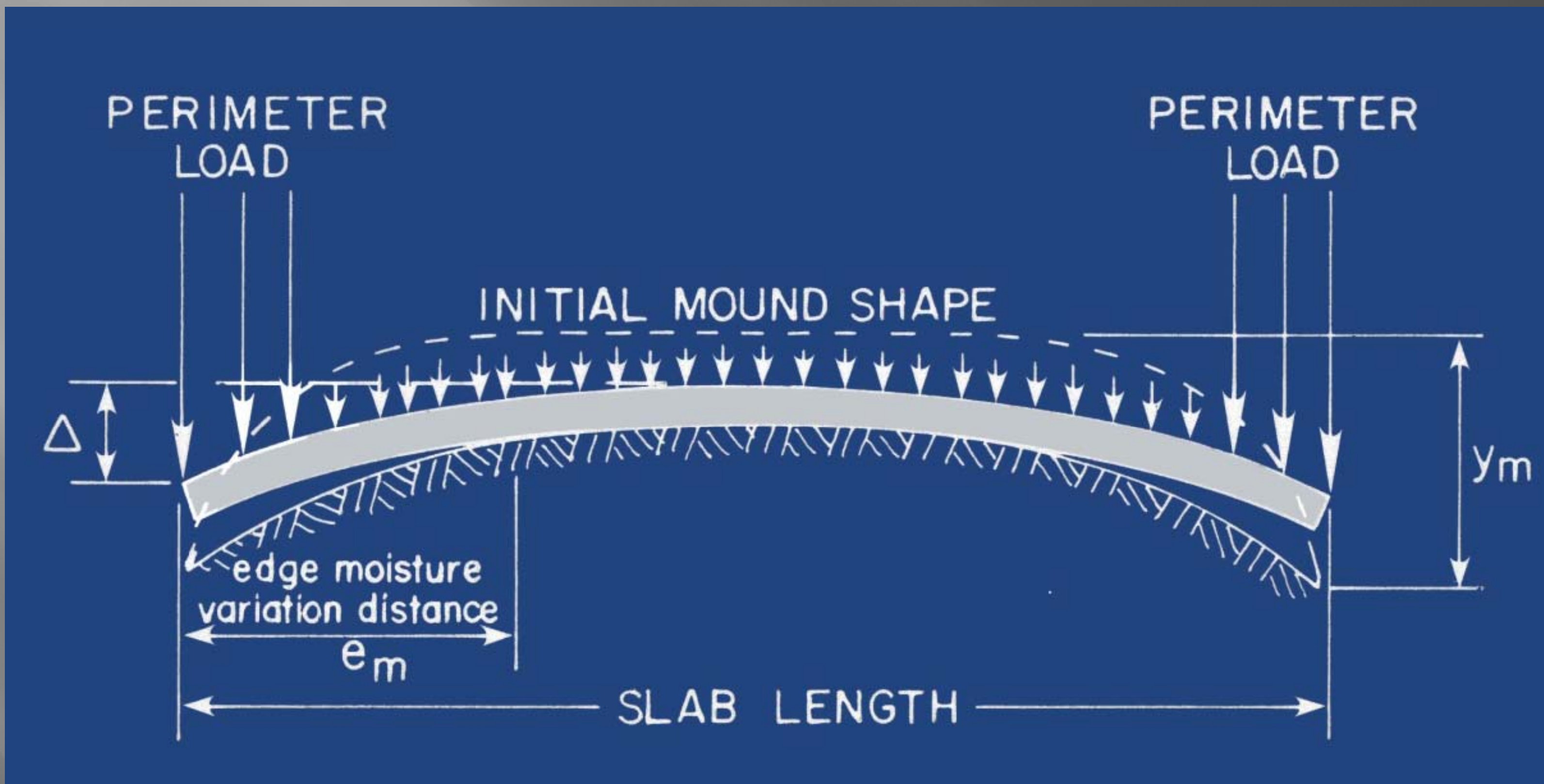
# PTI's implementation of Unsaturated Soil Mechanics.

- PTI adopted the principles of unsaturated soil mechanics to model the complex interaction between the slab-on-ground foundation and the supporting expansive soil.

- The soil / structure interaction models are defined by $e_m$ and $y_m$ values.

# PTI Soil / Structure Interaction Model CENTER LIFT

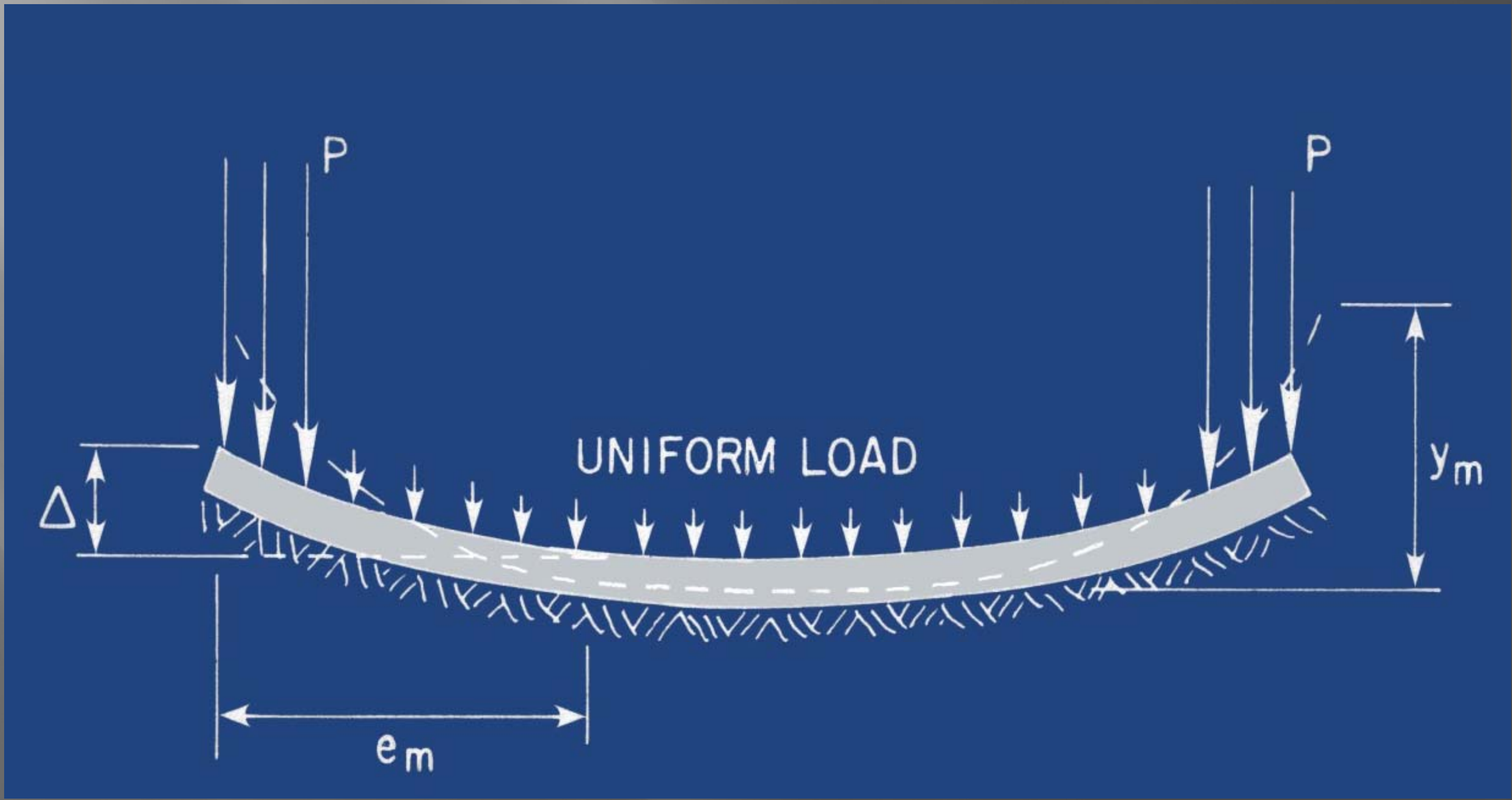
(Soils at edges shrinking)




Center Lift designation may be misleading.
Edge Drop may be more appropriate.

# PTI Soil / Structure Interaction Model EDGE LIFT

(Soils at edges swelling)

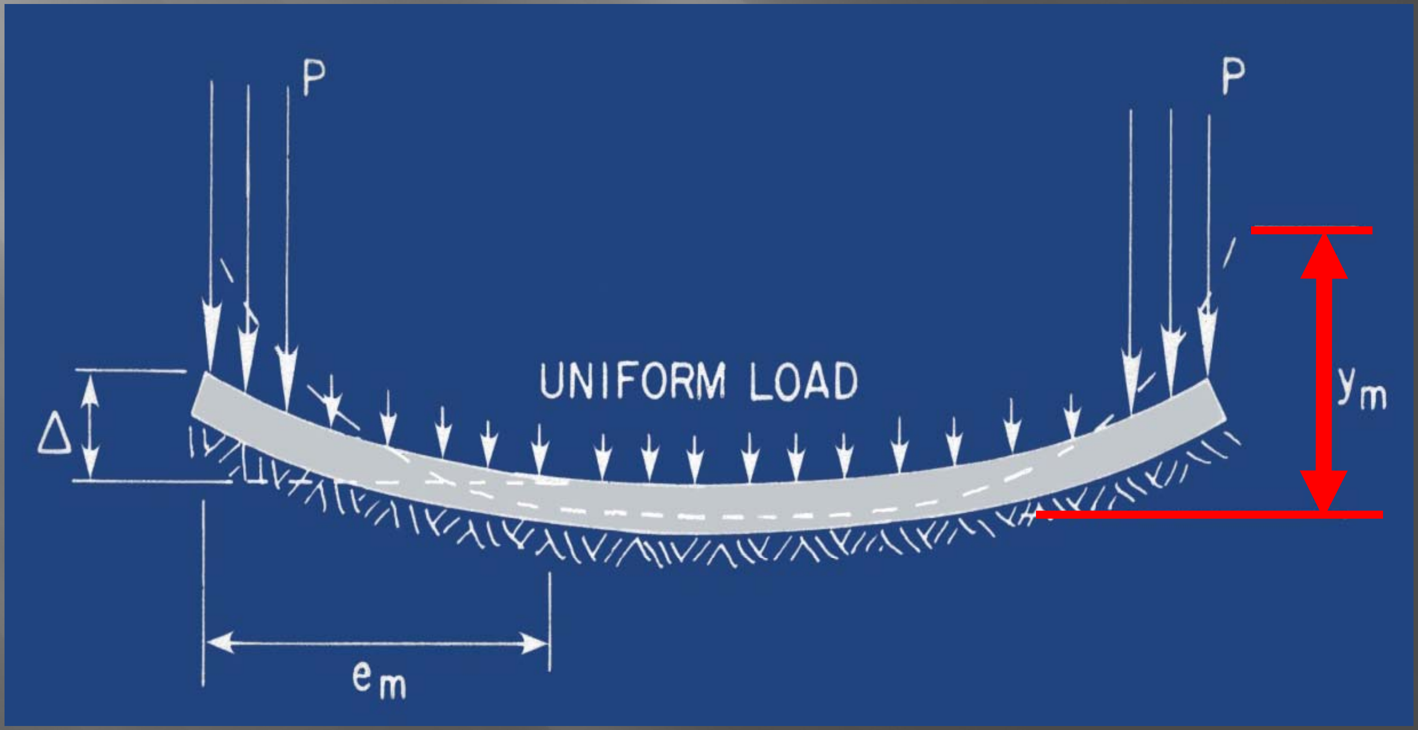


# $y_m$

PTI's Differential Soil Movement

# What is $y_m$?

- $y_m$ represents the change in the soil surface elevation at two locations.



# What is $y_m$?

- $y_m$ is **(and always has been)** developed using the principles of unsaturated soil mechanics.

- Boundary conditions, assumptions and methods have been revised over time to reflect changes in the state of the art and account for performance issues.

# WHAT $y_m$ IS NOT!

- $y_m$ is **NOT** the expected differential deflection of the foundation. $y_m$ should always be greater than the actual differential deflection of the foundation due to foundation stiffness.

- $y_m$ would only equal the differential deflection for a “perfectly flexible” foundation with no externally applied loads.

- $y_m$ is not PVR

# $y_m$ (Differential Soil Movement)

**$y_m$**, in very simple terms, is a function of a **change in suction** AND how much the soil changes volume for a given suction change.

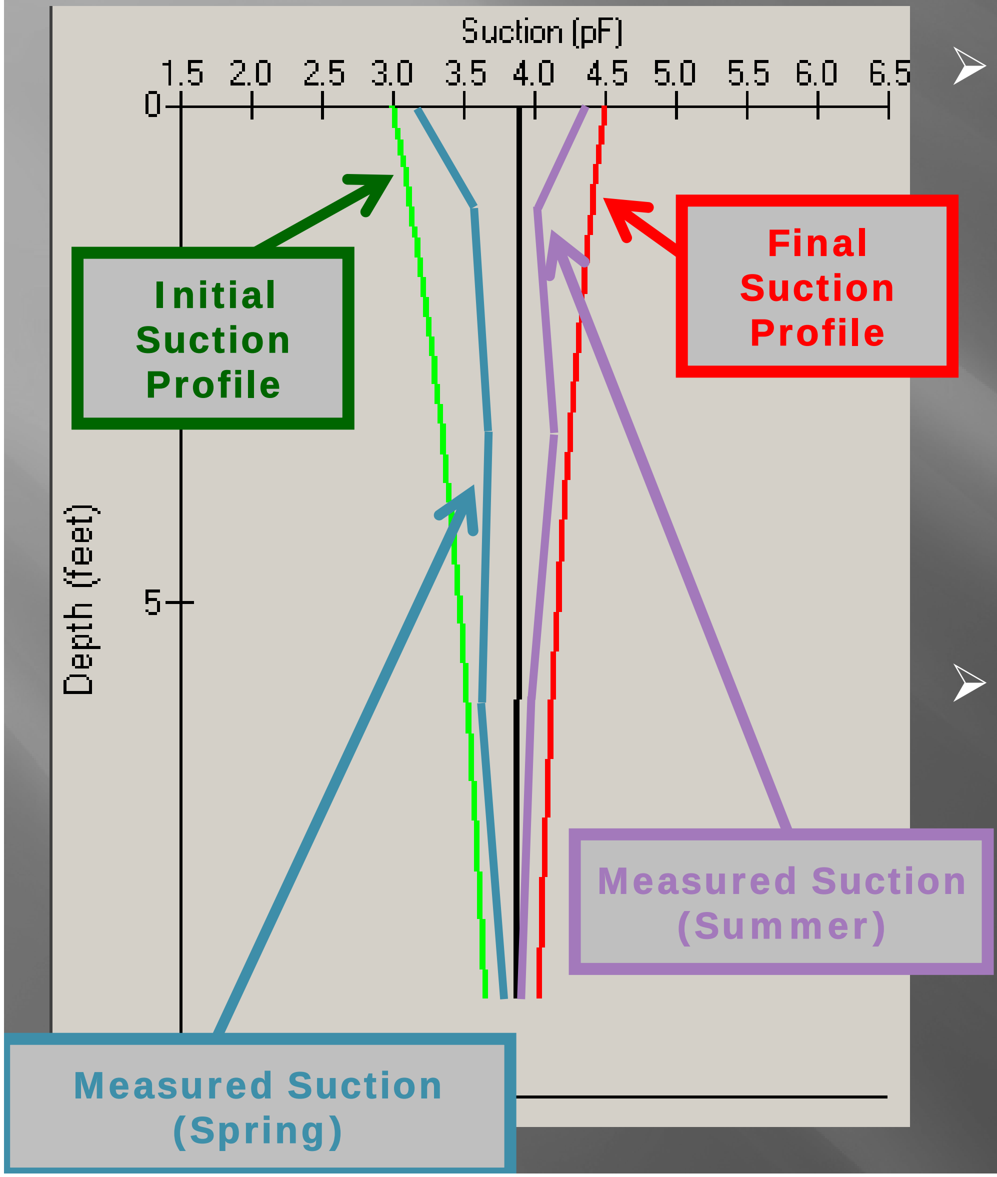
# DESIGN SUCTION ENVELOPES

The change in suction used for design is typically represented by a suction envelope since actual suction values are not known at the time of construction of the foundation or over the life of the structure. (suction does not need to be measured for typical design for this reason)

The design suction envelope approach will be conservative.

Assuming you know exactly what the suction values are at the time of construction would be dangerous.

# Example of Suction Envelope




- A Suction Envelope consists of an **Initial Suction Profile** (assumed suction at the time of foundation construction) and a **Final Suction Profile** (assumed maximum or minimum suction to be expected over the life of the foundation).

- The suction profiles do not represent the actual field suction but the boundary conditions which the suction is not expected to go beyond.

# Suction Profiles

Suction Profiles used to construct the envelopes can model :

- Sites controlled by climate (precipitation, evaporation, etc.) – commonly assumed to be "trumpet" shape based on Mitchell's permeability **(typical FINAL PROFILE for Houston area)**
- Equilibrium condition **(typical INITIAL PROFILE for Houston area)**
- Site modifications such as:
  - Moisture controlled fill pads
  - Moisture injection
- Vertical moisture barriers
- Vegetation
  - Trees (remove before or planted after foundation construction)
  - Flower Beds
- Poor Drainage

# PART II

## MODELING VARIOUS CASES USING USM AND RESULTING $y_m$ VALUES

# WHAT ARE THE TYPICAL DESIGN SUCTION ENVELOPES FOR THE HOUSTON AREA?

# PTI Recommended Design Suction Envelopes

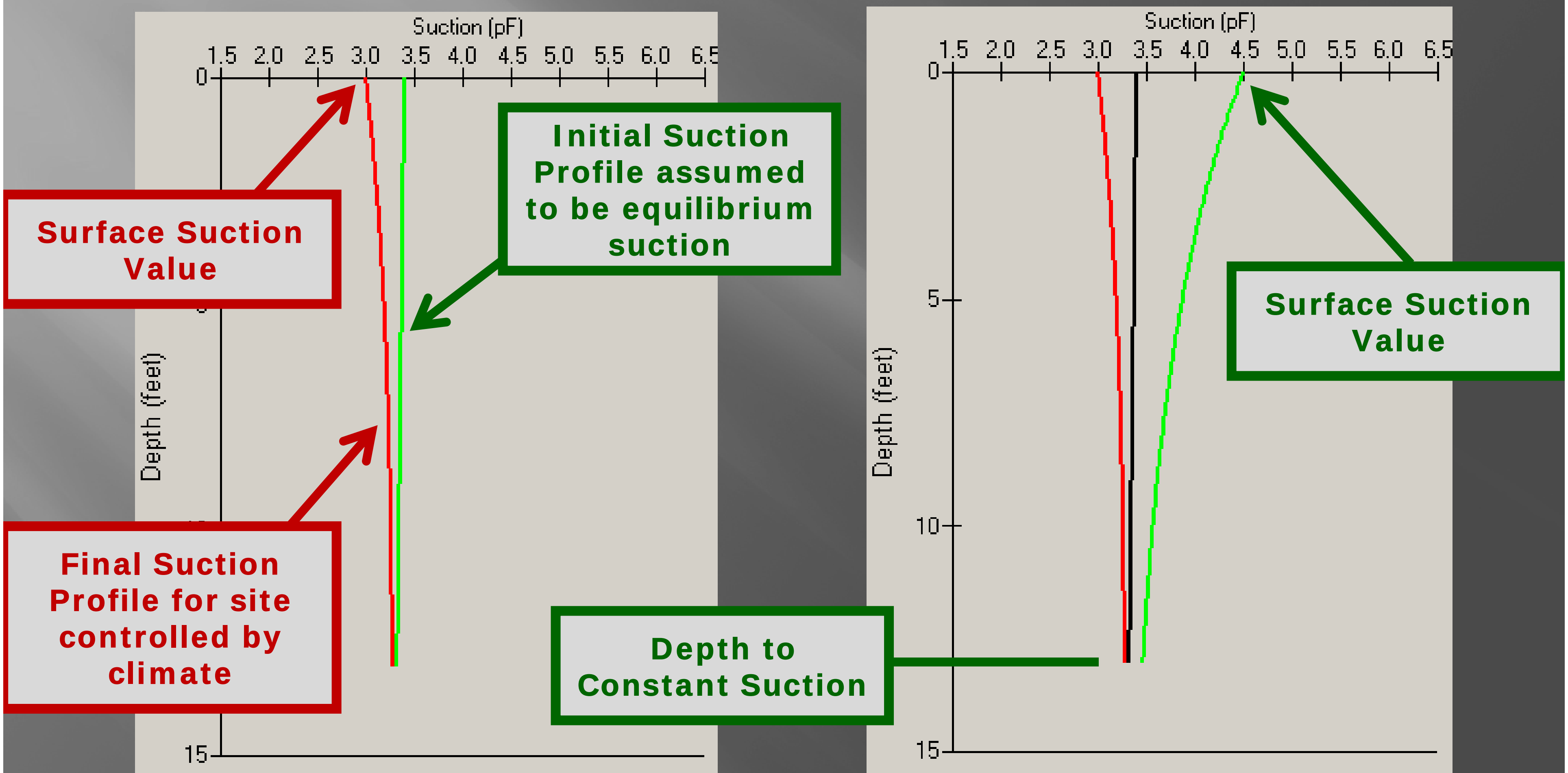
## FOR SITES CONTROLLED BY CLIMATE ONLY

**Post-Equilibrium Suction Envelope -** Starts with an initial equilibrium suction profile and changes to either a final wet or dry climate controlled suction profile.

**Post-Construction Suction Envelope -** Starts with either an initial wet or dry climate controlled suction profile and changes to the opposite climate controlled suction profile.

# Design Suction Envelopes

**Swell Case – Both envelopes start dry and end wet.**




**Post–Equilibrium** **Post–Construction**

# Design Suction Envelopes

**Shrink Case – Both envelopes start wet and end dry.**


**Post–Equilibrium**


**Post–Construction**

# Design Suction Envelopes

**The magnitude of shrink and swell is a function of the area between the two profiles.**


**Post-Equilibrium**


**Post-Construction**

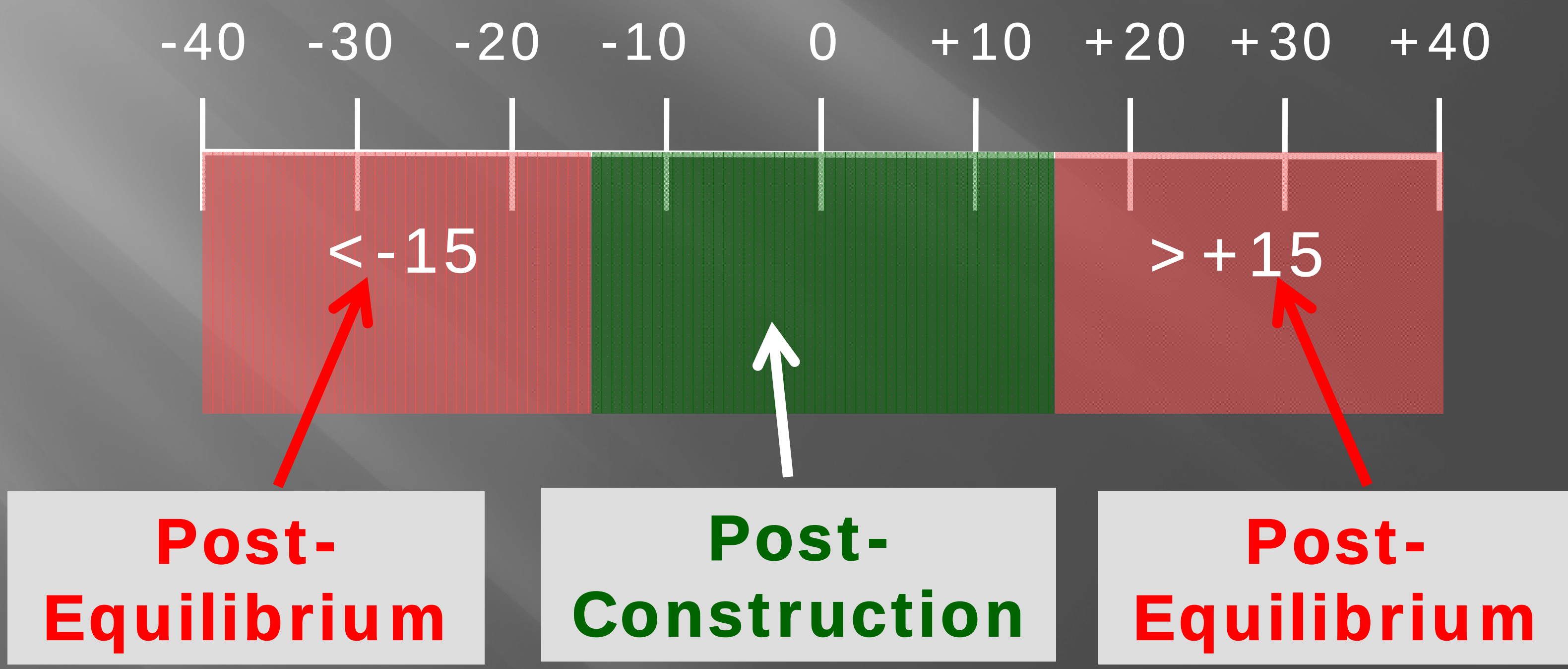
**For the same soil, the Post-Construction Envelope (on the right) will produce significantly more swell than the Post-Equilibrium Envelope on the left.**

# Post-Equilibrium versus Post-Construction

**When to use Post-Equilibrium Envelopes versus Post-Construction Envelopes?**

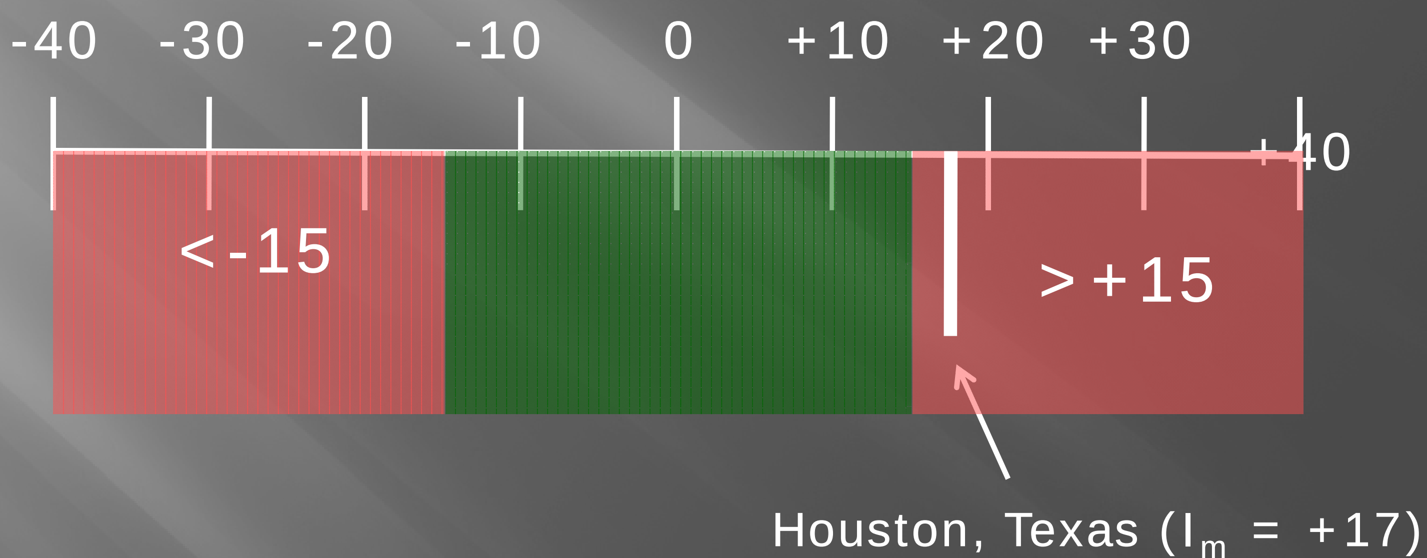
**(PTI Addendum #1)**

Thornthwaite Moisture Index (TMI)



# Climate Controlled Sites

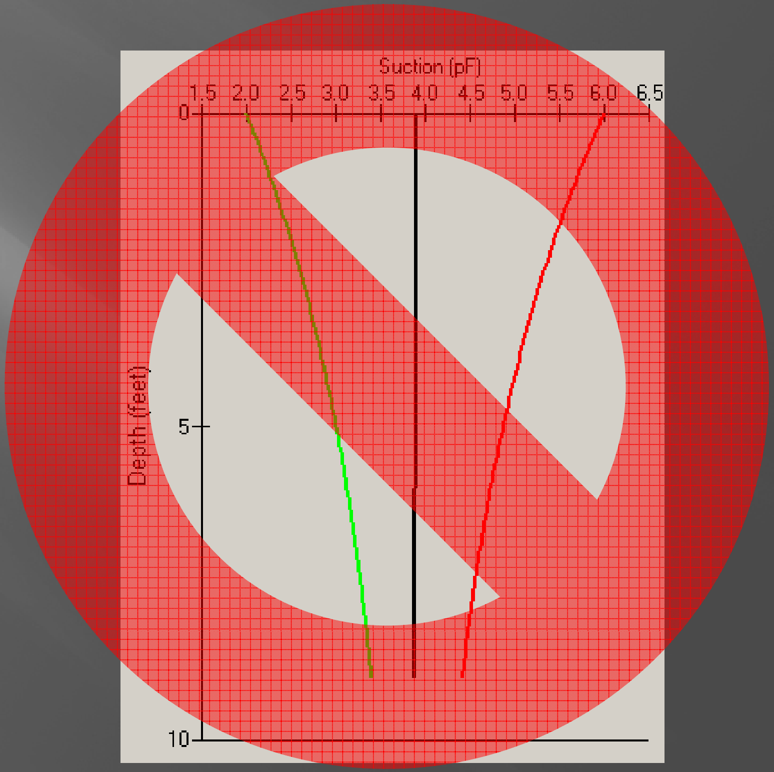
Thornthwaite Moisture Index (TMI)




**USE POST-EQUILIBRIUM MODEL**

# Suction Envelopes

**The magnitude of shrink and swell is a function of the area (sum of the volume change for each element) between the two profiles.**


**For the same soil the envelope on the right will produce significantly more shrink.**

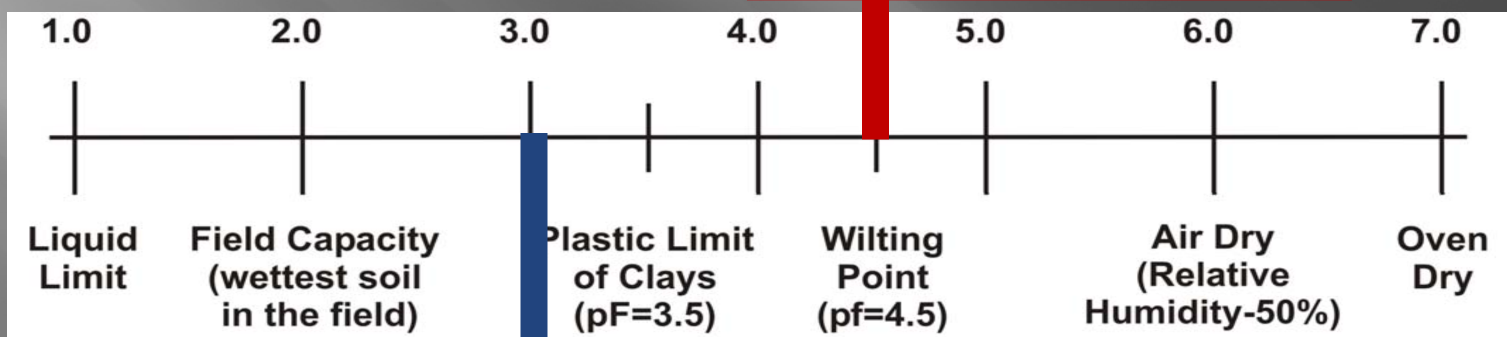
**Note the right envelope is for illustration purposes only and is NOT representative of an envelope that should be used for design purposes.**

# Design Surface Suction Values

**What values of the surface suction should be used for “typical” design?**

PTI RECOMMENDS A TOTAL DESIGN SURFACE SUCTION CHANGE OF 1.5

4.5 pF Typical dry surface suction value



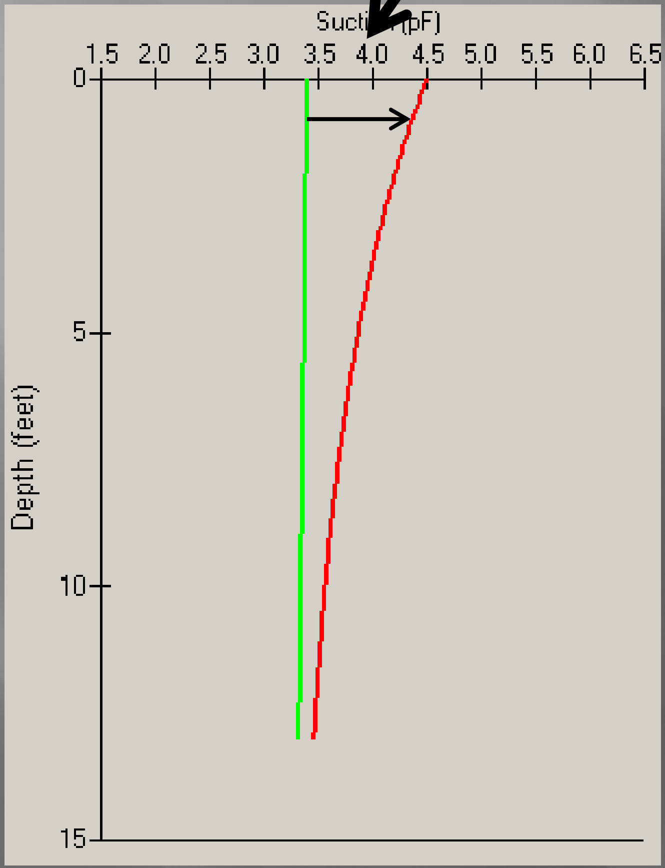

3.0 pF Typical wet surface suction value

Changed to 3.0 pF from 2.5 pF in Addendum #1.

# Suction Envelopes

## FOR SITES CONTROLLED BY CLIMATE ONLY

**1.1 pF + 0.4 pF = 1.5 pF (Total Suction Change at Surface)**




**Shrinking**


**Swelling**

# Sample $y_m$ values
# Climate Controlled Sites

| | $y_{m\ center}$ | $y_{m\ edge}$ | $\gamma_h$ |
|---|---|---|---|
| Low Expansive Soil (PI = 19) | 0.6 inches | 0.2 inches | 0.03 |
| Moderately Expansive Soil (PI = 28) | 0.9 inches | 0.4 inches | 0.05 |
| Expansive Soil (PI = 56) | 1.6 inches | 0.7 inches | 0.09 |

# WHAT SUCTION ENVELOPES SHOULD BE USED TO MODEL A TREE REMOVED NEAR THE PERIMETER BEFORE CONSTRUCTION OF A FOUNDATION?

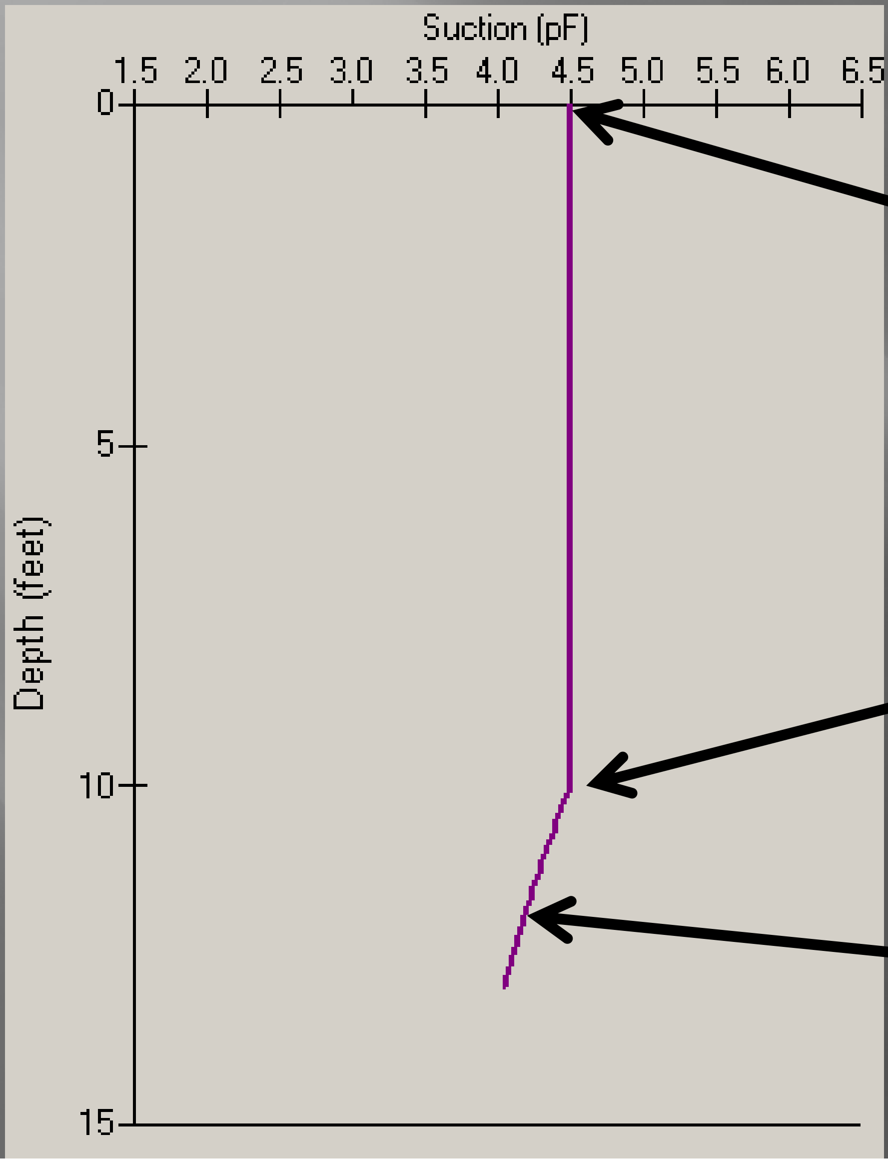
# TREE REMOVED NEAR PERIMETER RIGHT BEFORE CONSTRUCTION

To model special non-climate controlled conditions you have to determine:

1. Shape of suction profile for non-climate controlled conditions

2. Which suction profile (initial or final) will be affected

# SHAPE OF TREE SUCTION PROFILE

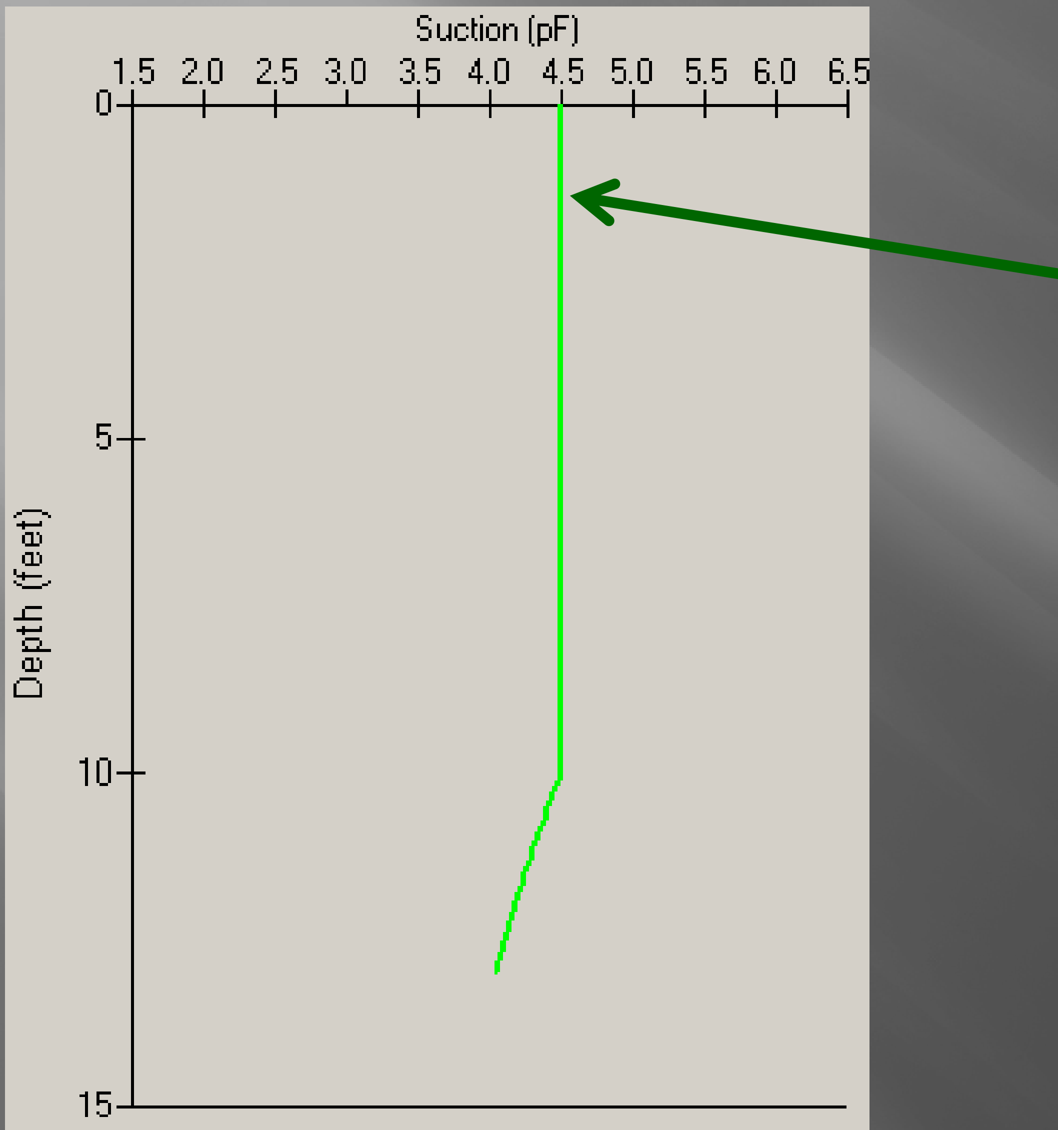



**4.5 pF is considered the wilting point of most vegetation. For the root zone, it is assumed that the tree will dry out the soil to a suction of 4.5 pF.**

**The depth of soil affected by trees is commonly assumed to be 2 feet deeper than the deepest root.**

**Below the depth influenced by the tree, the suction profile will trend back to the equilibrium suction value.**

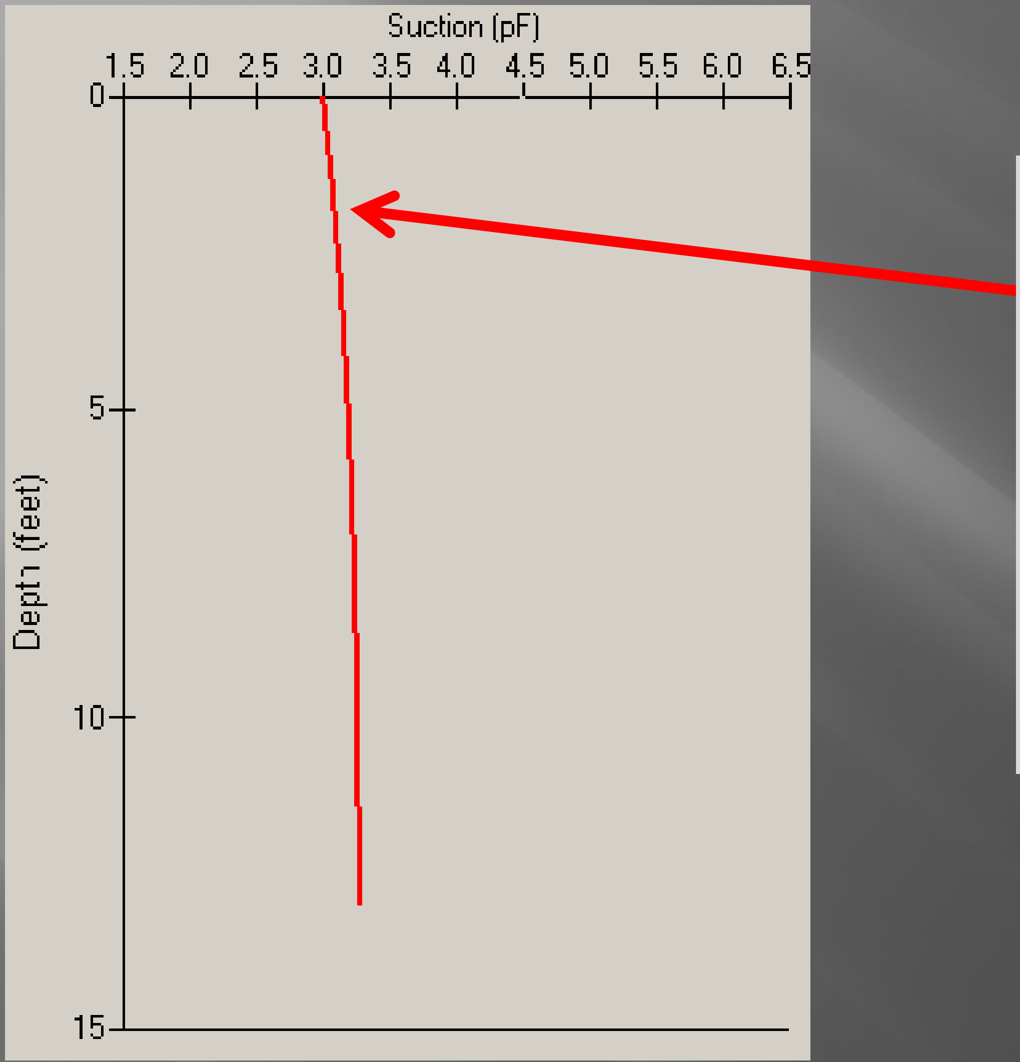
# Which suction profile will be affected by a tree removed from the perimeter before construction?




**Since the tree is removed JUST BEFORE (<30 days) construction it will affect the INITIAL SUCTION PROFILE.**

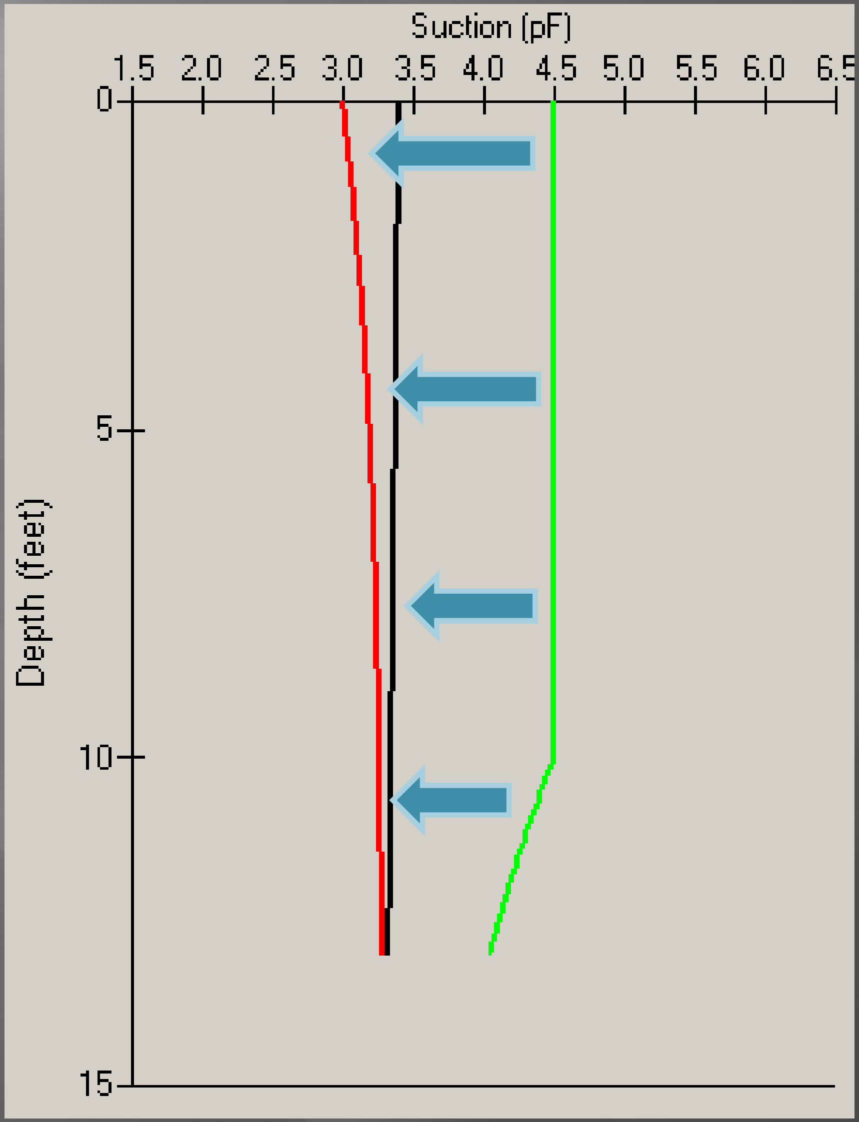
**This profile would not be appropriate if the soil has sufficient time after the tree has been removed to “rehydrate” before construction.**

# What final suction profile should be used?

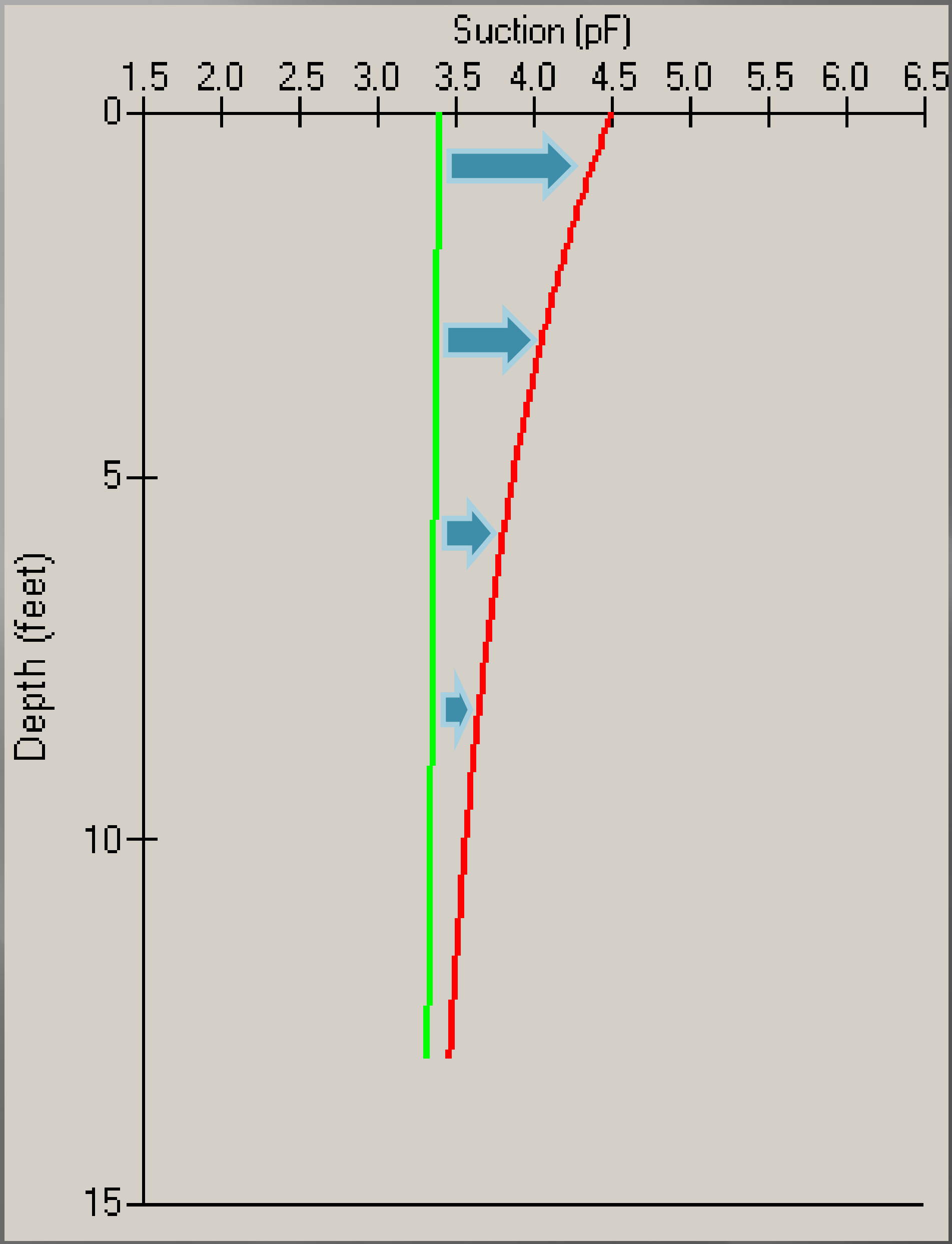



**Since climate will control how wet the soil can get after construction the climate controlled wet suction profile should be used for the FINAL SUCTION PROFILE.**

# SWELLING SUCTION ENVELOPE
## TREE REMOVED NEAR PERIMETER JUST BEFORE CONSTRUCTION



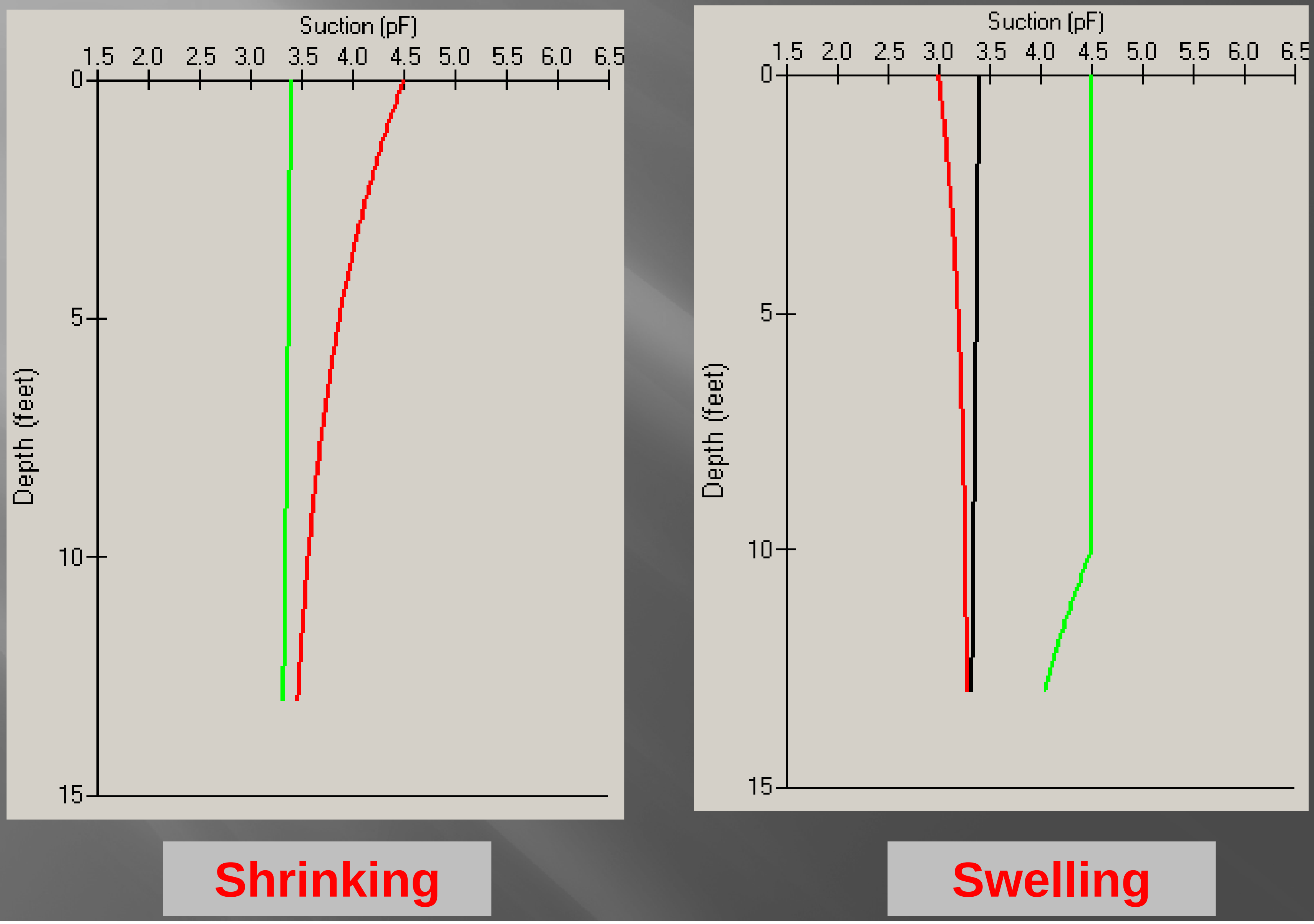
# SHRINKING SUCTION ENVELOPE




After the tree has been removed the only mechanism to reduce the suction would be the climate. Therefore the climate controlled envelope would be appropriate for shrinking.

# Design Suction Envelopes

## TREE REMOVED NEAR PERIMETER JUST BEFORE CONSTRUCTION



# Design Suction Envelopes

**The magnitude of swell is a function of the area between the two profiles.**


**Swell due to climate only**


**Swell due to tree being removed just before construction.**

**For the same soil, the envelope due to the tree being removed will produce significantly more swell than the envelope being controlled just by the climate.**

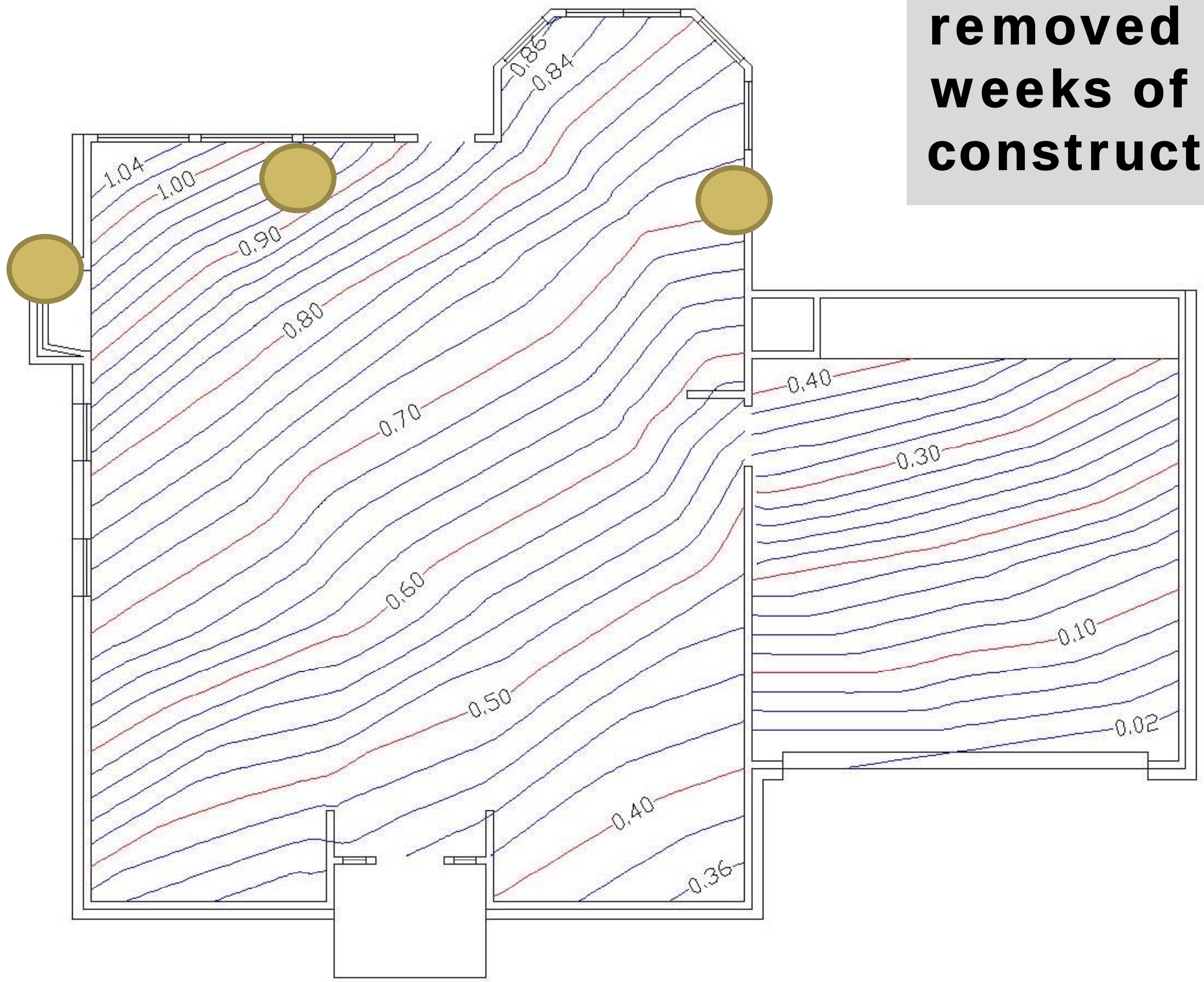
# Sample $y_m$ values

## TREE REMOVED NEAR PERIMETER JUST BEFORE CONSTRUCTION

| | $y_{m\ center}$ | $y_{m\ edge}$ | $\gamma_h$ |
|---|---|---|---|
| Low Expansive Soil (PI = 19) | 0.6 inches | 2.5 inches | 0.03 |
| Moderately Expansive Soil (PI = 28) | 0.9 inches | 4.2 inches | 0.05 |
| Expansive Soil (PI = 56) | 1.6 inches | **8.4 inches *** | 0.09 |

* It is not reasonable to construct ANY type of slab-on-ground foundation on this expansive of soil if a tree is removed just before construction without treating the soil or allowing it to at least partially equilibrate with the surrounding soils.

3 large trees reportedly removed within 2 weeks of foundation construction.




PI between 50 and 60

**Total Elevation differential = 8.2 inches**

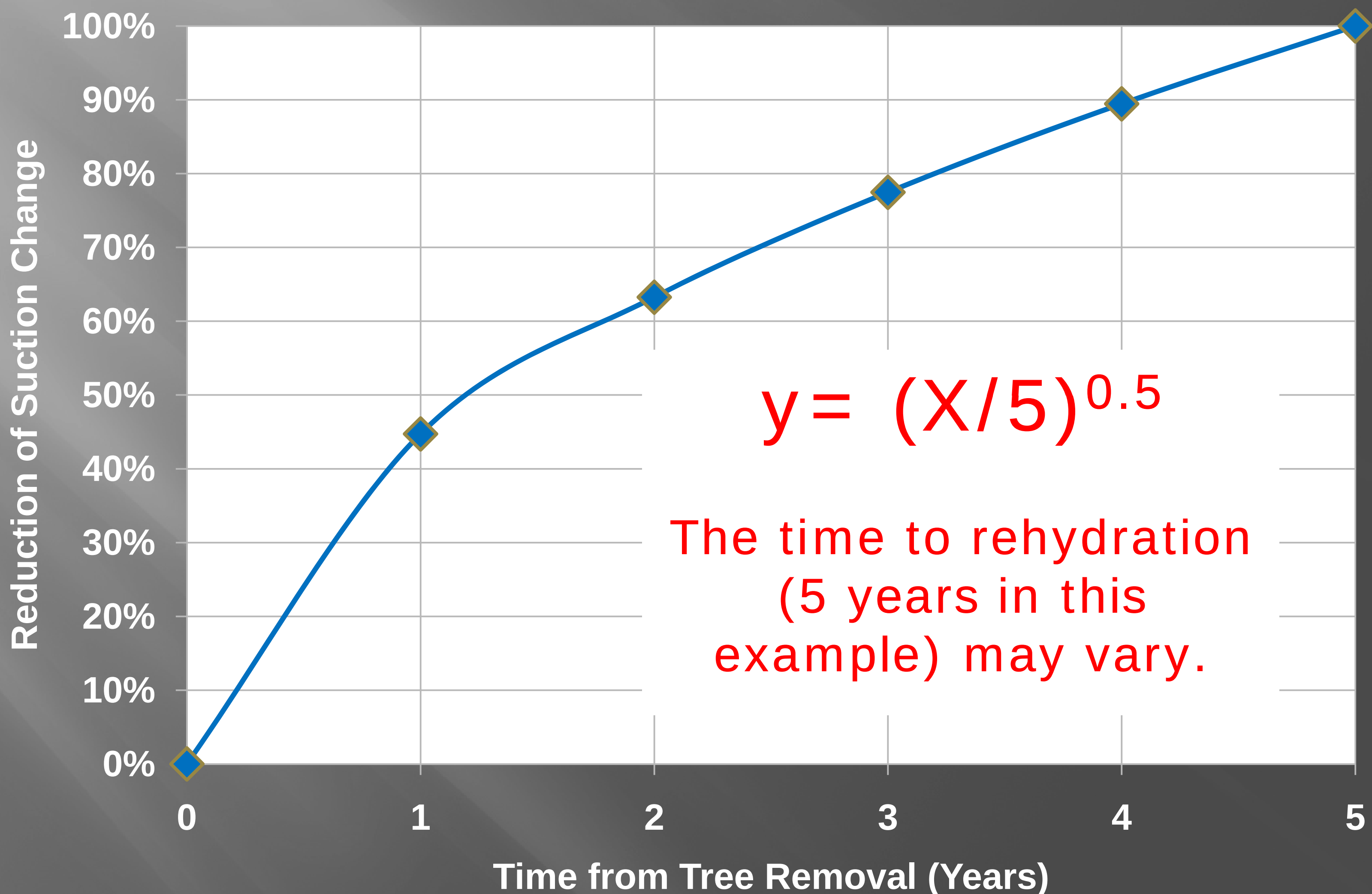
**Trees typically are not removed just before the construction of foundations.**

**More commonly sites are cleared and foundations are constructed 1 to 2 years later and therefore the previously presented model will be excessively conservative.**

## *HOW COULD THIS MORE COMMON SCENARIO BE MODELED?*

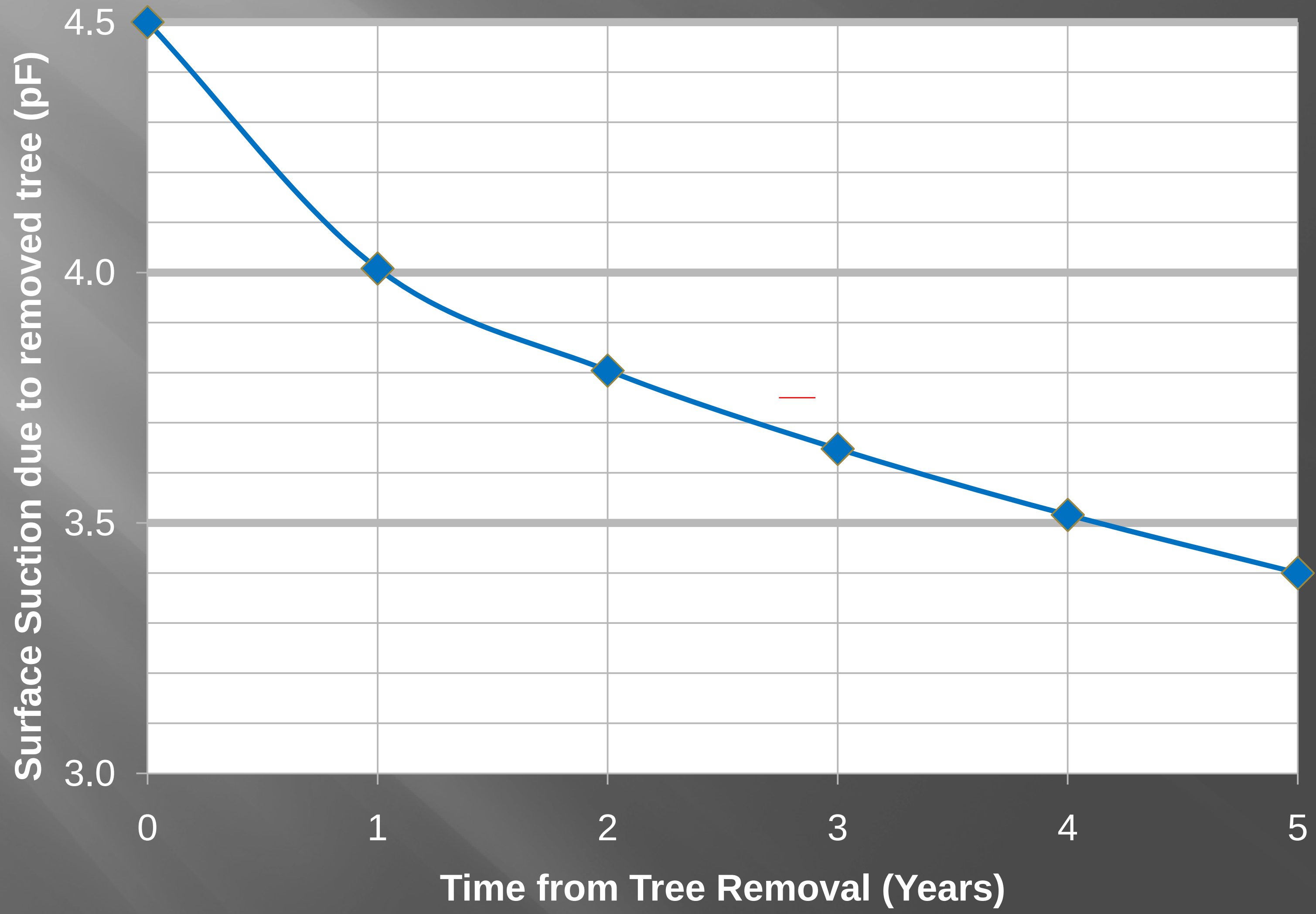
# Assumed relationship between time and the effect of a tree removed prior to foundation construction.

Relationship provided by Dr. Robert Lytton June 2009



# Relationship between time and the surface suction due to removing a tree prior to foundation construction

## Based on relationship provided by Dr. Robert Lytton June 2009



# Envelopes illustrating the reduction of surface suction values due to a removed tree as a function of time

Based on relationship provided by Dr. Robert Lytton June 2009


Time = 0


Time = 1 Year

# Envelopes illustrating the reduction of surface suction values due to a removed tree as a function of time.

Based on relationship provided by Dr. Robert Lytton June 2009


Time = 2 Years


Time = 4 Years


Time = 5 Years

# Sample $y_m$ values

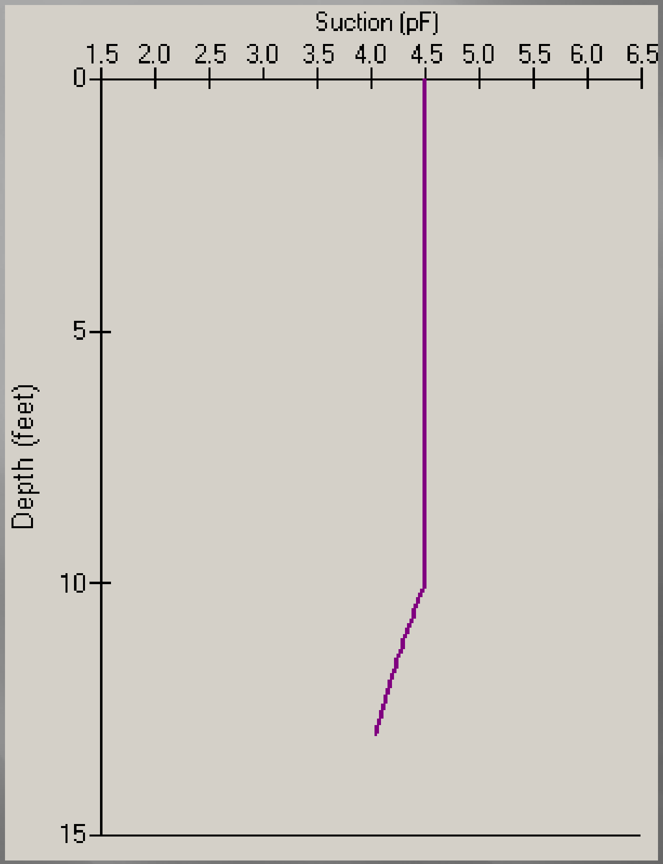
## TREE REMOVED NEAR PERIMETER JUST BEFORE CONSTRUCTION

| Time between tree removal and foundation construction | Surface Suction due to tree | Expansive Soil | Moderately Expansive Soil |
|---|---|---|---|
| 0 | 4.5 pF | **8.4 inches** | 4.2 inches |
| 1 Year | 4.0 pF | 3.9 inches | 2.0 inches |
| 2 Years | 3.8 pF | 2.4 inches | 1.3 inches |
| 3 Years | 3.6 pF | 1.4 inches | 0.7 inches |
| 4 Years | 3.5 pF | 1.1 inches | 0.5 inches |
| 5 Years | 3.4 pF | 0.7 inches | 0.4 inches |

Based on relationship provided by Dr. Robert Lytton June 2009

# WHAT SUCTION ENVELOPES SHOULD BE USED TO MODEL A HEAVILY WOODED SITE CLEARED RIGHT BEFORE CONSTRUCTION OF A FOUNDATION?

# Heavily Wooded Site Cleared Just Before Construction




**The suction profile to a heavily wooded site will be similar to an isolated tree**

**EXCEPT**

**the extent of the dry zone will be greater.**

**The dry zone will encompass a greater portion of the foundation than an isolated tree.**

# SWELLING SUCTION ENVELOPE
## Heavily Wooded Site Cleared Just Before Construction


Due to climate influences alone after construction, the soil around the perimeter will respond to moisture changes very quickly but it will take a long time for moisture to reach the interior.

Since $y_m$ is a change in the soil surface elevation at two locations the conservative assumption would be that the soil at the perimeter would experience its full change in moisture before the interior experiences any.

Over time the suction in the interior may trend towards equilibrium.

# SHRINKING SUCTION ENVELOPE
## Heavily Wooded Site Cleared Just Before Construction


**Since it is unlikely that the dry zone from a heavily wooded site will encompass the entire foundation, there is still a potential for some soil shrinkage to occur.**

**The foundation should also be designed for shrinkage resulting from climate only.**

# SUCTION ENVELOPES

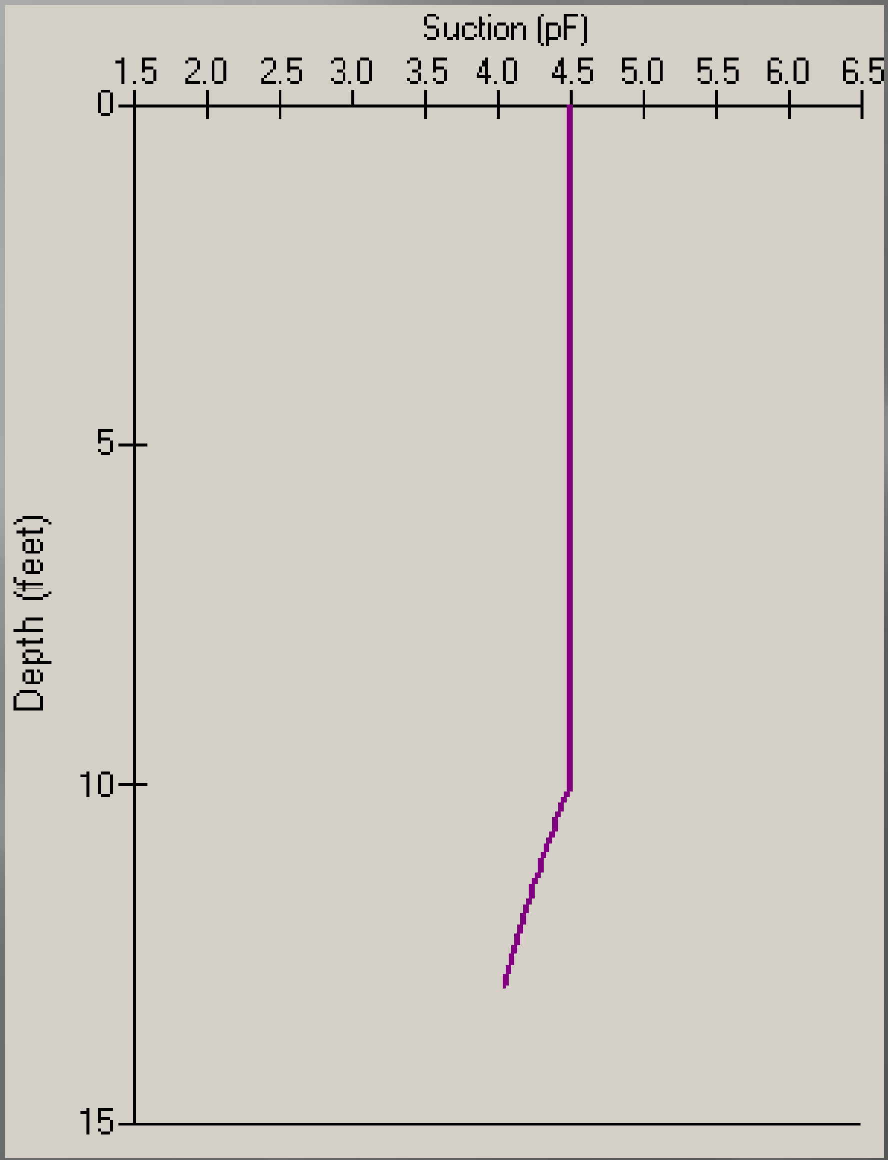
## Heavily Wooded Site Cleared Right Before Construction


**Shrinking**


**Swelling**

# WHAT SUCTION ENVELOPE SHOULD BE USED TO MODEL A TREE PLANTED AFTER CONSTRUCTION (OR AN EXISTING TREE GROWS SUCH THAT IT AFFECTS THE FOUNDATION)?

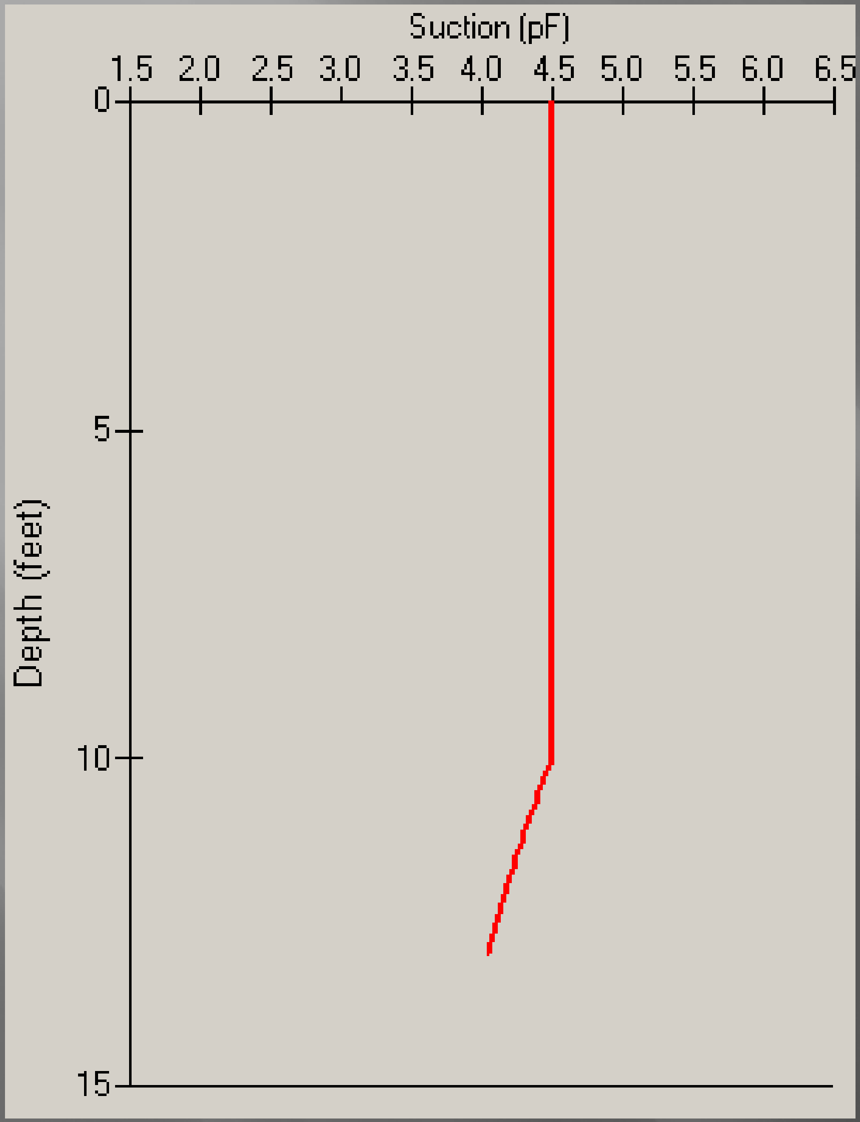
# SHAPE OF TREE SUCTION PROFILE




**The same suction profile can be assumed to model the effect of a tree planted after construction**

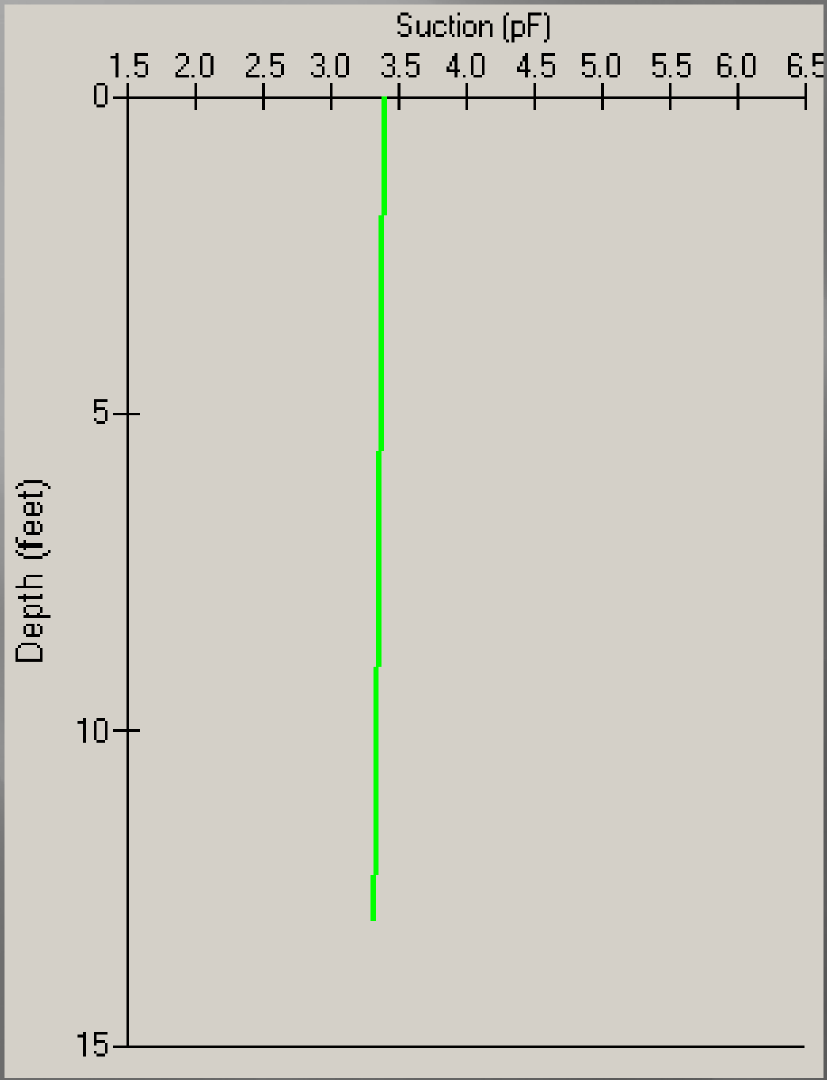
**EXCEPT .....**

# SHAPE OF TREE SUCTION PROFILE




**.... it would be the final suction profile.**

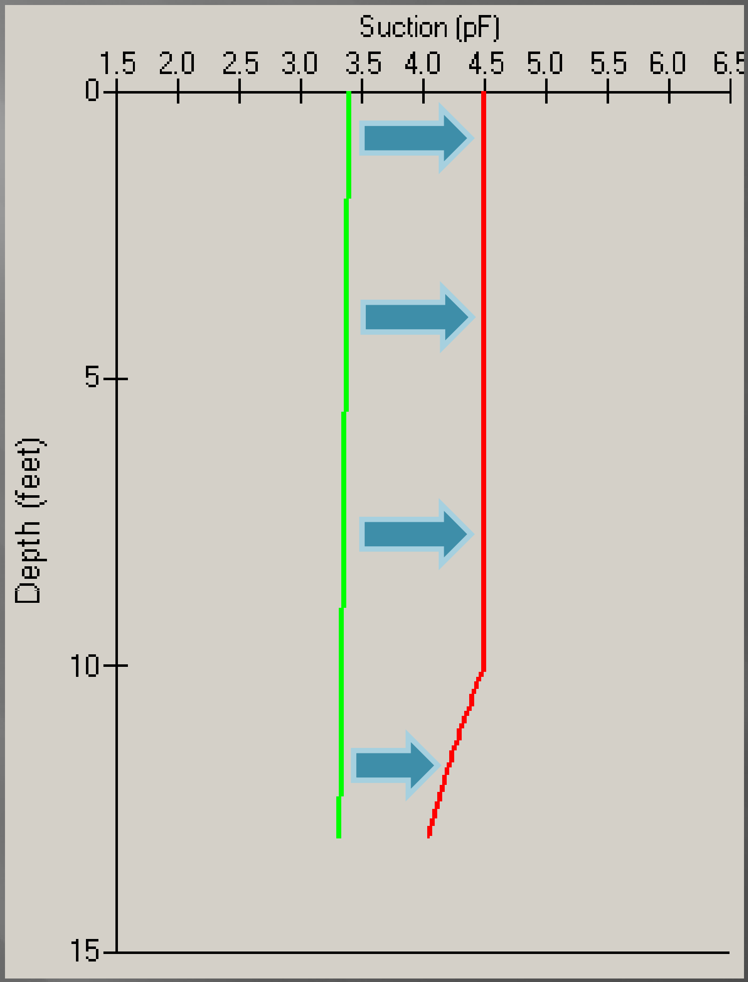
# Tree Planted After Construction




**For post-equilibrium areas (such as Houston) the INITIAL SUCTION PROFILE would be assumed to be the equilibrium profile (at the time of construction).**

# SHRINKING SUCTION ENVELOPE

## Tree Planted After Construction




**Note: This is used primarily for analysis of foundation performance after construction. It is not typically used as a design suction envelope. If it is to be used for design, the corresponding swelling suction envelope would be climate controlled.**

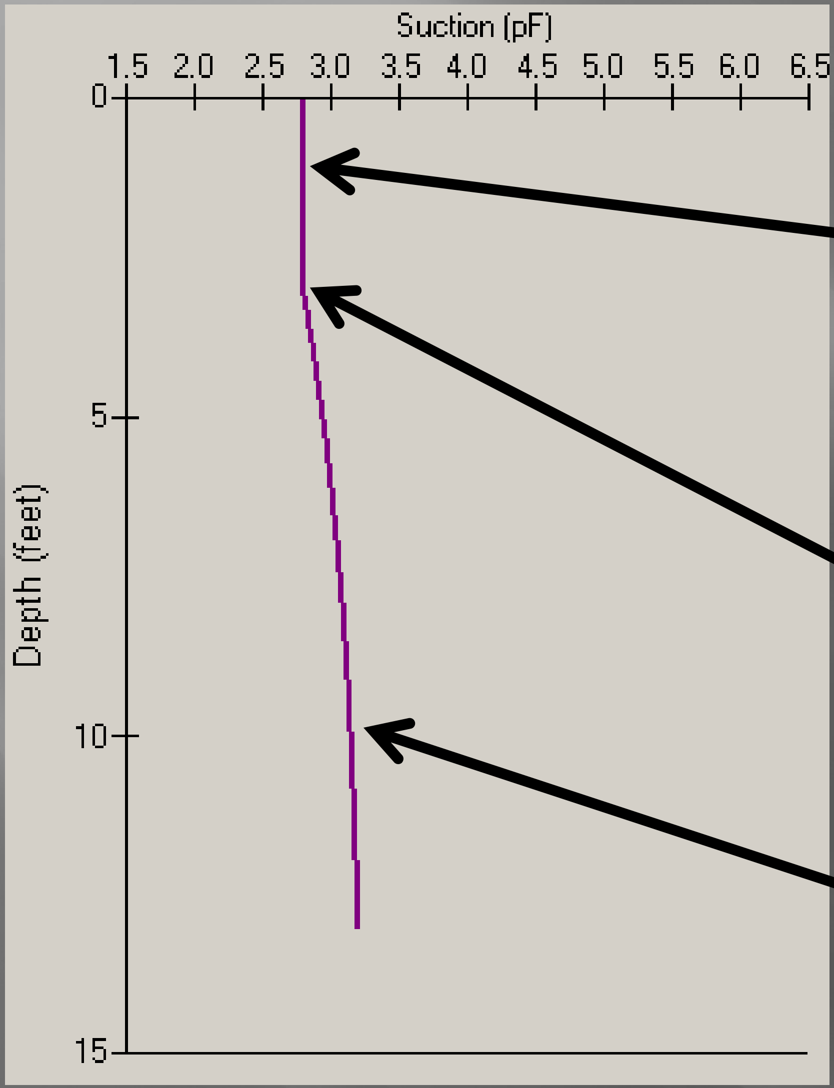
# Sample $y_m$ values

## TREE PLANTED AFTER CONSTRUCTION

| | $y_m$ center | $\gamma_h$ mean |
|---|---|---|
| Low Expansive Soil (PI = 18) | 1.3 inches | 0.03 |
| Moderately Expansive Soil (PI = 28) | 2.2 inches | 0.05 |
| Expansive Soil (PI = 56) | 4.0 inches | 0.09 |

# WHAT SUCTION ENVELOPE SHOULD BE USED TO MODEL A FLOWER BED WITH EXCESSIVE WATERING NEXT TO A FOUNDATION?

# FLOWER BED WITH EXCESSIVE WATERING SUCTION PROFILE

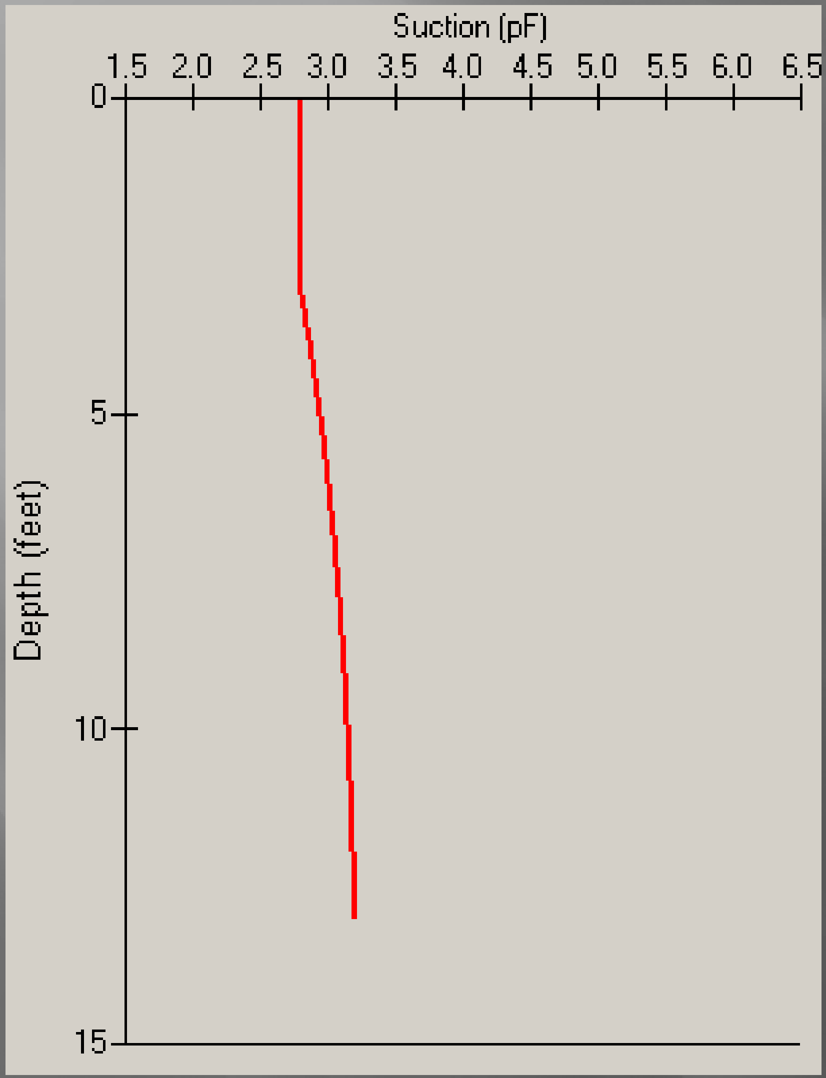



Excessive watering of a flowerbed could lower the suction below 3.0 pF. Depending on the amount of watering the suction could be as low as 2.5 pF.

The excessive watering will decrease the suction for several feet. The depth of influence may vary but 3 to 4 feet is possible.

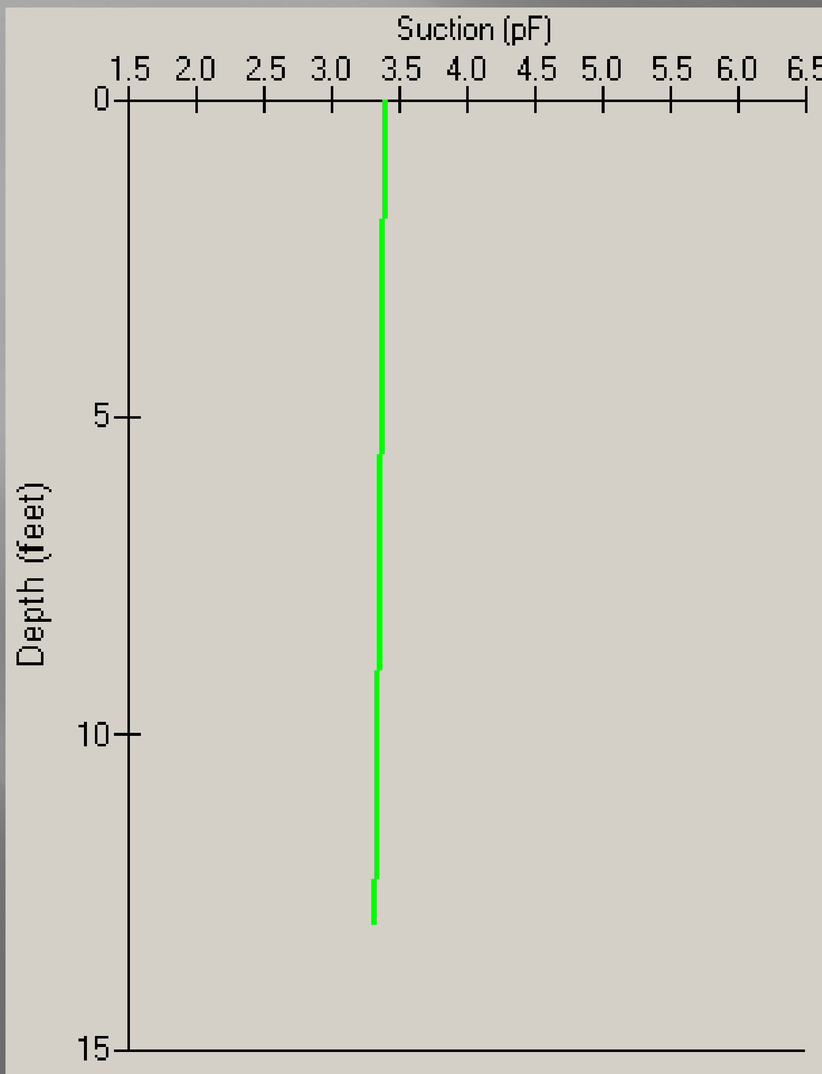
Below the depth influenced by the excessive watering, the suction profile will trend back to the equilibrium suction value.

# FLOWER BED WITH EXCESSIVE WATERING SUCTION PROFILE




**Since the excessive watering of the flower bed doesn't occur until after the foundation is built, the flower bed profile would be used as the FINAL SUCTION PROFILE.**

# FLOWER BED WITH EXCESSIVE WATERING SUCTION PROFILE




**For post-equilibrium areas (such as Houston) the INITIAL SUCTION PROFILE would be assumed to be the equilibrium profile (at the time of construction).**

# Sample $y_m$ values

FLOWER BED WITH EXCESSIVE WATERING

| | $y_m$ edge Climate | $y_m$ edge Flower Bed | $\gamma_h$ mean |
|---|---|---|---|
| Low Expansive Soil (PI = 19) | 0.2 inches | 0.5 inches | 0.03 |
| Moderately Expansive Soil (PI = 28) | 0.4 inches | 0.9 inches | 0.05 |
| Expansive Soil (PI = 58) | 0.7 inches | 1.8 inches | 0.09 |

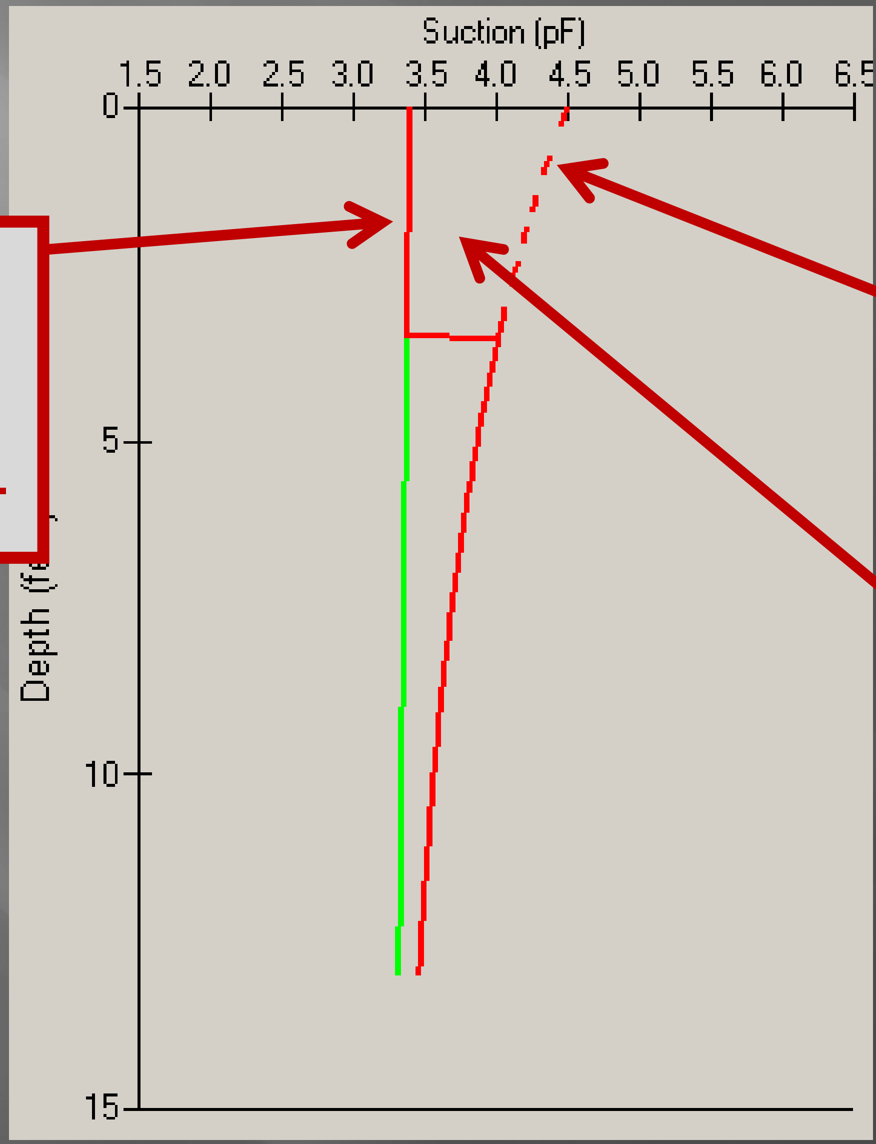
# HOW DOES A VERTICAL MOISTURE BARRIER EFFECT SUCTION ENVELOPES?

# Effect of Moisture Barriers on Suction Envelopes

A vertical moisture barrier will limit the suction of the soil behind the barrier such that it does not increase or decrease beyond the equilibrium value.

# Effect of Vertical Moisture Barrier

## FOR SITES CONTROLLED BY CLIMATE ONLY




Assumed 3' deep barrier. Barrier prevents suction from increasing beyond equilibrium.

Suction profile for climate controlled site

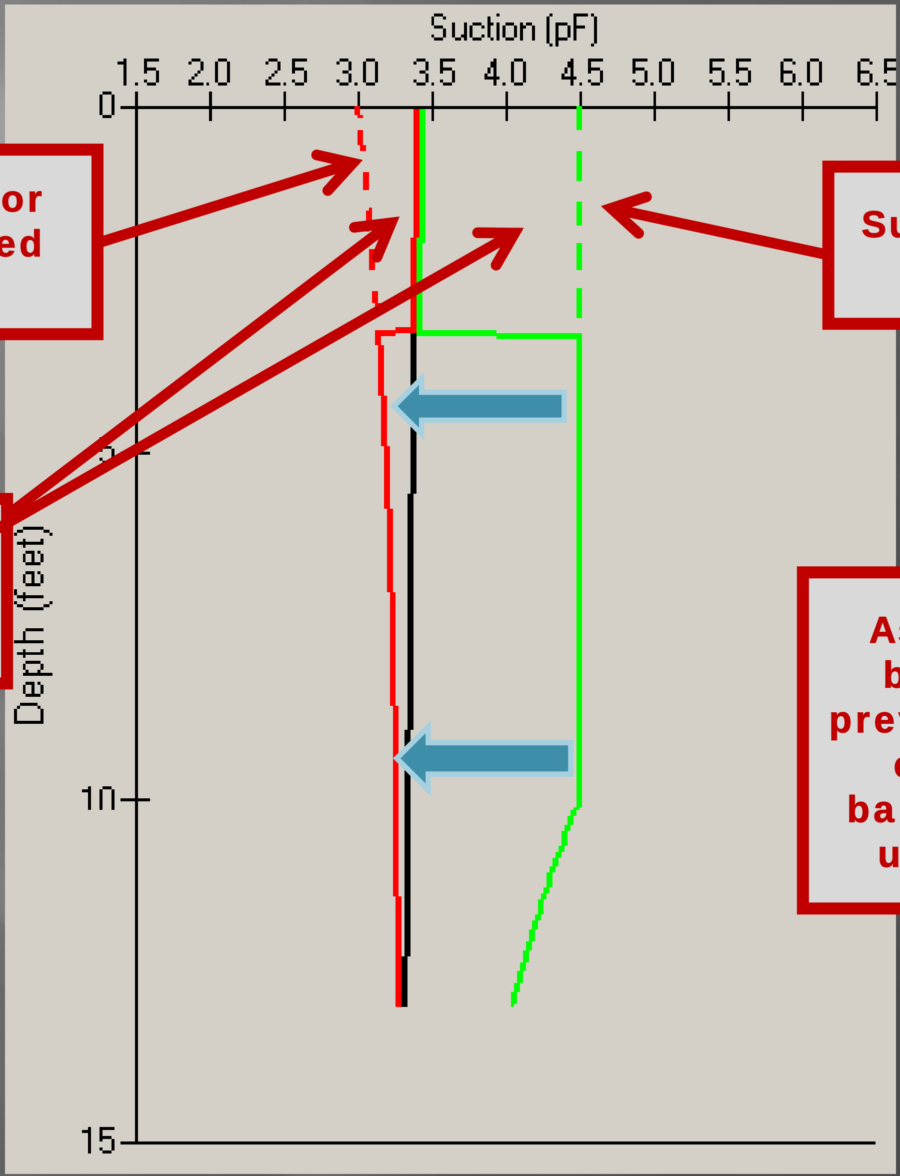
Shrink is reduced by eliminating this change in suction

# Effect of Vertical Moisture Barrier

## FOR REMOVED TREE CASE (ALTERNATE MODEL)

**Suction profile for climate controlled site**

**Swell is reduced by eliminating this change in suction**




**Suction Profile for removed tree**

**Assumed 3' deep barrier. Barrier prevents any suction change behind barrier (potentially unconservative)**

# Sample $y_m$ values

## TREE REMOVED NEAR PERIMETER RIGHT BEFORE CONSTRUCTION

| | $y_m$ edge | $y_m$ edge w/3ft barrier |
|---|---|---|
| Low Expansive Soil (PI = 19) | 2.5 inches | 1.33 inches |
| Moderately Expansive Soil (PI = 28) | 4.2 inches | 2.3 inches |
| Expansive Soil (PI = 58) | 8.4 inches | 4.4 inches |