GIS Map of Equilibrium Suction as Controlled by the Soil and Vegetation

FPA PRESENTATION
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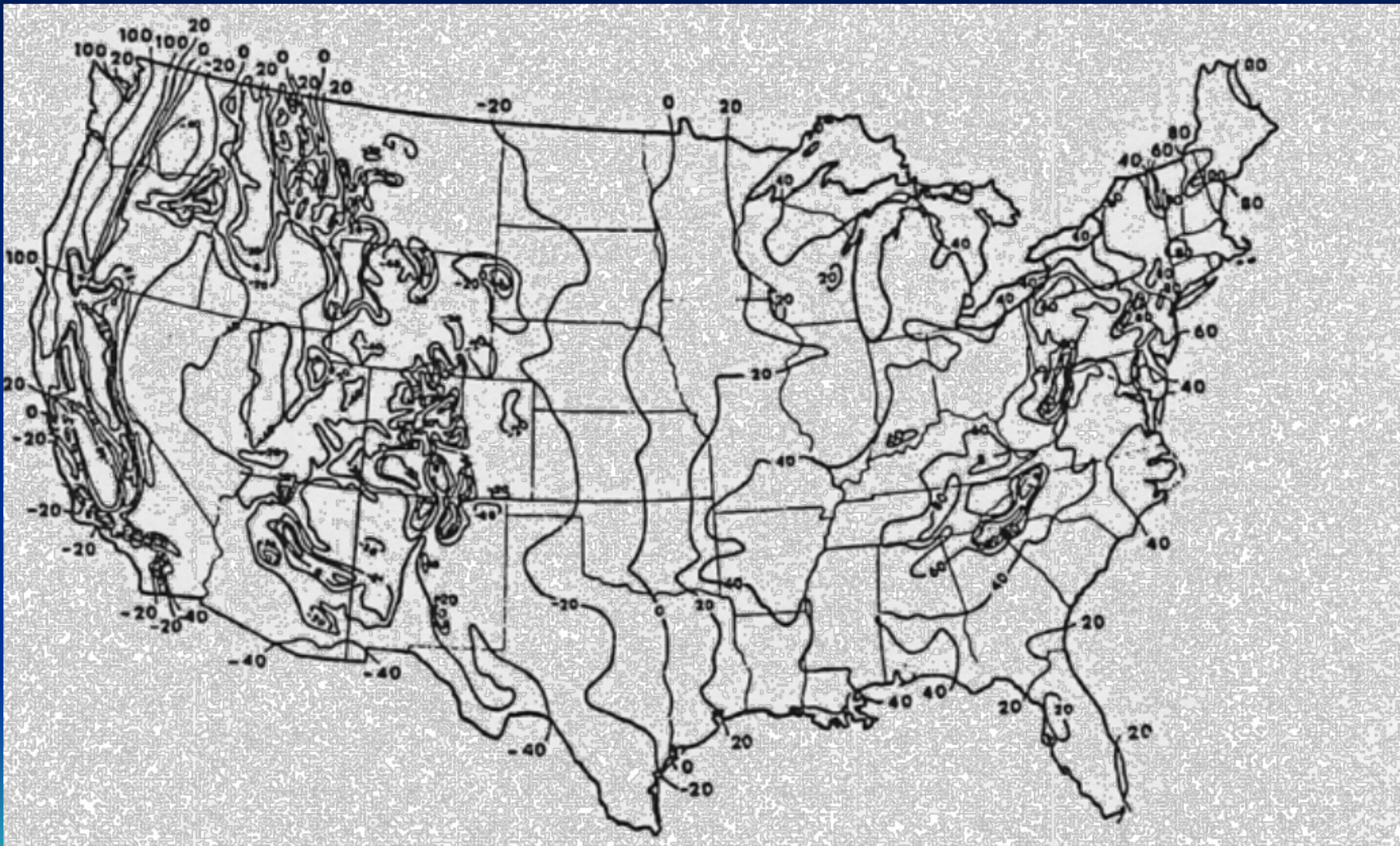
HOUSTON, TEXAS

WEDNESDAY DECEMBER 12, 2018

TMI Distribution in United States



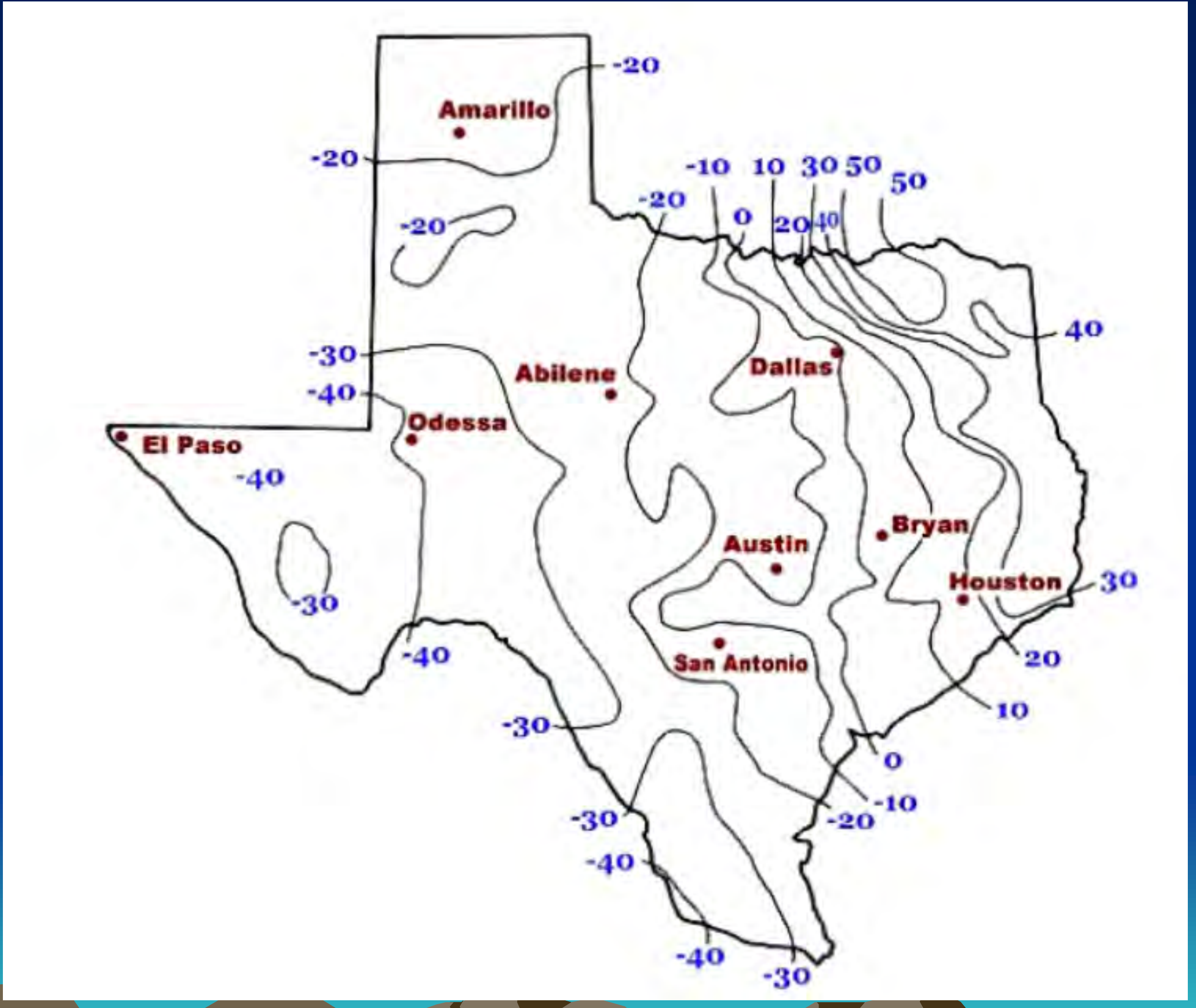
(After Thornthwaite 1948)

Contributing Factors in TMI

- Precipitation
- Potential Evapotranspiration
- Depth of Available Moisture
- Initial Value for Depth of Moisture

- Monthly Moisture Balance
    - Rainfall
    - Evapo-transpiration
    - Storage
    - Runoff

TMI Distribution in Texas



(After Lytton et al. 1974)

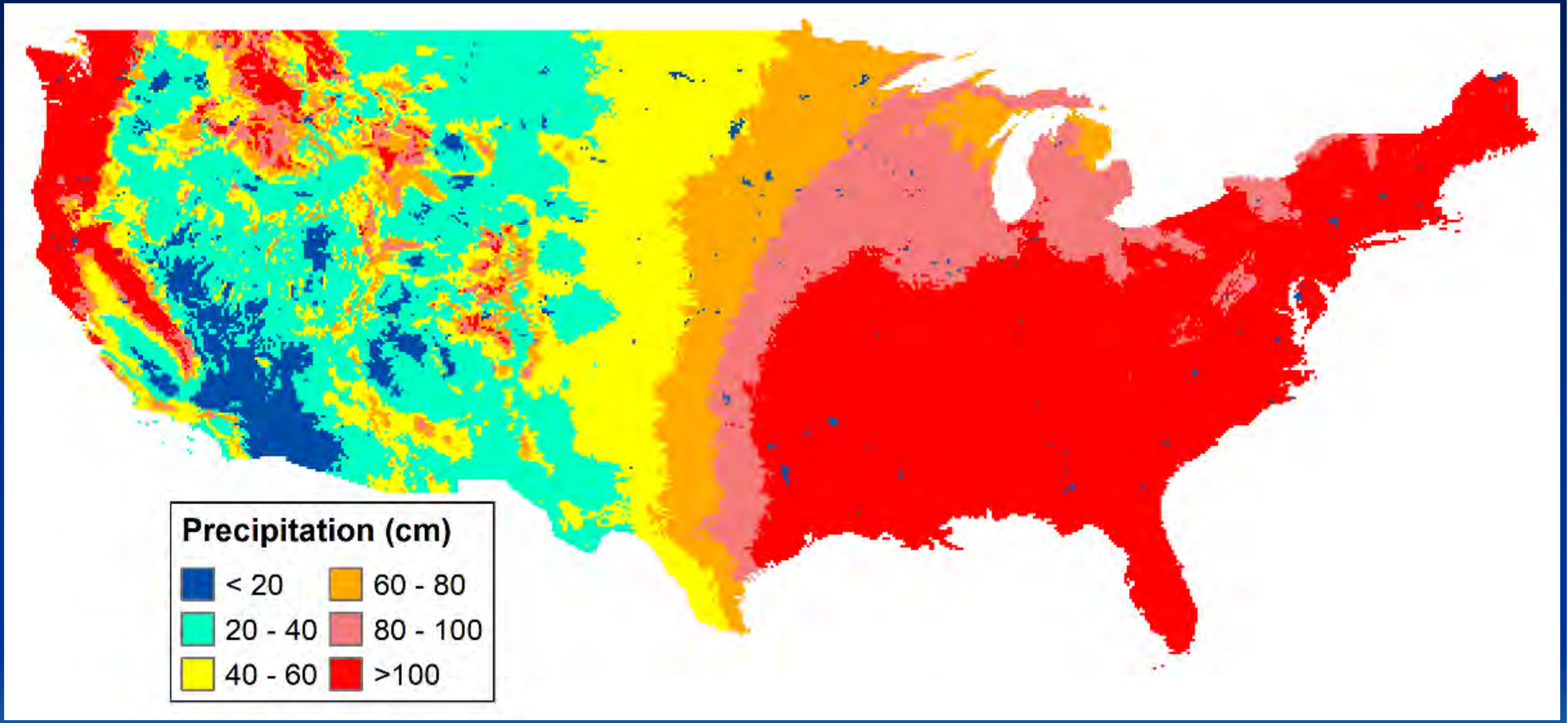
Simplified TMI Model

Witczak's TMI Model

$$TMI = 75\left(\frac{P}{PE_y} - 1\right) + 10$$

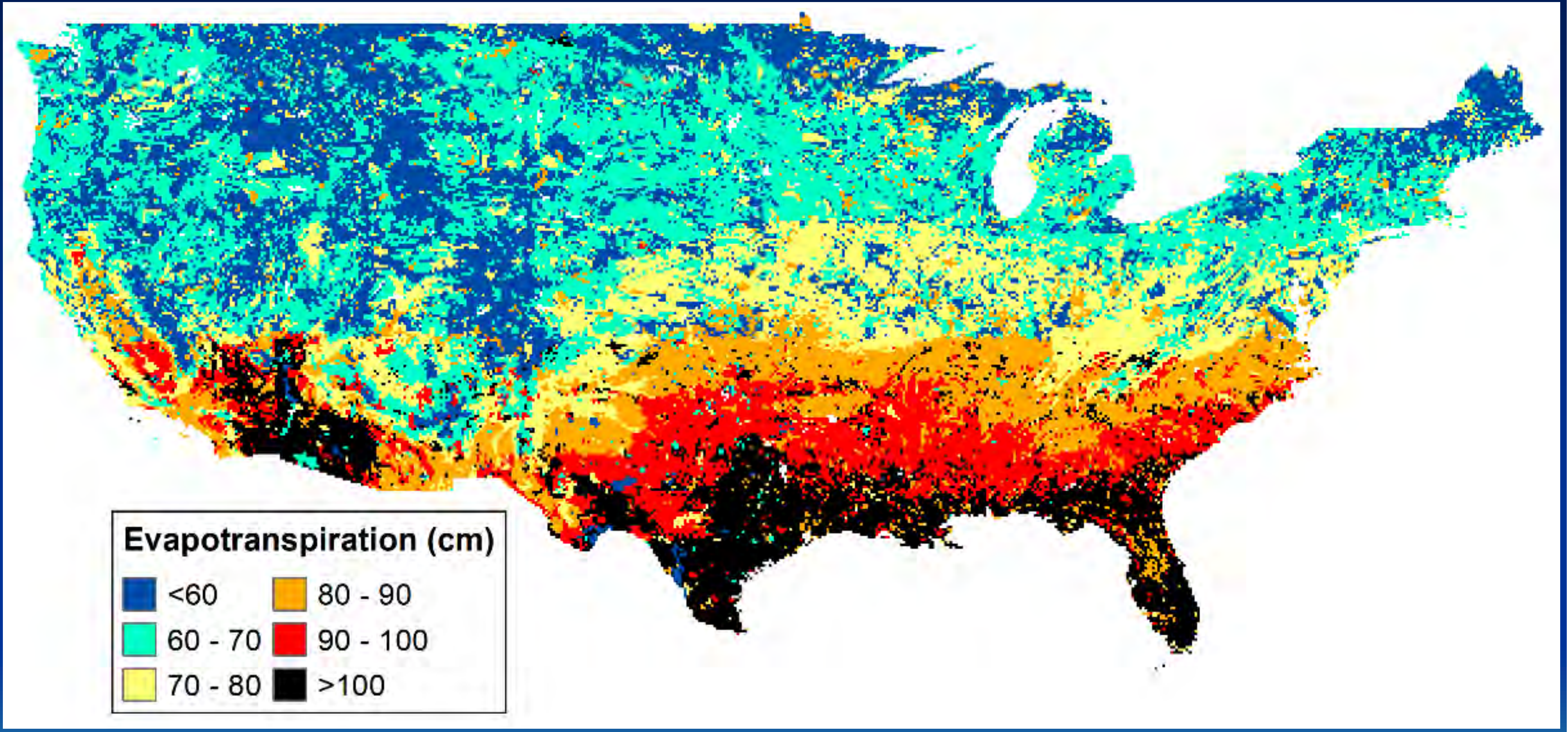
where P = Annual Average Precipitation;
PE_y = Annual Average Potential Evapotranspiration

Average Anuual Precipitation



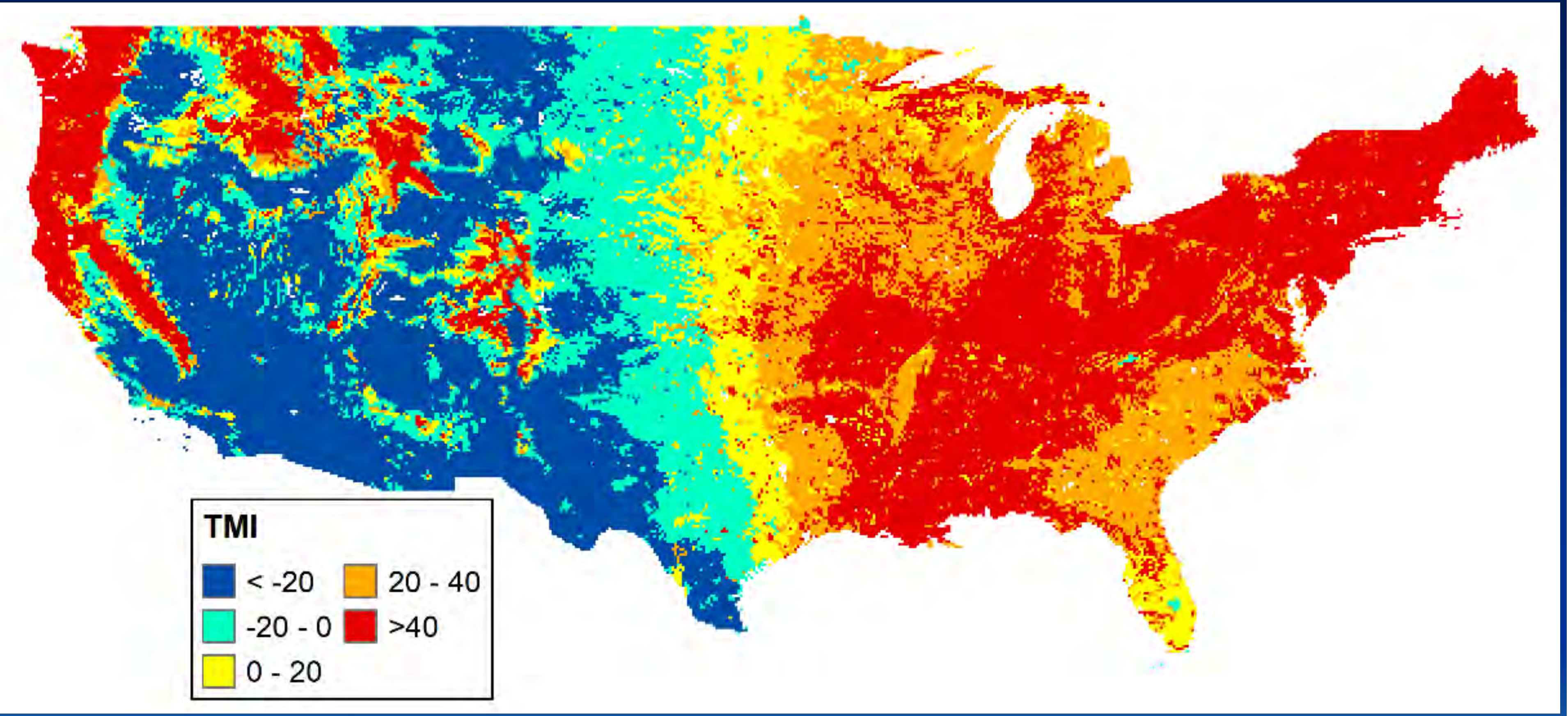
Precipitation Map in GIS Platform
(1981 t0 2010)

Average Anuual Potential Evapotranspiration



Potential Evapotranspiration Map in GIS Platform (1981 t0 2010)

Average Annual TMI



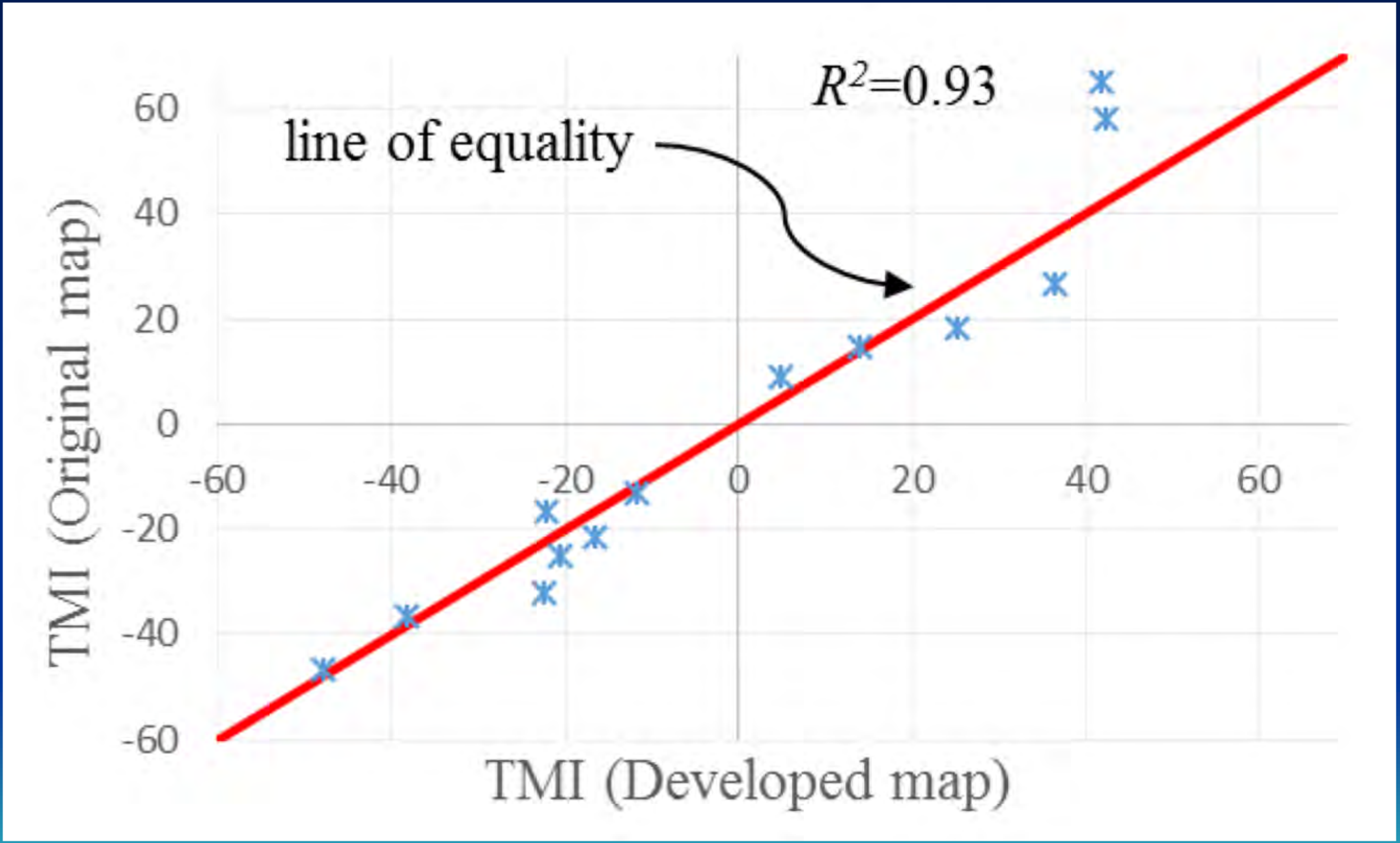
TMI Map in GIS Platform (1981 t0 2010)

Validation of TMI Map

Locations	Latitude	Longitude	TMI (original map)	Locations	Latitude	Longitude	TMI (original map)
Gallup, New Mexico	35.52	-108.74	-32	Port Arthur, Texas	29.88	-93.93	26.8
Synder, Texas	32.71	-100.91	-25	Lake Charles, Louisiana	30.22	-93.21	58.2
Durant, Oklahoma	33.99	-96.39	18.4	Reliance, South Dakota	43.87	-99.60	-12.9
Houston, Texas	29.76	-95.36	14.8	Ellsworth, Kansas	38.73	-98.22	9.1
San Antonio, Texas	29.42	-98.49	-21.3	Limon, Colorado	39.26	-103.69	-16.8
El Paso, Texas	31.76	-106.48	-46.5	Price, Utah	39.59	-110.81	-36.4
Monroe, Louisiana	32.51	-92.11	65.1				

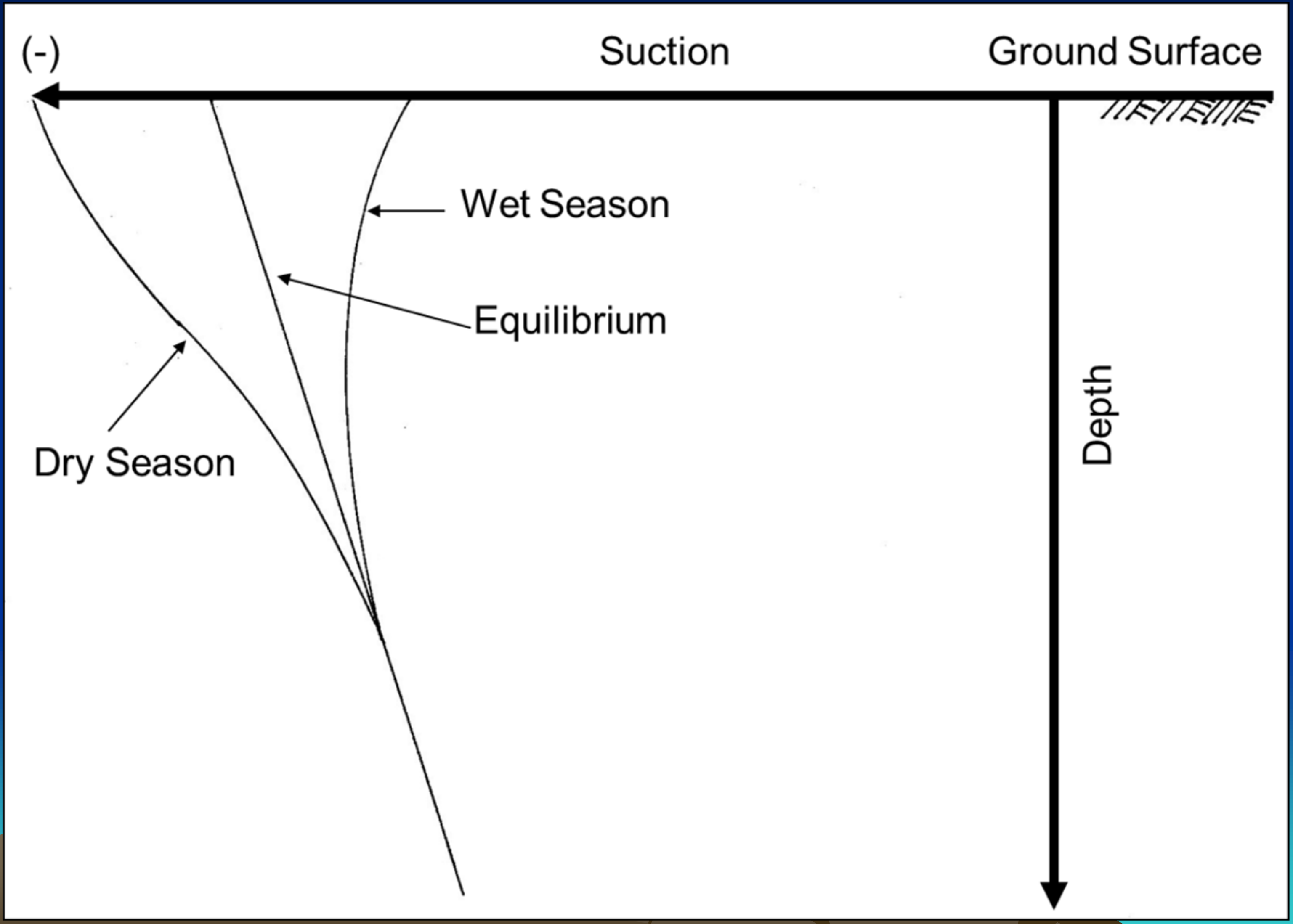
Collected TMI Values from Original Map

Validation of TMI Map



Comparison of TMI Values

Typical Equilibrium Suction Profile with Depth



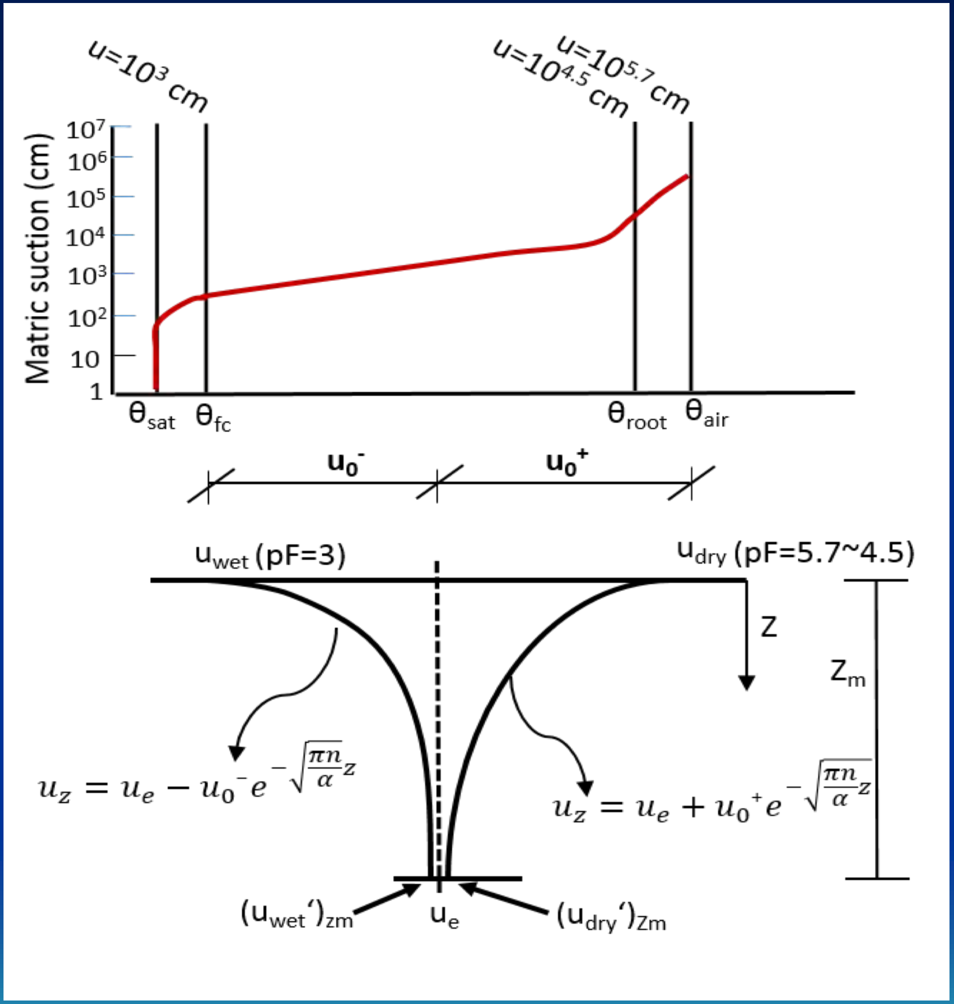
Development of a Modified Equilibrium Suction Model

Modified Equilibrium Suction Model

Contributing Factors

- Soil Properties [Steady State Diffusivity Equation (Mitchell 1979)]
- Climatic Factors [Relationship between TMI and Max Available Moisture Depth (Gay 1994)]

Suction Profile in Unsaturated Soil



Mitchell's Diffusivity Equation,

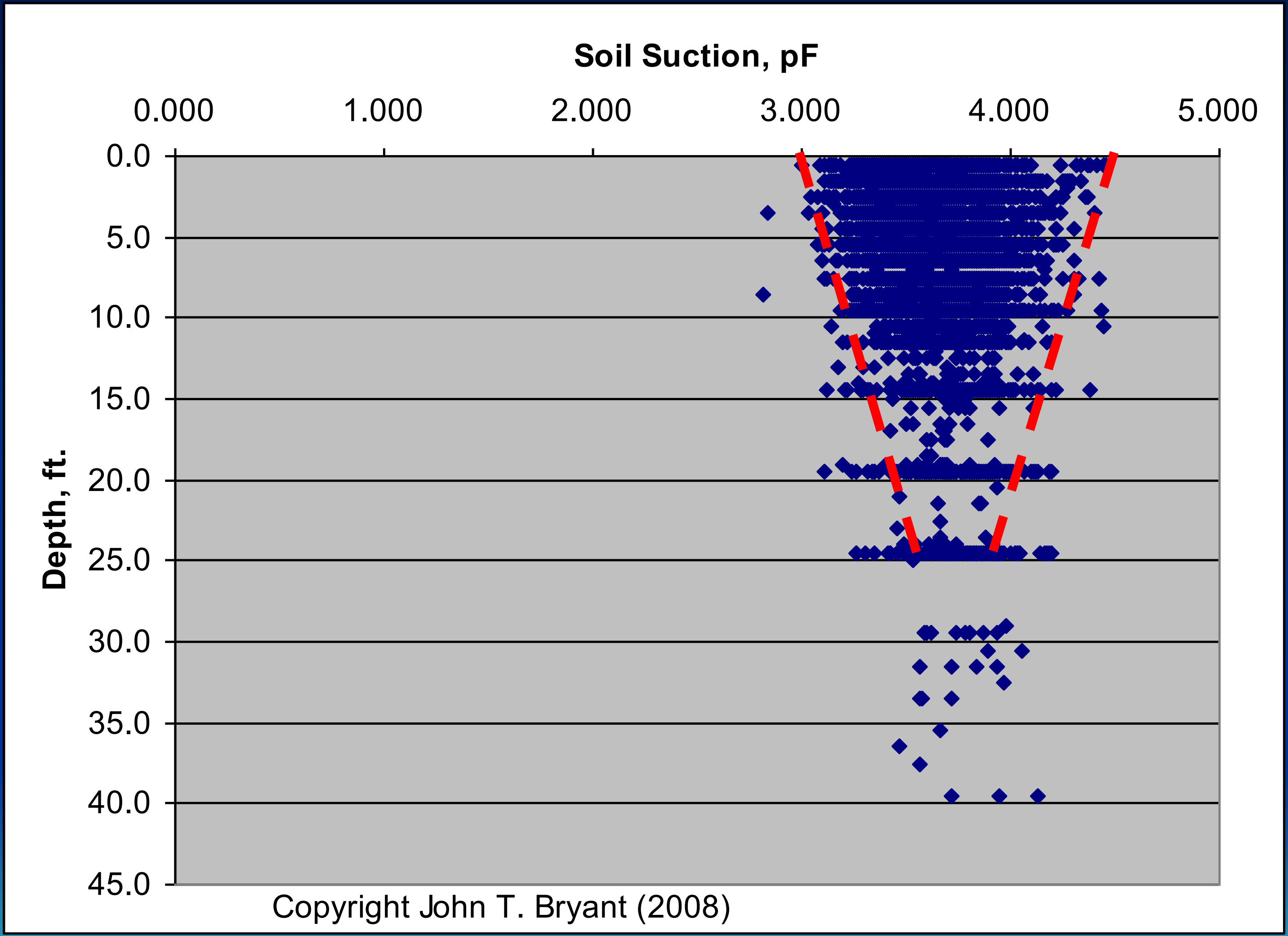
$$u(z) = u_e \pm u_0 * e^{-\sqrt{\frac{\pi n}{\alpha}}z}$$

Suction Profile Between Wet and Dry State

Soil Suction at Surface Ranges Between

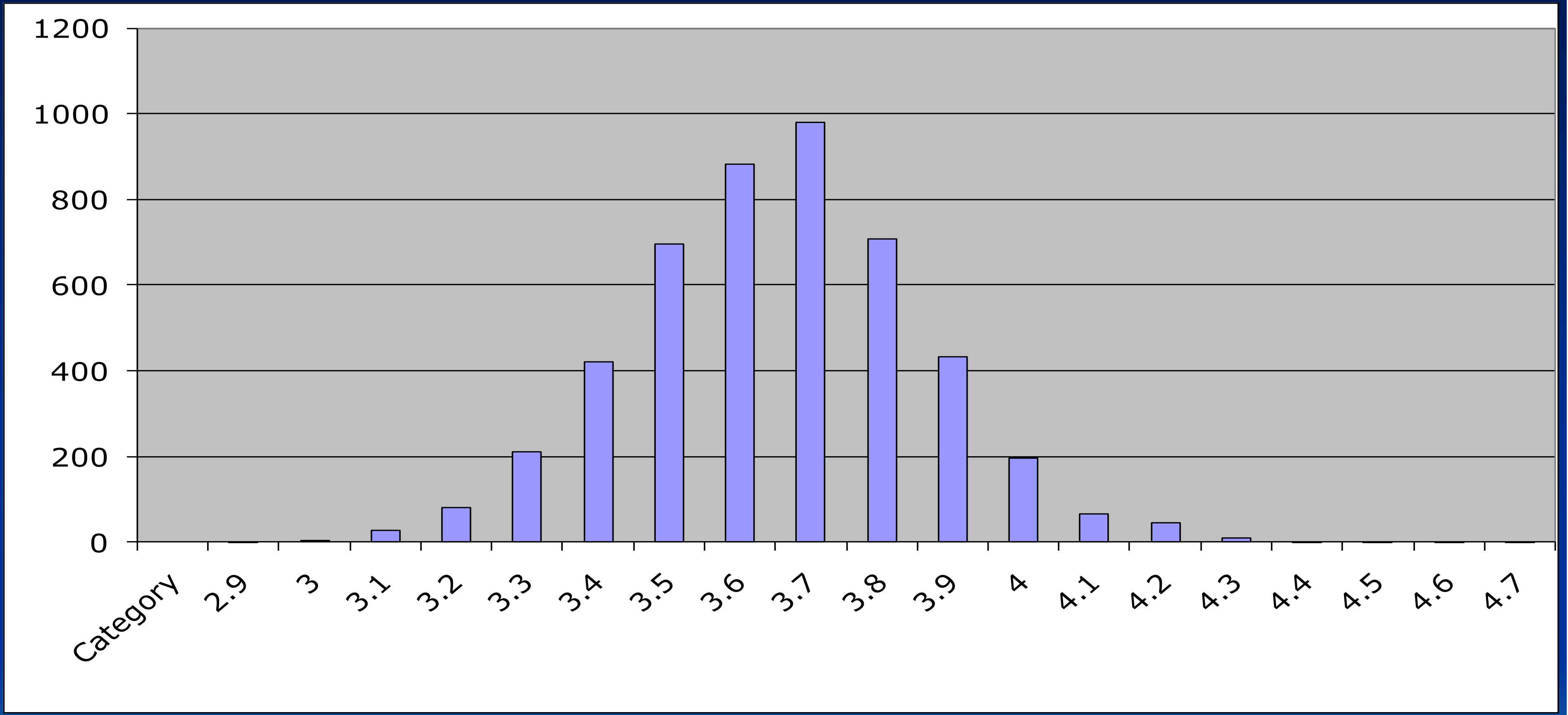
pF=3 to pF =4.5

Measured Suction Data



Empirically Measured Suctions BCI 2002 to 2008 = 26,000+ Data Points

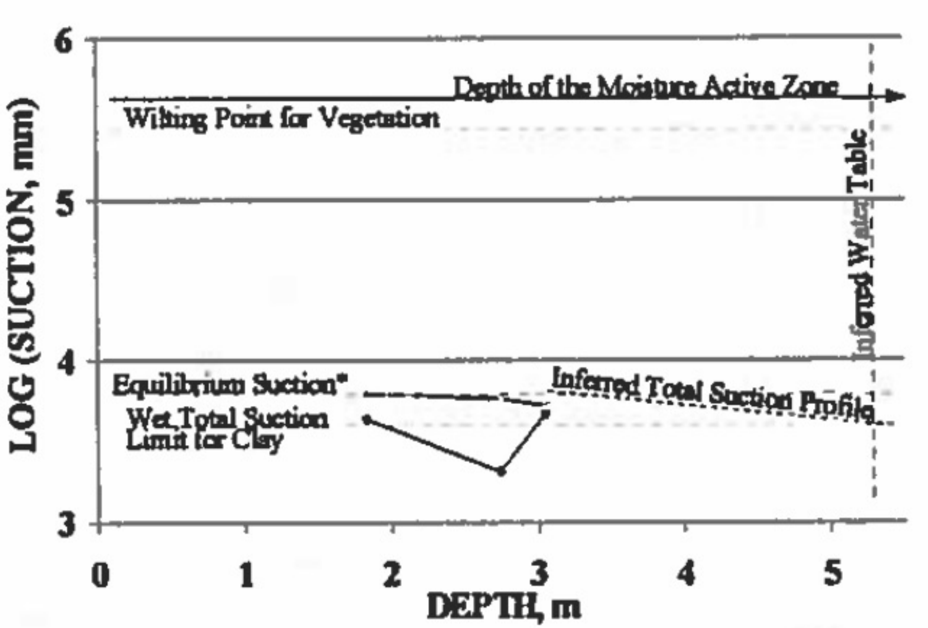
Total Soil Suction Histogram

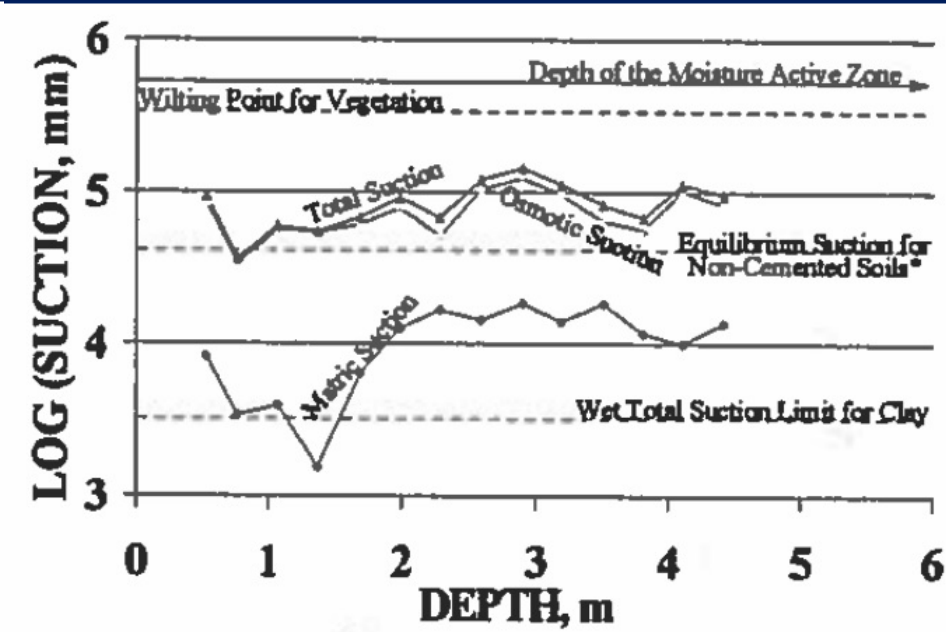


2003 TOTAL SOIL SUCTION DATA (4776 OBSERVATIONS

Depth of Moisture Active Zone, Z_m Varies Between 9.3 and 21 feet Depending on Vegetation

Case Studies of Moisture Active Zone Depth



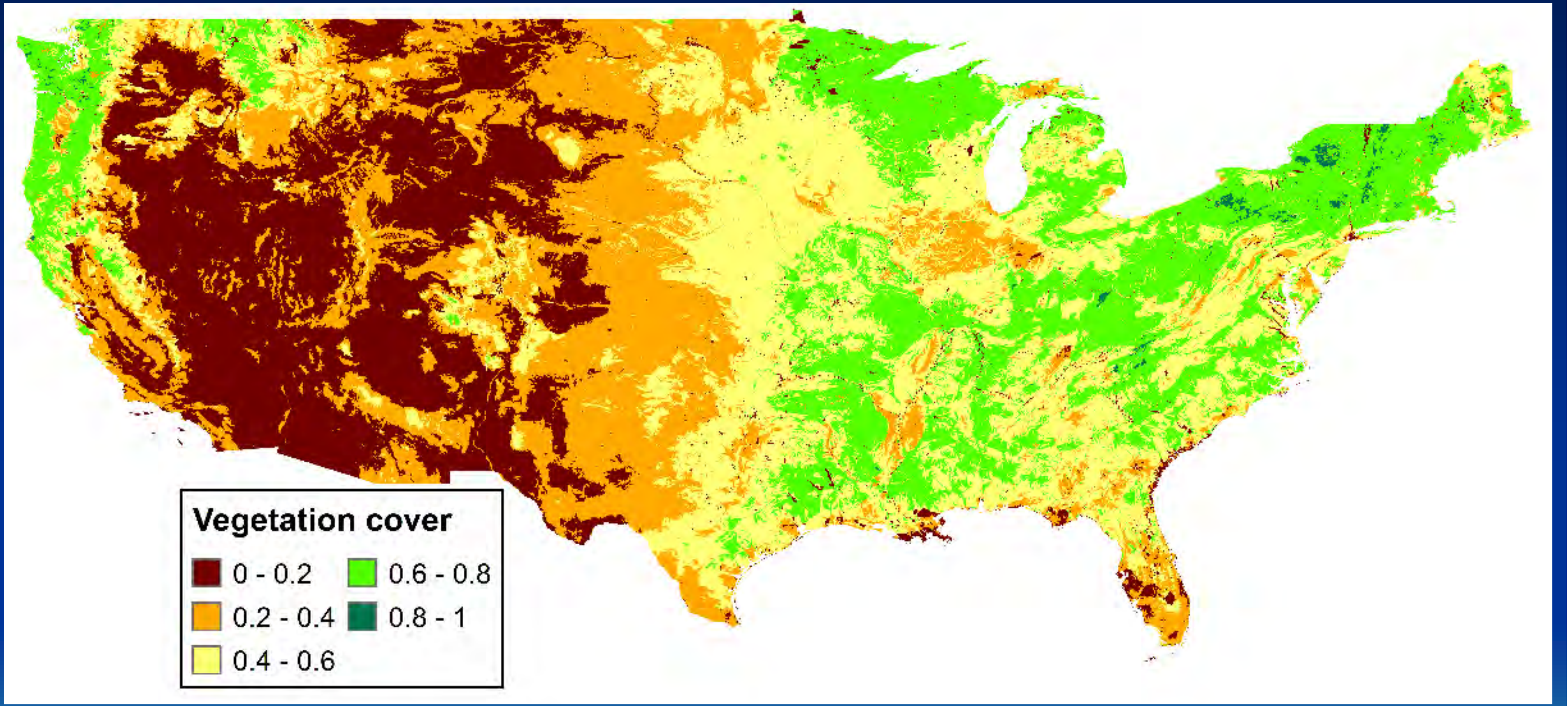


Around a Root Zone in Louisiana

Around a Root Zone in Texas

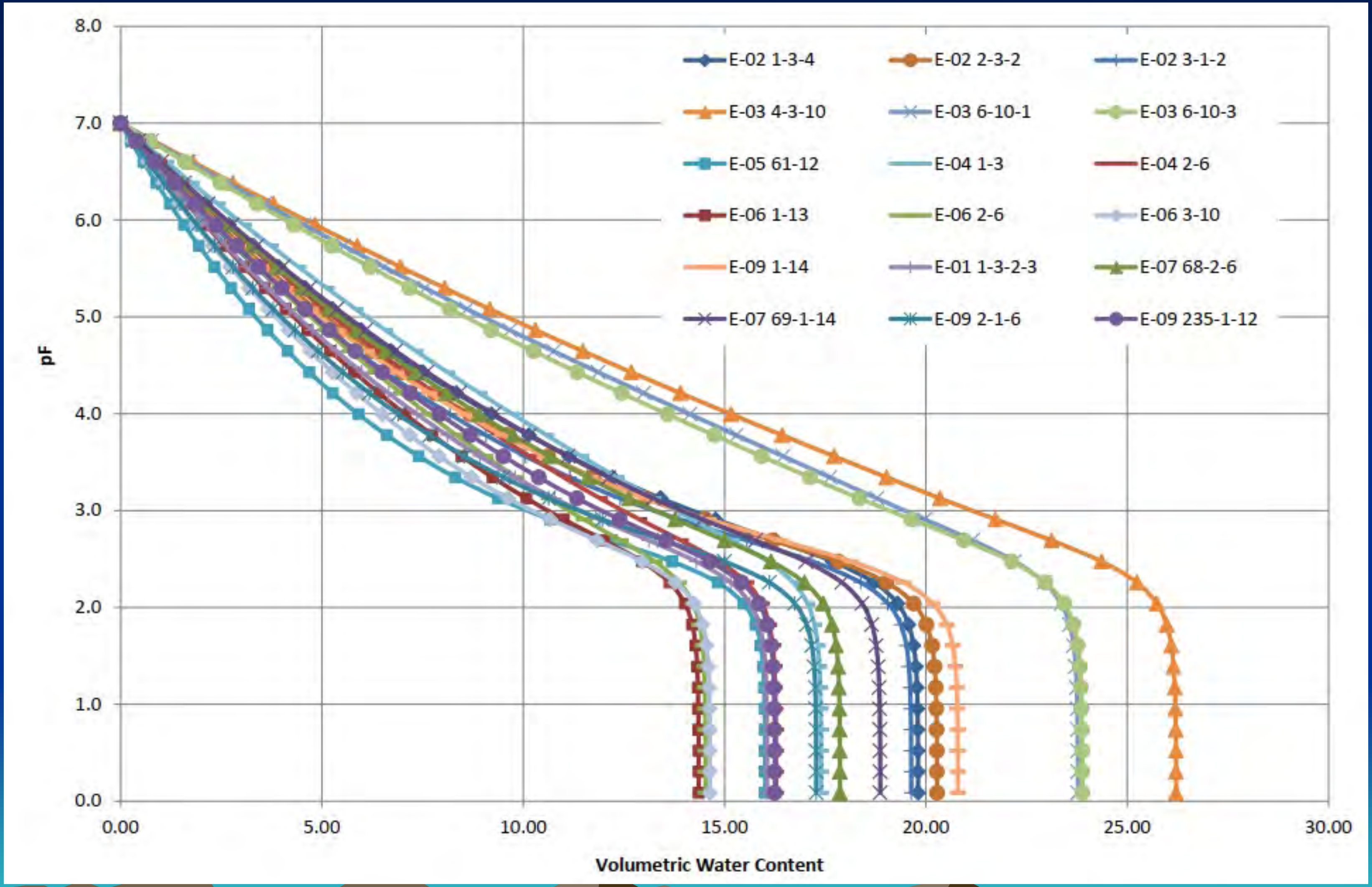
(After Lytton et al. 1994)

Fraction of Vegetation Cover Map



From NOAA Climatic Data Records

Typical Suction Vs Water Content Curve



(After Sahin 2014)

Diffusivity Coefficient

$$\alpha = \frac{k_{sat}}{\partial \theta_w / \partial h}$$

where k_{sat} = Saturated Permeability;

$\partial\theta_w/\partial h$ = Slope of SWCC Curve

SWCC Curve

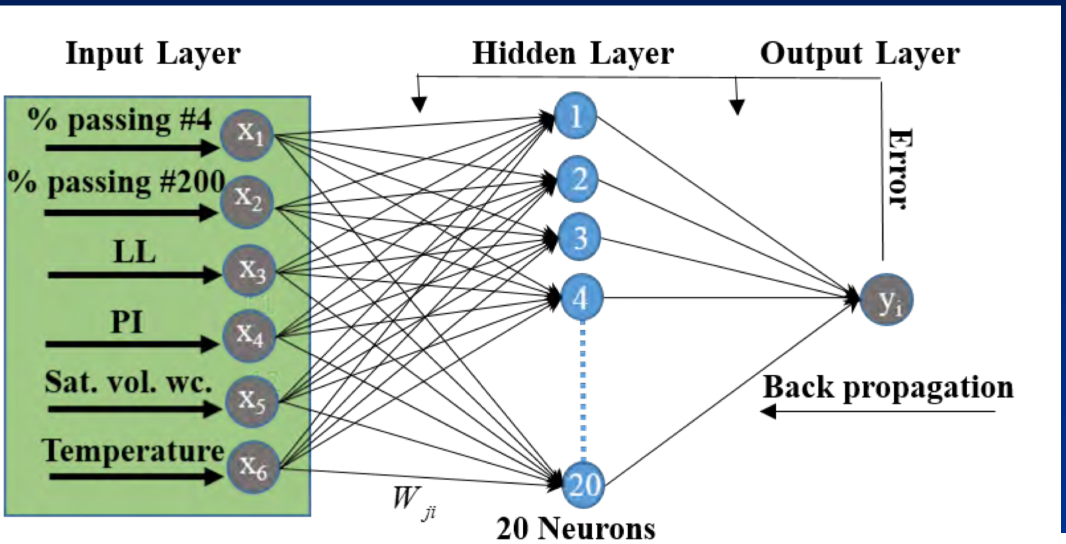
From Fredlund-Xing Equation

$$\theta_w = C(\mathrm{h})\,\mathrm{x}\left[\frac{\theta_{sat}}{\{\ln[\mathrm{e}+(\frac{h}{a_f})^{\mathrm{b_f}}]\}^{\mathrm{c_f}}}\right]$$

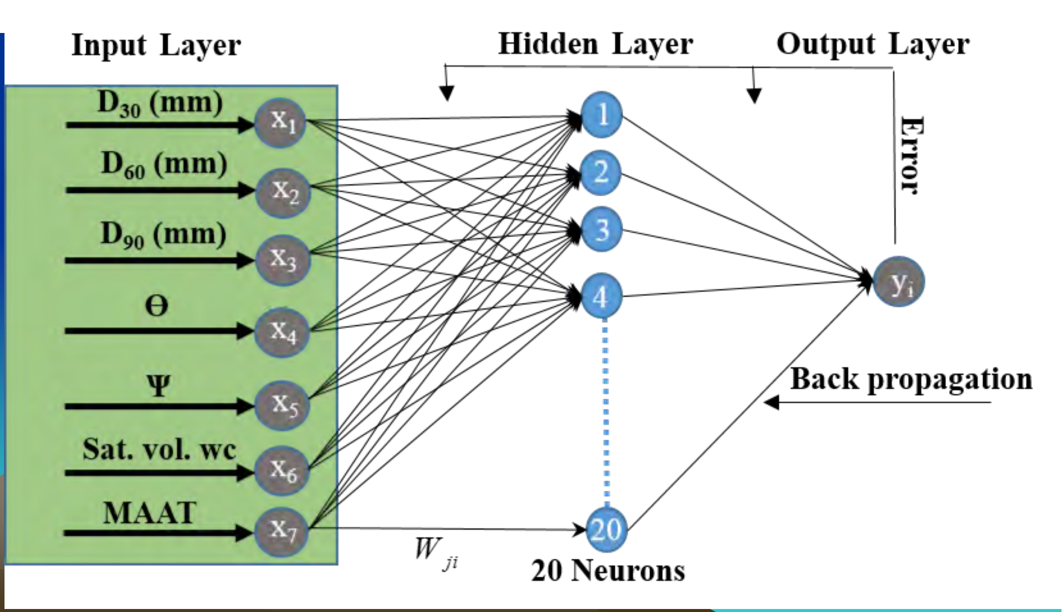
$$\mathrm{C}(h) = 1 - \frac{\ln(1+\frac{h}{h_r})}{\ln[1+(\frac{1.021x10^7}{h_r})]}$$

a_f, b_f, c_f and h_r are Fitting Parameters

Prediction Model for SWCC Fitting Parameters



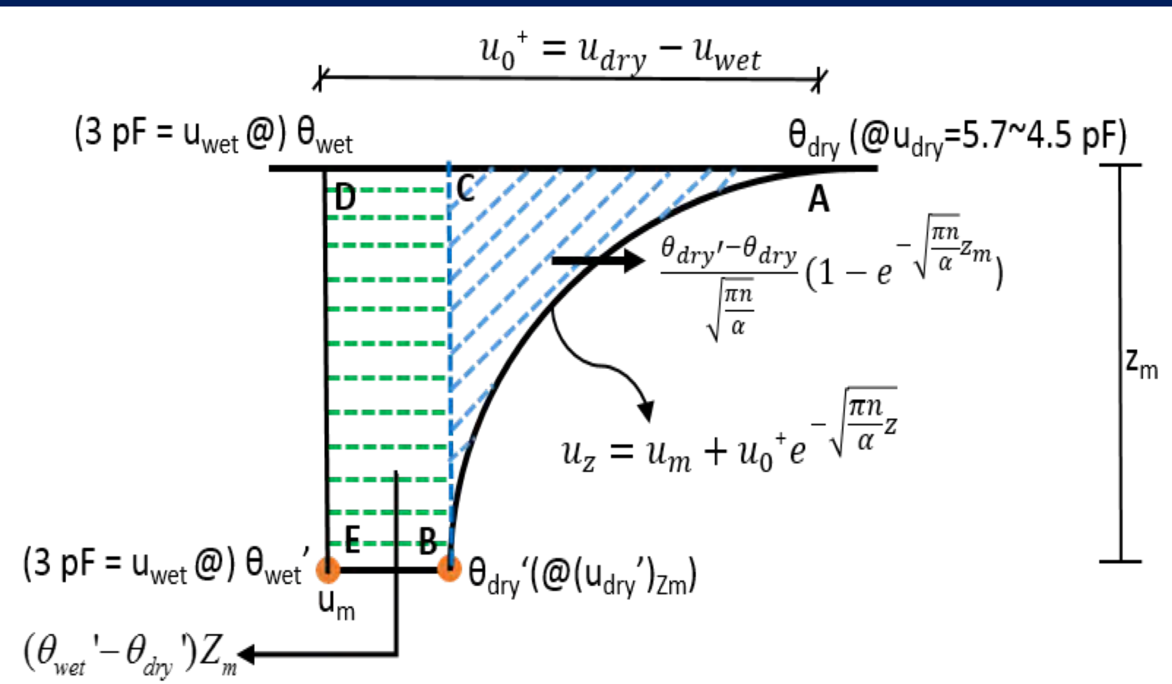
Plastic Soil



Non-Plastic Soil

(After Saha et al. 2018)

Available Annual Moisture Depth, d_{am}



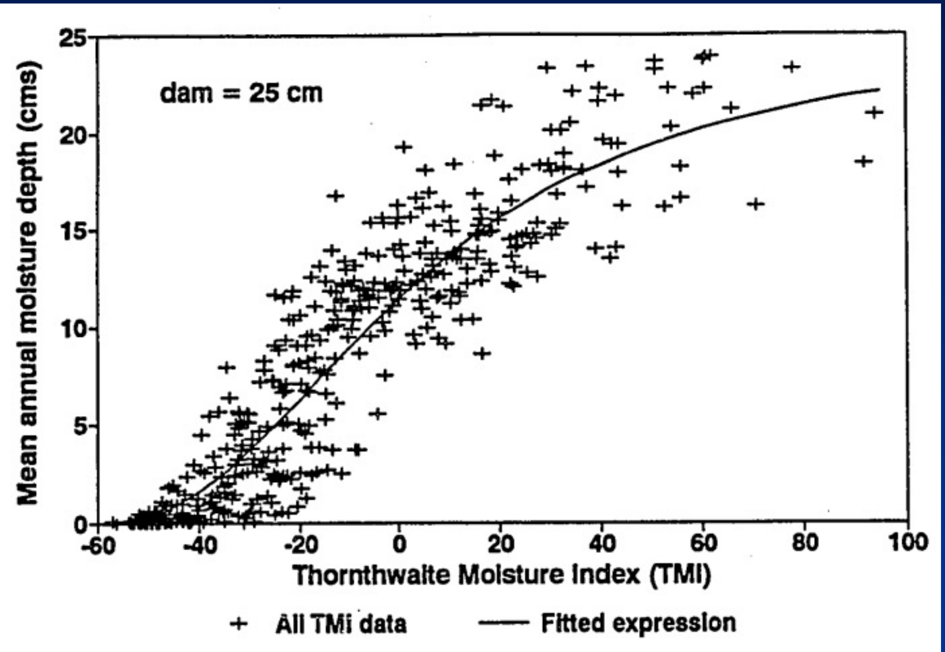
$$d_{am} = \int_0^{z_m} [\theta_{wet}(z) - \theta_{dry}(z)]$$

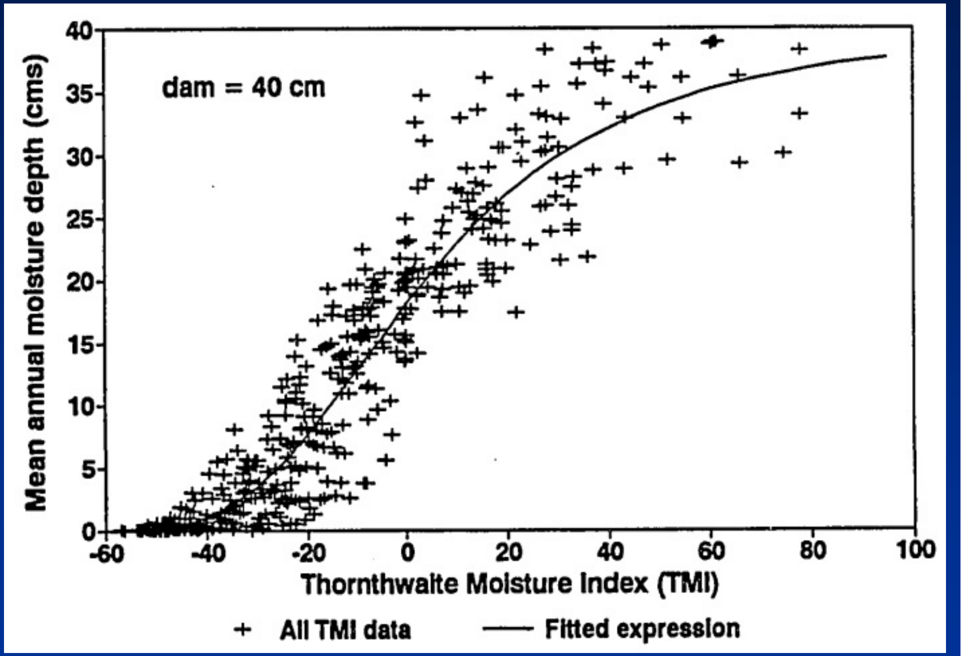
$$= Area\ \mathbf{ABC} + Area\ \mathbf{BCDE}$$

$$\frac{\theta_{dry}' - \theta_{dry}}{\sqrt{\frac{n\pi}{\alpha}}}(1 - e^{-\sqrt{\frac{n\pi}{\alpha}} z_m}) + (\theta_{wet}' - \theta_{dry}')z_m$$

Maximum Moisture Stored Between Dry and Wet Profile

Mean Annual Moisture Depth Vs TMI

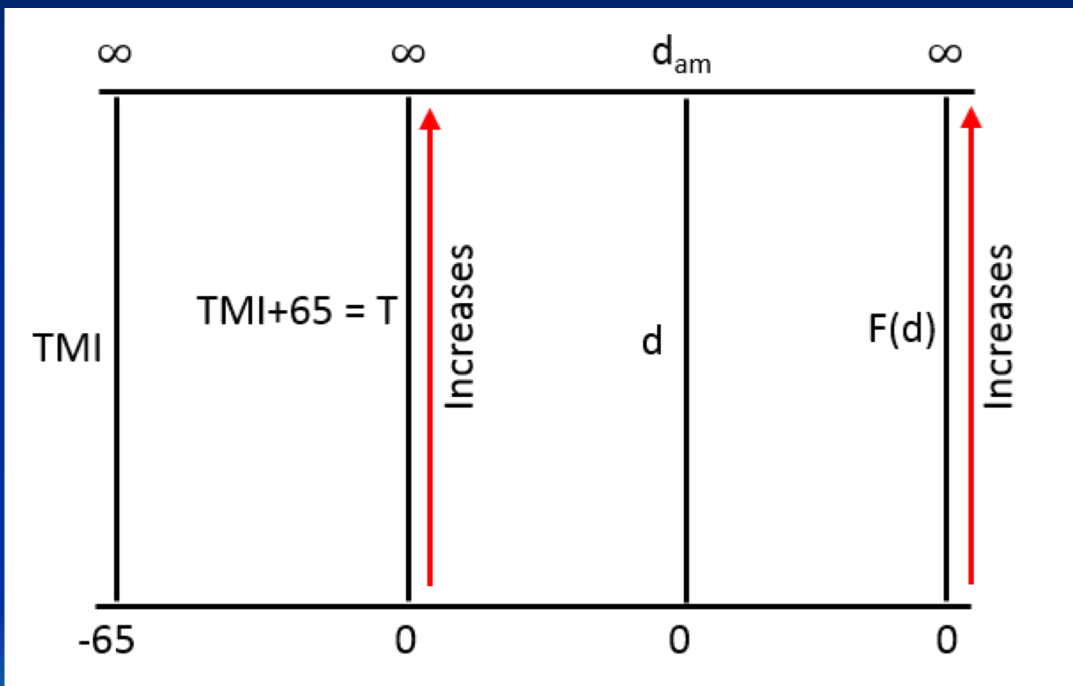




(After Gay 1994)

Relationship Between TMI and Moisture Depth

Using Juarez-Badillo's approach



$$\gamma \frac{dT}{T} = \frac{dF(d)}{F(d)}$$

$$\gamma \ln[\frac{T}{T_1}] = \ln[\frac{\frac{1}{d_{am}-d_m} - \frac{1}{d_{am}}}{\frac{1}{d_{am}-d_1} - \frac{1}{d_{am}}}]$$

Mean Annual Moisture Depth

Using Juarez-Badillo's approach

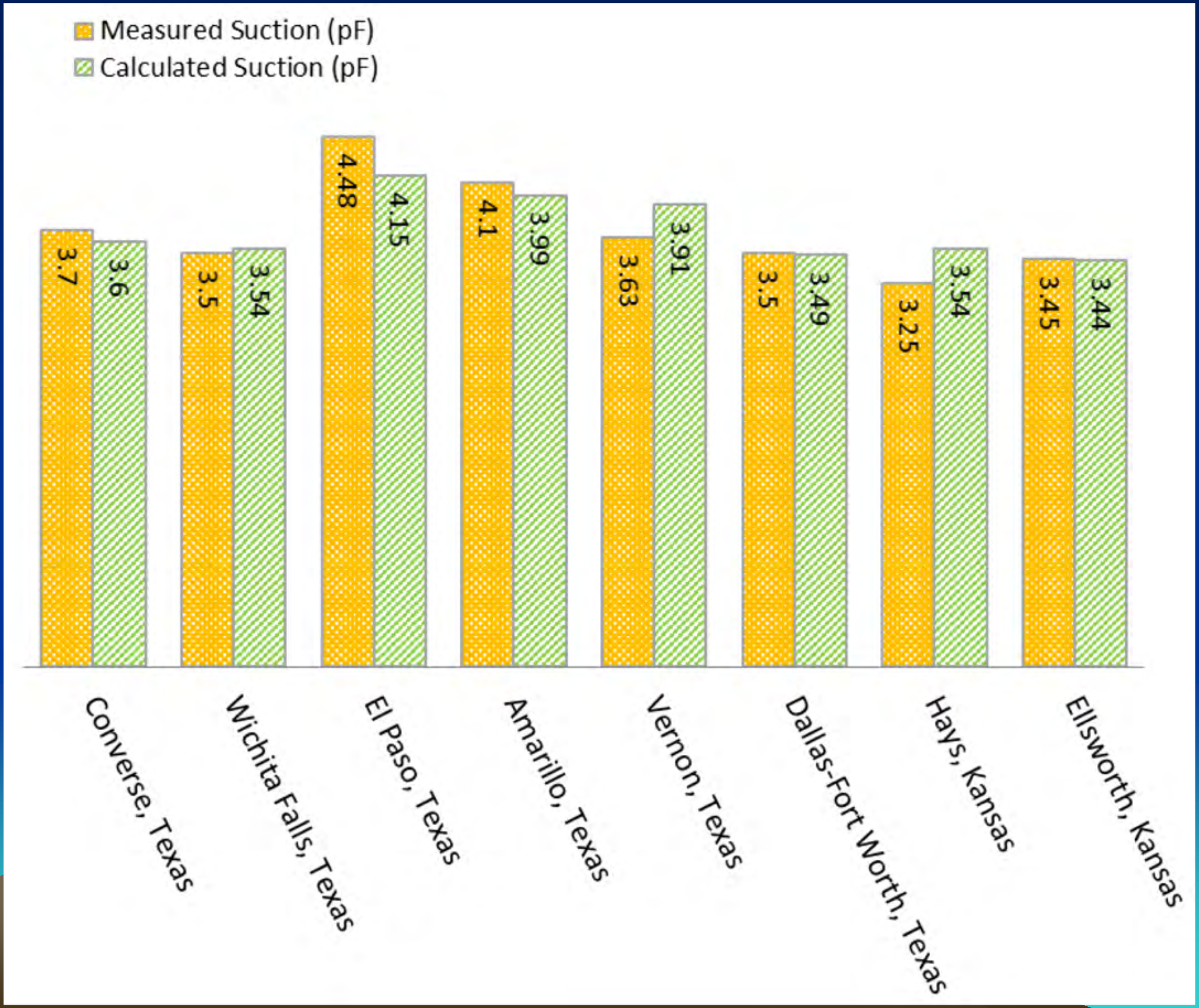
$$d_m = \frac{d_{am}}{[1 + \frac{d_{am} - d_1}{d_1 (\frac{T}{T_1})^{\gamma}}]}$$

where T = TMI + 65;

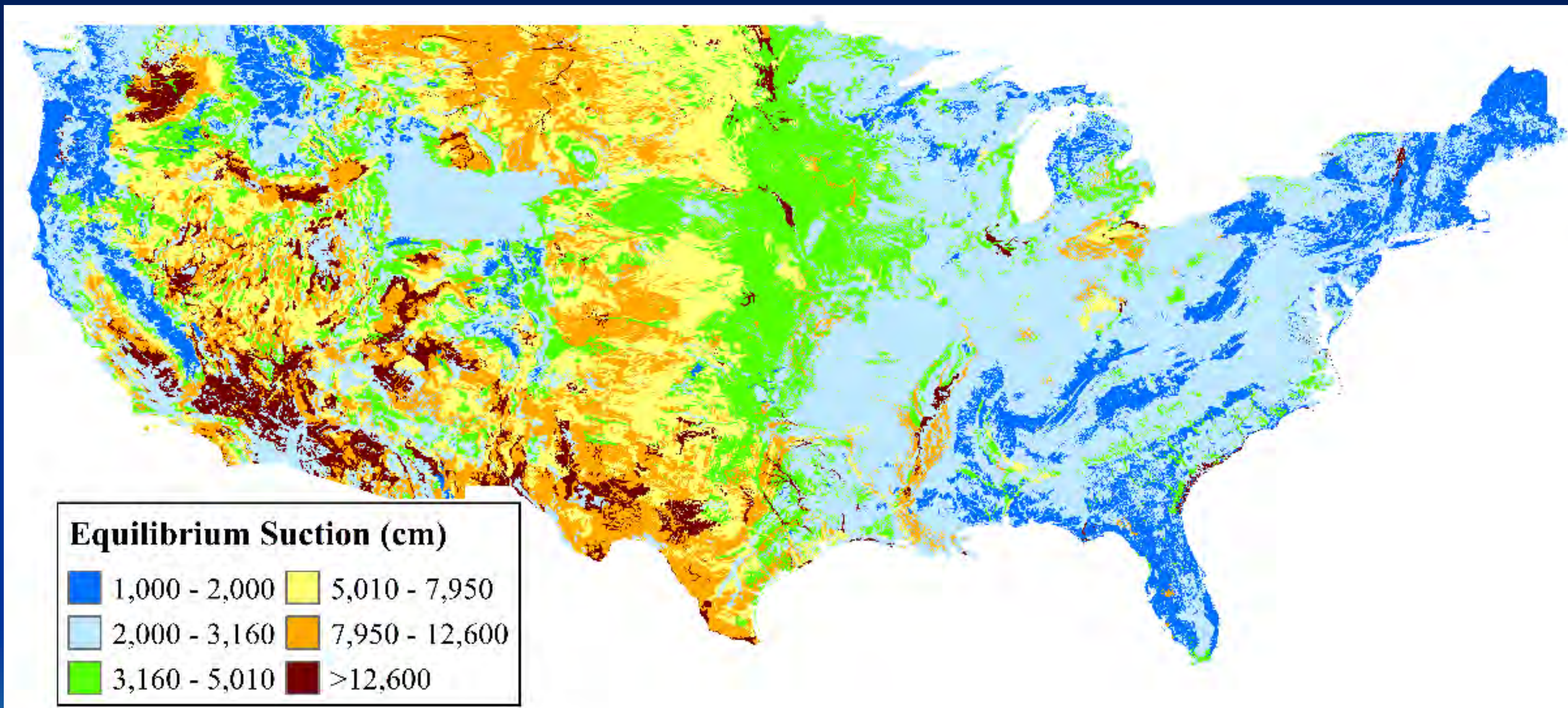
d_m = Mean Annual Moisture Depth;

γ, T_1 and d_1 are Regression coefficient

Validation of Equilibrium Suction Model



Equilibrium Suction Map

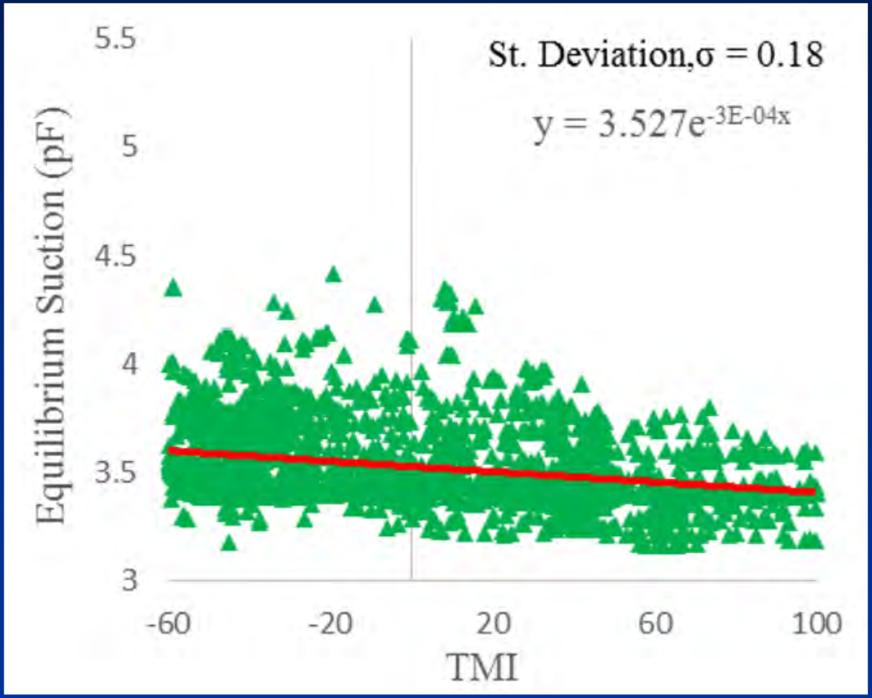


Equilibrium Suction Map in GIS Platform

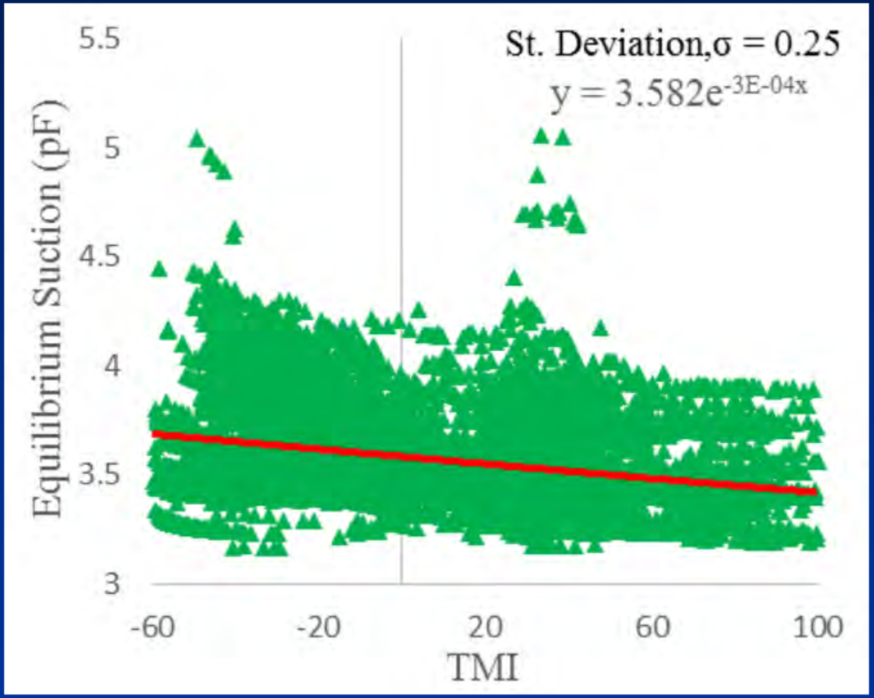
Significant Parameters of Equilibrium Suction

Variables	Degree of freedom	Parameter estimate	Standard error	t Ratio	p-value
Intercept	1	1.267	0.406	3.118	0.0021
TMI	1	-0.00114	0.000593	-1.9306	0.0451
PI	1	0.0297	0.00346	8.5991	4.41E-15
u_{dry}	1	0.5153	0.0647	7.9623	2.054E-13
Z_m	1	0.00046	0.000318	1.444	0.1503
F_r	1	-0.1153	0.1859	-0.6203	0.5358
$\sqrt{1/\alpha}$	1	-0.0042	0.00084	-4.9505	1.731E-06
θ_{sat}	1	-0.4327	0.3182	-1.36	0.175
a_f (pF)	1	-0.00174	0.0265	-0.0656	0.9477
b_f	1	0.00349	0.00617	0.5665	0.5717
c_f	1	-0.1758	0.1183	-1.4859	0.1391

Equilibrium Suction Vs TMI

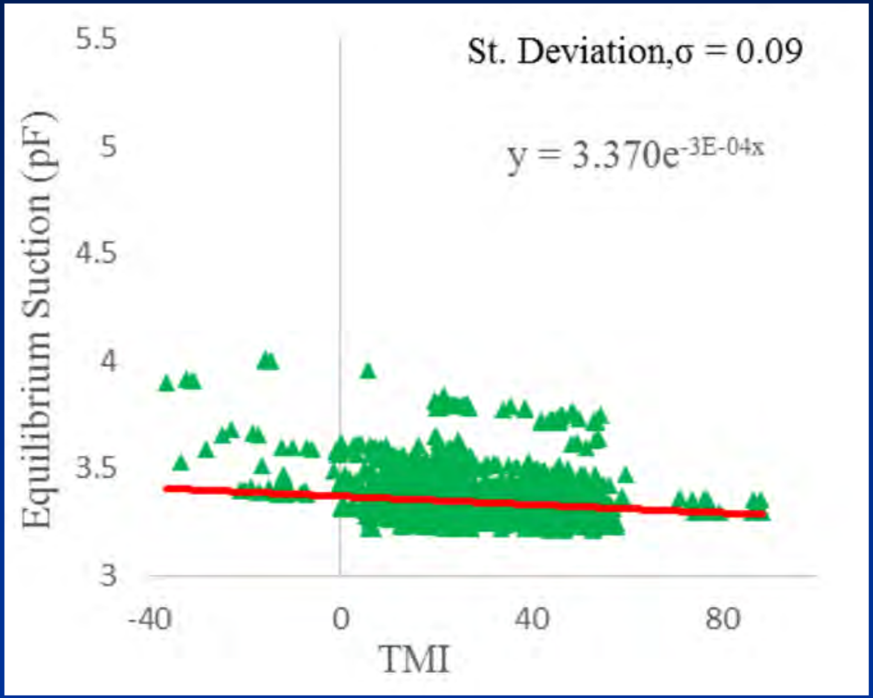


AASHTO soil type: A-1

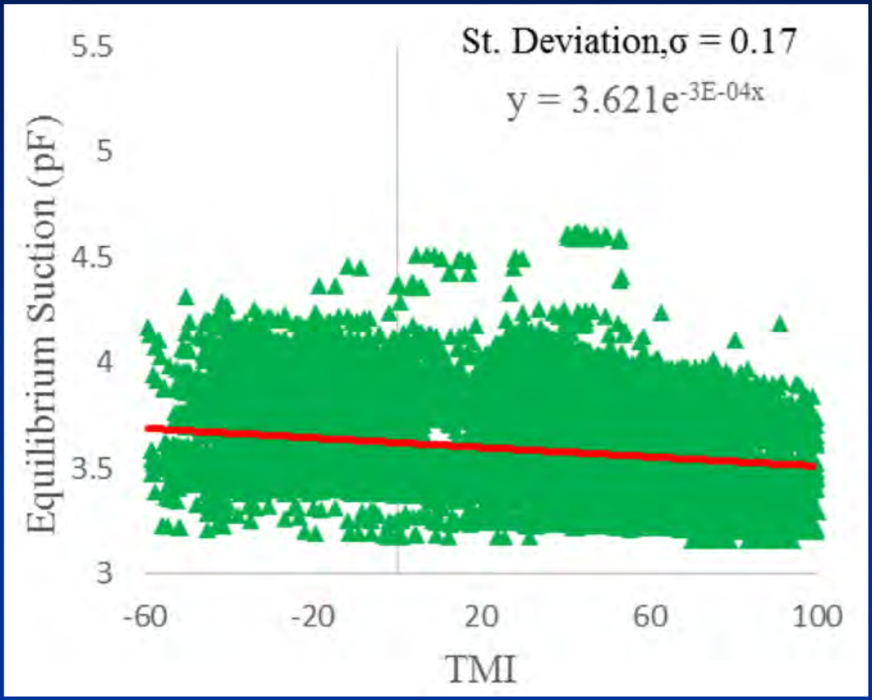


AASHTO soil type: A-2

Equilibrium Suction Vs TMI

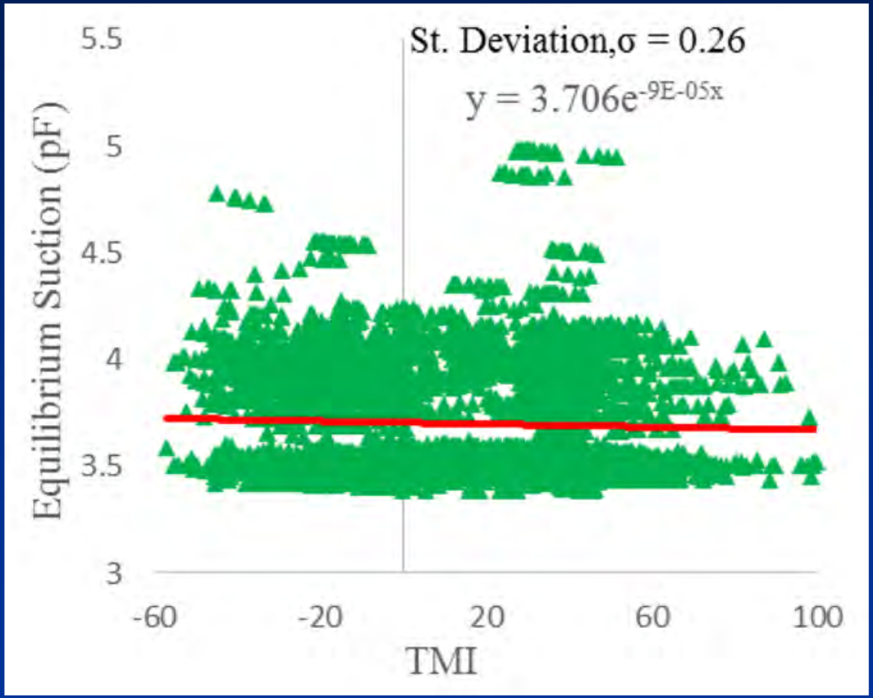


AASHTO soil type: A-3

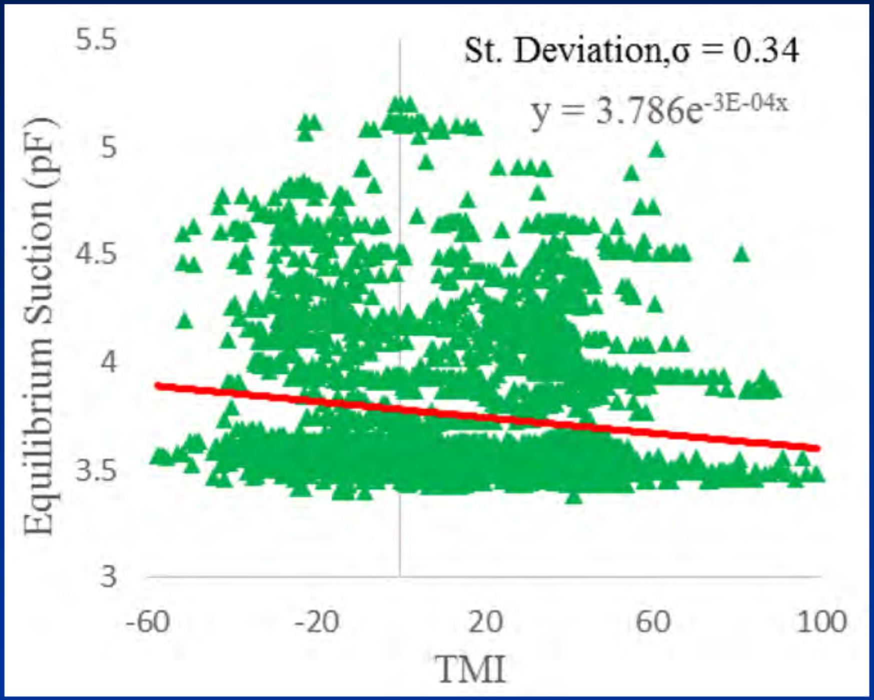


AASHTO soil type: A-4

Equilibrium Suction Vs TMI

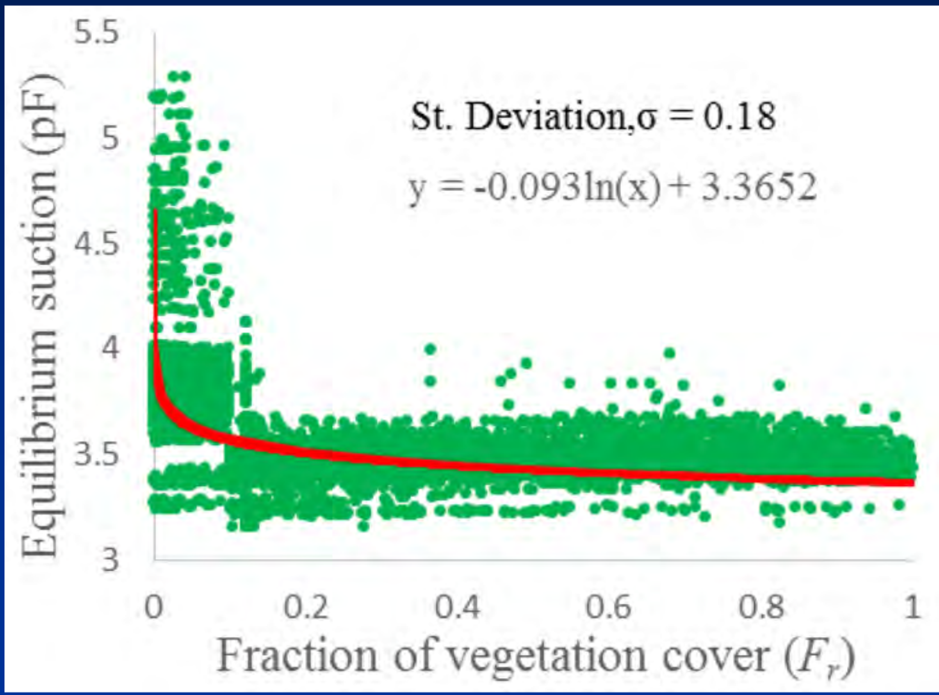


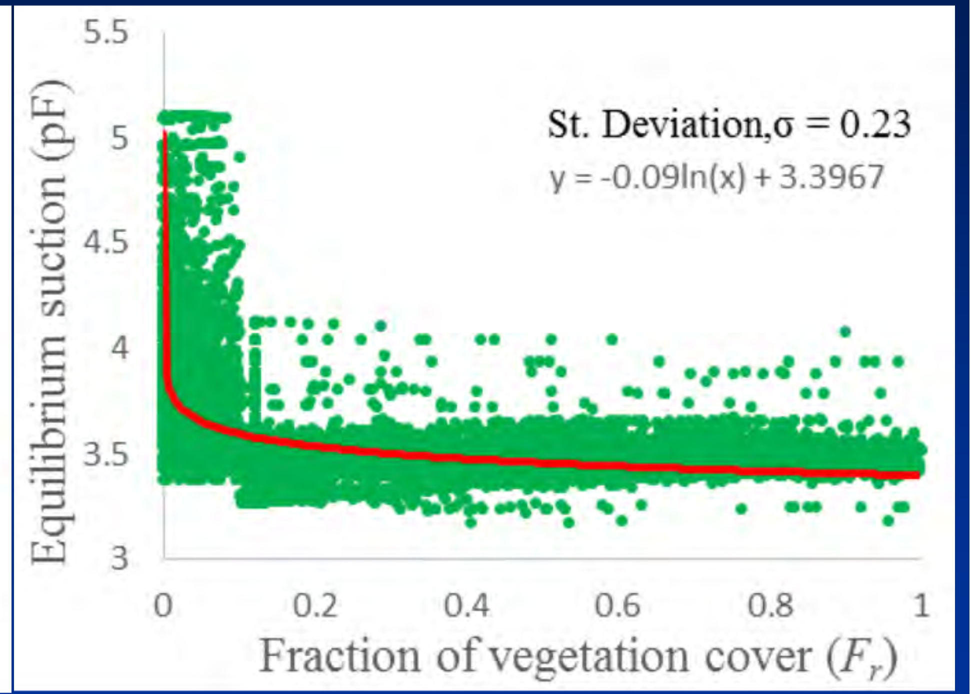
AASHTO soil type: A-6



AASHTO soil type: A-7-6

Equilibrium Suction Vs Vegetation Cover

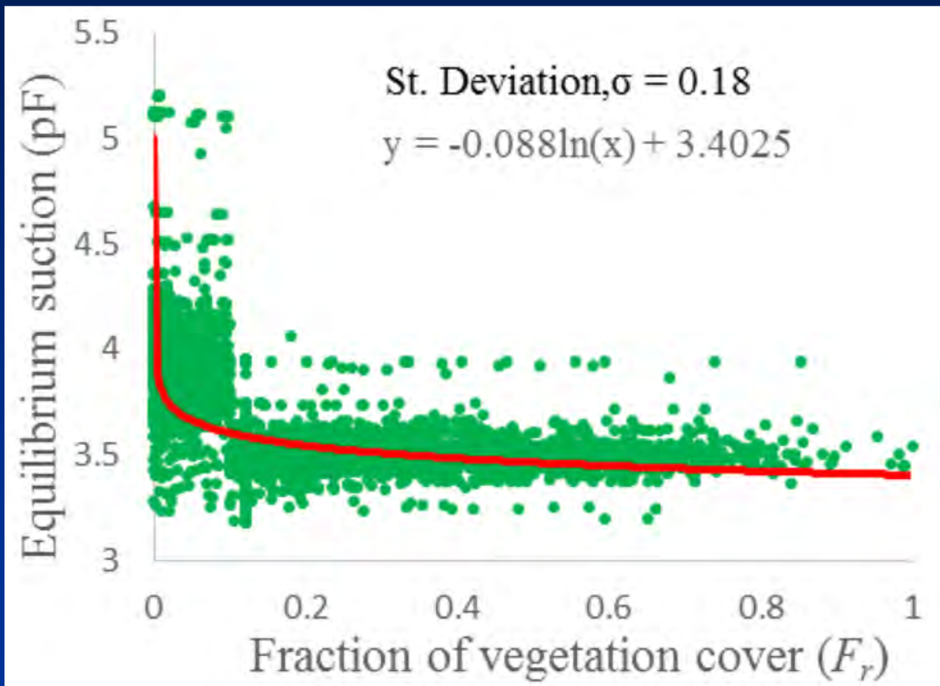




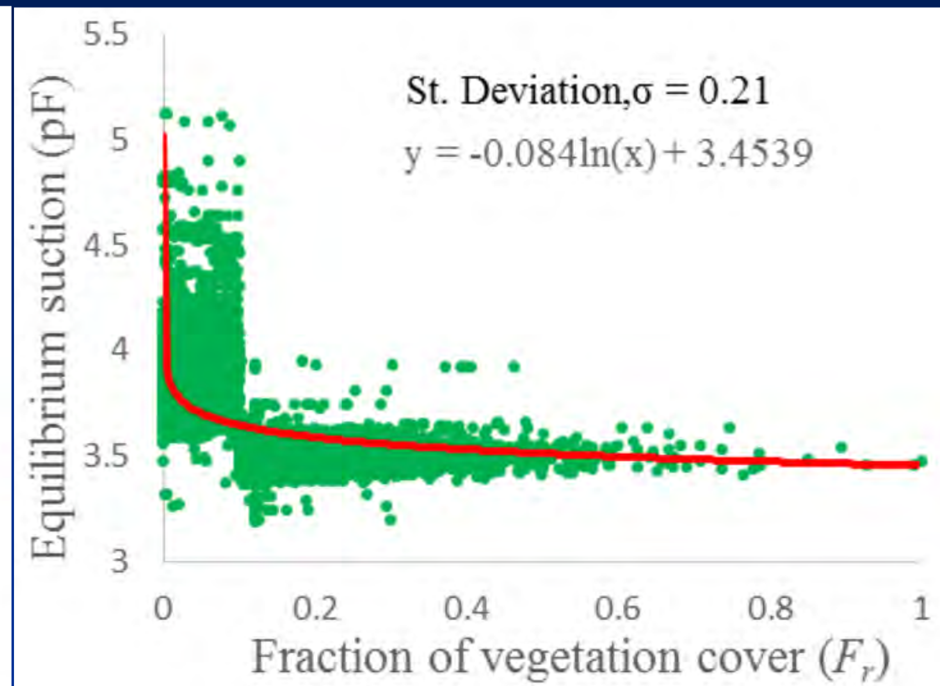
TMI: >40

TMI: 40 to 10

Equilibrium Suction Vs Vegetation Cover

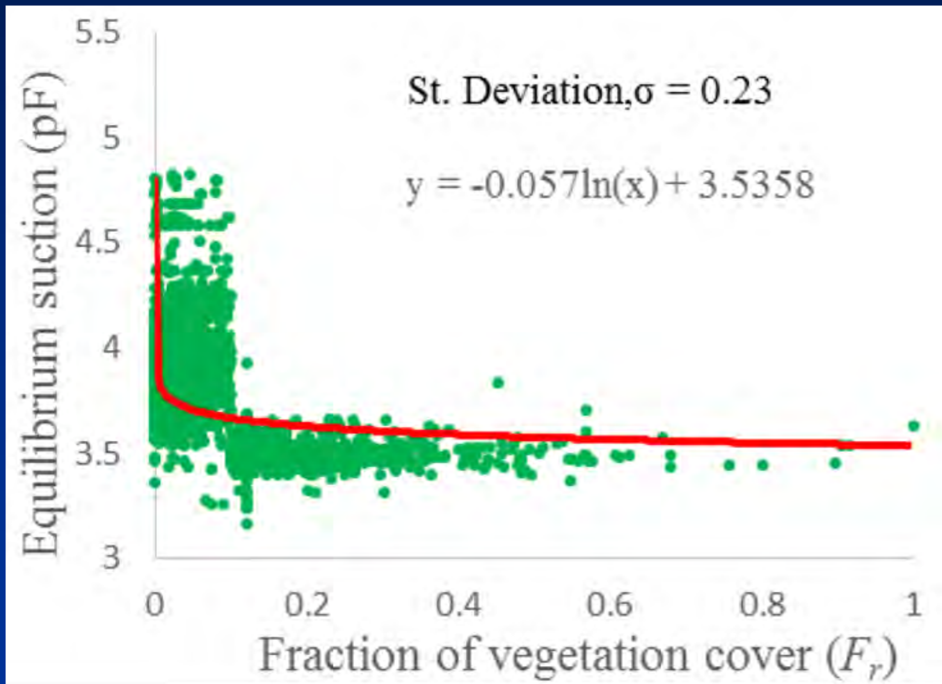


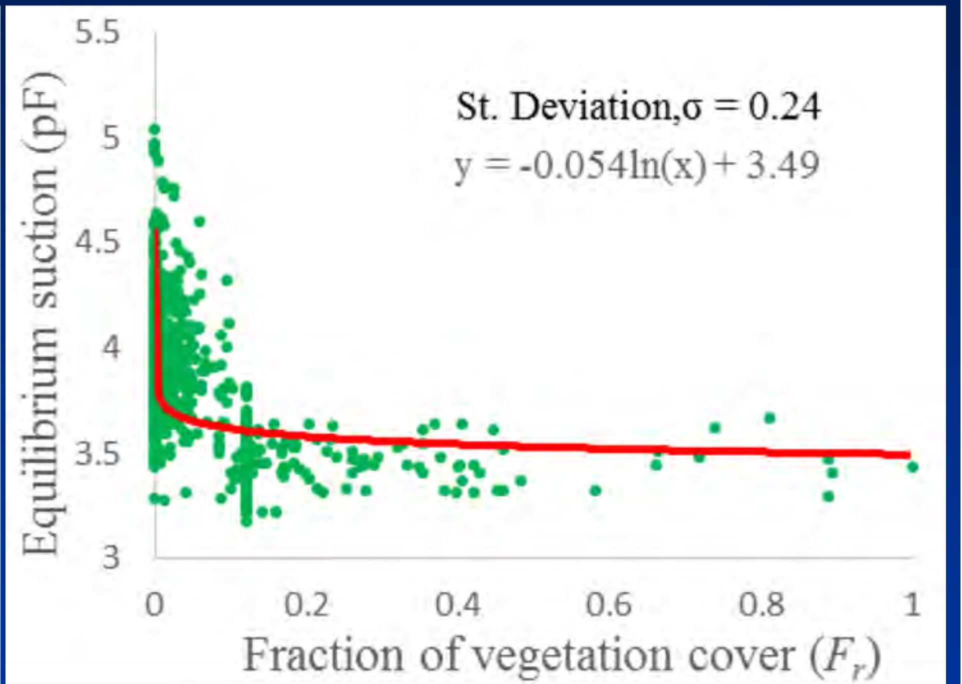
TMI: 10 to -5



TMI: -5 to -25

Equilibrium Suction Vs Vegetation Cover





TMI: -25 to -40

TMI: < -40

Depth of Constant Suction Based on TMI Intervals

Climatic Divisions in Australia		TMI		Depth to Constant Suction (m)	Equilibrium Suction (pF)
		AS2870-1996	AS2870-2011		
I	Alpine/coastal	TMI > 40	TMI > 10	1.5	3.6
II	Wet temperate	10 < TMI < 40	-5 < TMI < 10	1.8	3.8
III	Temperate	-5 < TMI < 10	-15 < TMI < -5	2.3	4.1
IV	Dry temperate	-25 < TMI < -5	-25 < TMI < -15	3.0	4.2
V	Semi–arid	TMI < -25	-40 < TMI < -25	4.0	4.4
VI	Arid*	N/A	TMI < -40	> 4.0	4.6

Climatic divisions in Australia in AS2870-2011

Thank You !!!!!

Development of a Modified Equilibrium Suction Model for Subgrade Layers

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