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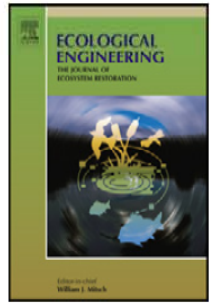

Alteration of soil hydraulic properties during the construction of mitigation wetlands in the Virginia Piedmont

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OUTLINE

Introduction/Problem Statement
Study Objectives
Study Areas
Methods
Results
Implications
Conclusions
Questions

As of 2010 there are over 950 wetland mitigation banks totaling over 950,000 acres in the USA
(National Mitigation Banking Association - mitigationbanking.org; accessed 11/27/2011, re-verified 3/11/2013)

- **Wetland mitigation has resulted in a net loss in terms of wetland function and habitat** (NRC, 2001)

- **Hydrology**
  - → **Too wet or too dry** (Whittecar and Daniels, 1999)
  - → **Different then reference wetlands**

- **Hydrologic characteristics** (Confer and Niering, 1992; Cole and Brooks, 2000)
- **HGM Assessment** (Shaffer et al., 1999)

Water Budgets

(Pierce, 1993; Daniels et al., 2000)

$$P + SRI + GWI – ET – SRO – GWO = \Delta S$$

P – PRECIPITATION
SRI – SURFACE RUNOFF IN
GWI – GROUND WATER IN
ET – EVAPOTRANSPIRATION
SRO – SURFACE RUNOFF OUT
GWO – GROUND WATER OUT
S - STORAGE

→ PROBLEMS WITH DATA SOURCES

Why the near surface zone (upper 30 cm)?

- **Regulatory Success Demands**
- **Design Constraints**

USACE definition for wetland hydrology requires that a free water table be present within 30 cm of the soil surface for a consecutive duration of time during the growing season.

- **Jurisdictional Wetland Hydrology – 5% to 12.5% of the growing season** *(1987 Corps of Engineers Wetlands Delineation Manual* (Environmental Laboratory, 1987).
- **Jurisdictional Wetland Hydrology – 14 consecutive days within the growing season** *(Regional Supplements to the 1987 Corps of Engineers Wetlands Delineation Manual: Atlantic and Gulf Coastal Plain Region (V2), 2010; Regional Supplements to the 1987 Corps of Engineers Wetlands Delineation Manual: Eastern Mountains and Piedmont Region (V2), 2012*).
- **Wetland Mitigation Hydrology - 12.5% of the growing season** (USACE and VADEQ, July 2004).

Construction activities redistribute the upper soil horizons

(Clewell and Lea, 1990; Stolt et al., 2000; Bruland and Richardson, 2003)

→ **Low organic matter, high bulk density and increased rock fragments** (Campbell et al, 2002)

→ **Compaction, clay and water** (McIntyre, 1974)

→ **Soil disturbance and drainable water**

- **Drainable volume and water supply** (Sun et al., 2001)

- **Reduced drainable water, macropore space and saturated hydraulic conductivity** (Aust et al., 1995)

- **Soil Water Characteristic Curves** (Grace et al., 2006)

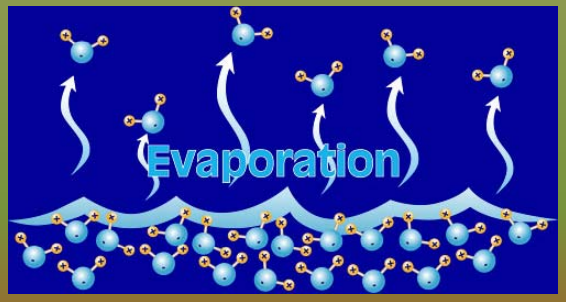
Constructed wetland guidance suggests ≤1.35 g/cm^3 D_b and ≥ 5% organic matter (Daniels and Whittecar, 1999)

DRAINABLE WATER AND EVAPOTRANSPIRATION

Example 1:

- Saturated nondisturbed 30 cm thick soil profile
- ET rate of 1 cm per week
-Drainable Porosity (DP) of 10%

→ Water table would be lowered by 10 cm



1 cm / 0.10 = 10 cm

(ET) / DP = h_2o table depth

DRAINABLE WATER AND EVAPOTRANSPIRATION

Problem: We predict hydrology using preconstruction site conditions……

Example 2:

- Saturated disturbed 30 cm thick soil profile
- ET rate of 1 cm per week
- Drainable Porosity (DP) of 5%

→ Water table would be lowered by 20 cm

1 cm / 0.05 = 20 cm

(ET) / DP = h_2o table depth

Objective(s)

To compare soil physical properties from two constructed wetlands to soil properties that represent their undisturbed site conditions.

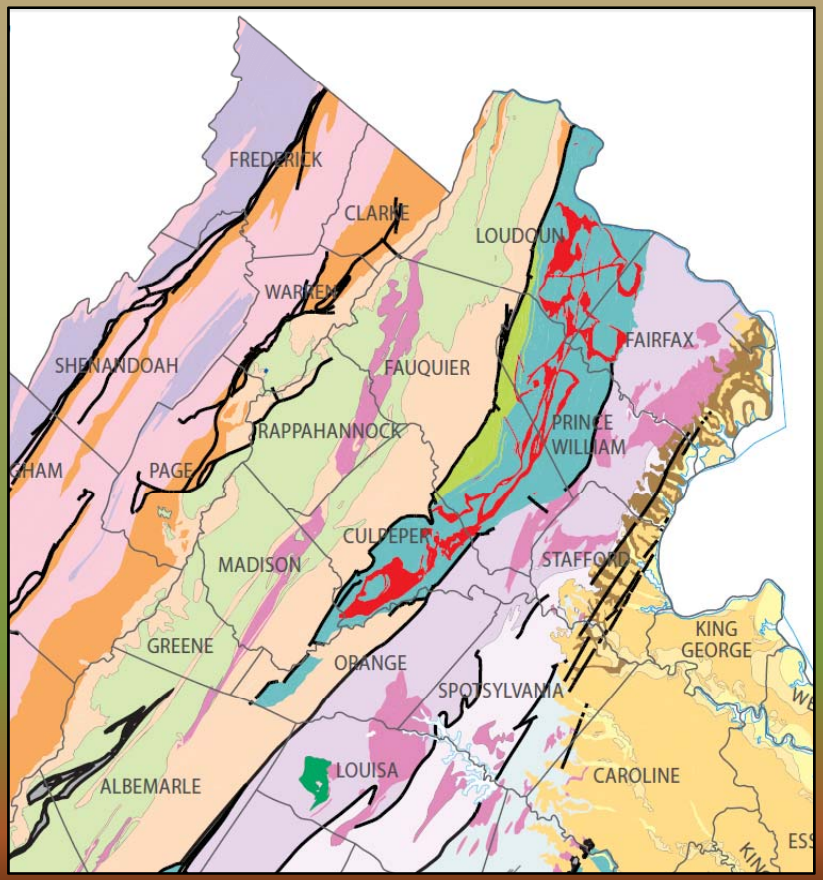
Methods: Study Areas

Blackjack Wetland Bank (BJ), Culpeper County, Virginia

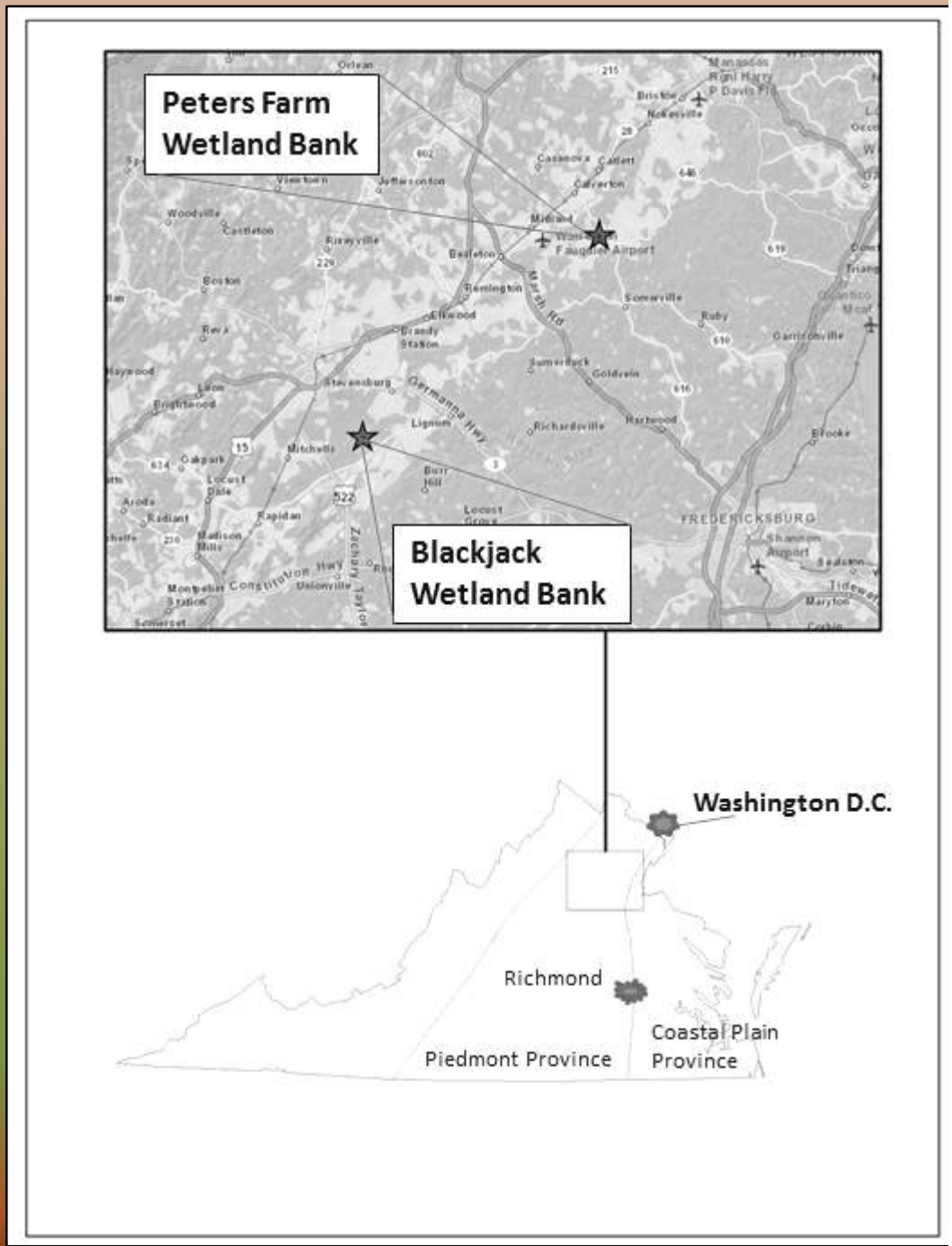
(38° 35’ 23.86” N, 77° 38’ 27.37” W)

Peters Farm Wetland Bank (PF), Fauquier County, Virginia

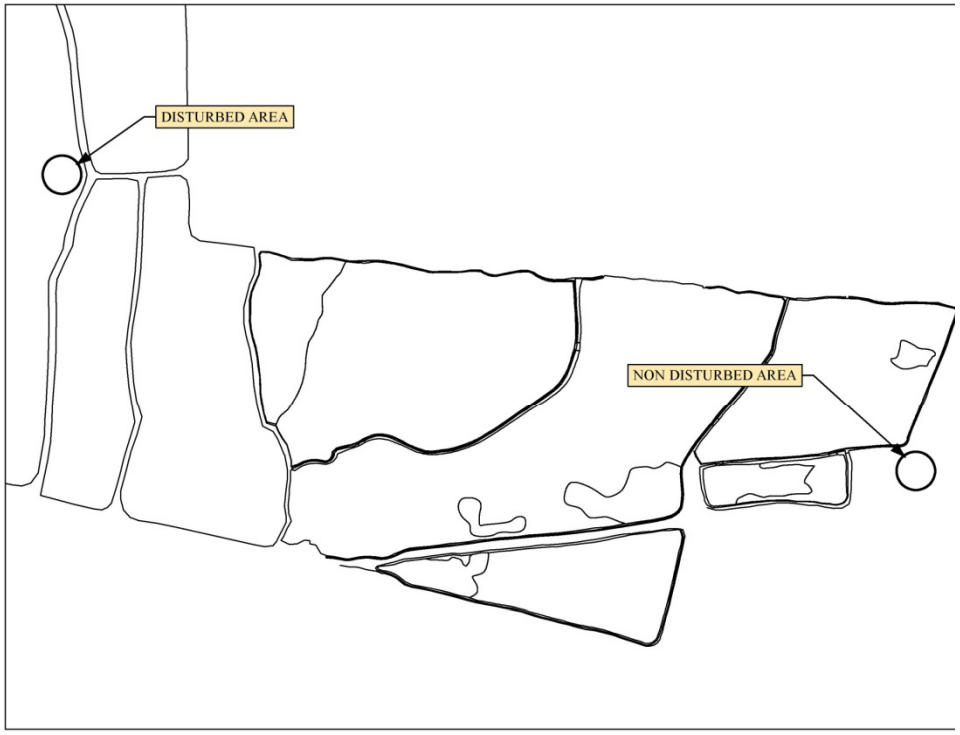
(38°23’44.38”N, 77°55’58.36”W)

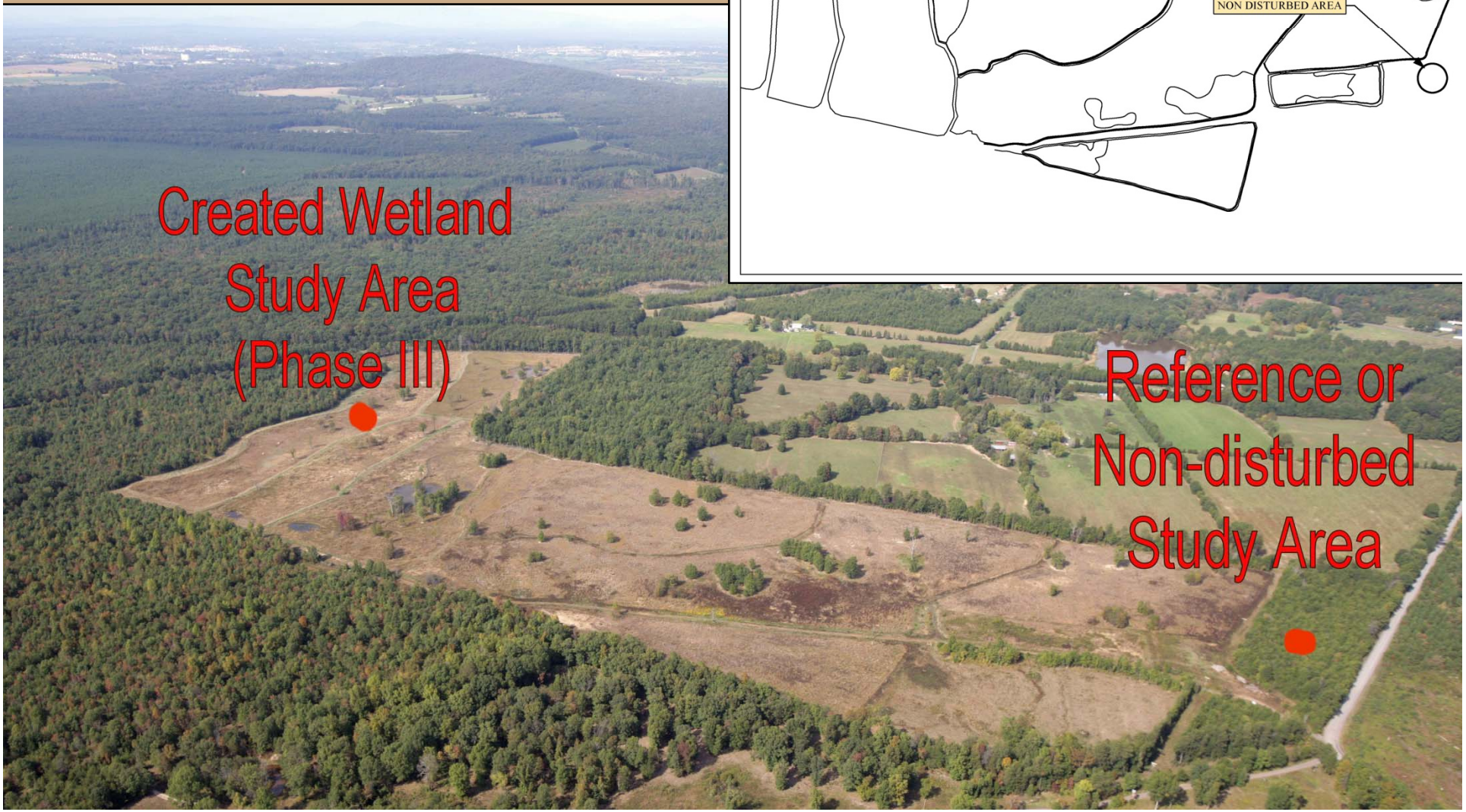


taken from VADMR, 1992)

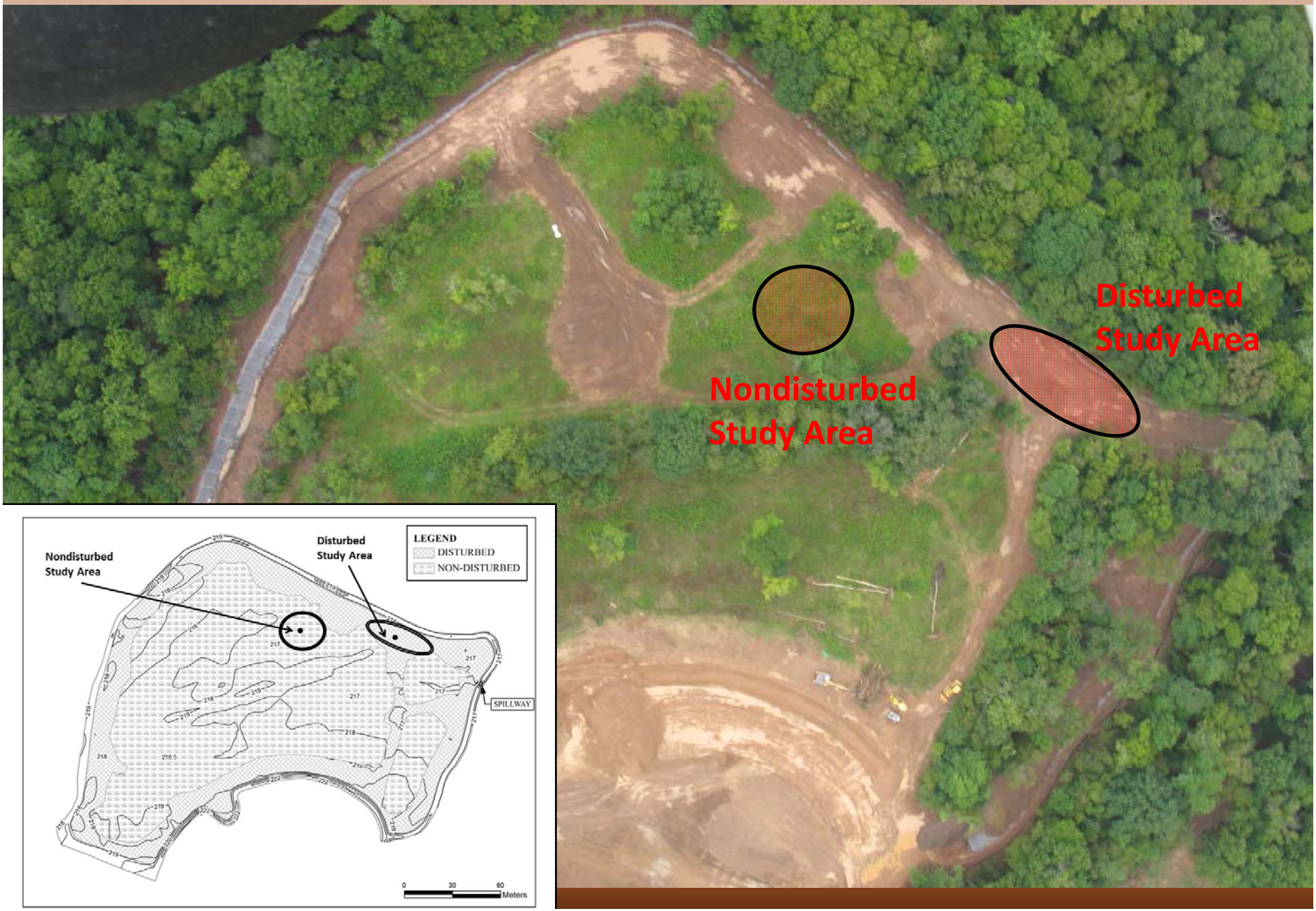


Blackjack Wetland Bank (BJ)





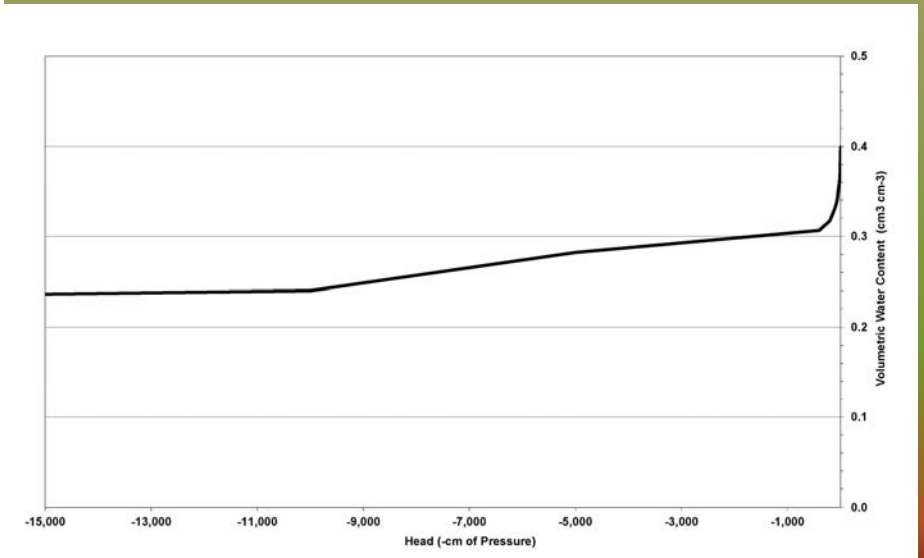
Peters Farm Wetland Bank (PF)

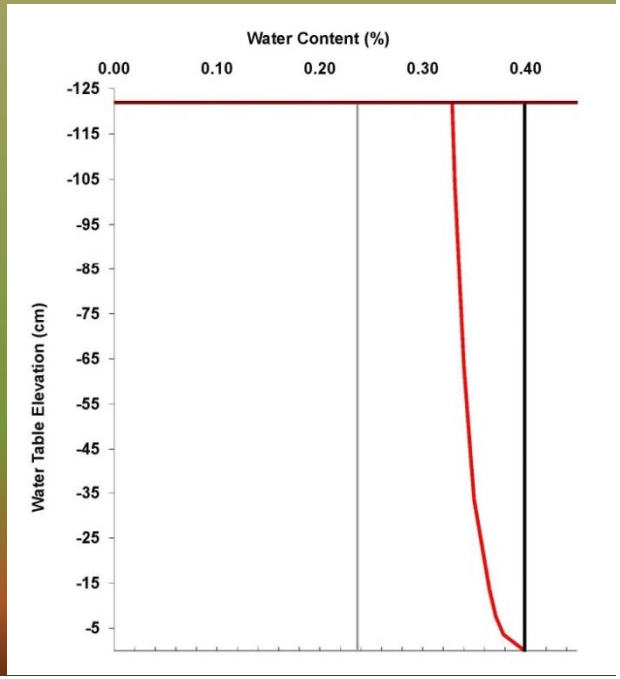


Methods – Soil Properties

- Particle Size Distribution (Texture)
- Soil Organic Matter (SOM)
- Bulk Density (Db)
- Total Pore Space (TPS)
- Lateral Saturated Hydraulic Conductivity ($Ksat_L$)
- Vertical Saturated Hydraulic Conductivity ($Ksat_V$)

- Soil Water Characteristic Curve (SWCC)
- Available Water Content (θ - AWC)





Methods - Soils

- **Soil Organic Matter (SOM); (%) Loss on Ignition,** Nelson and Sommers (1982)

- **Bulk Density (Db) & Total Pore Space (TPS); (g/cm^3) and (%) Respectively,** Blake and Hartage (1986)

- **Particle Size Distribution (Texture); Hydrometer Technique,** Gee and Bauder (1986)

Methods - Soils

Available Water Content (AWC)
Water Content (θ)

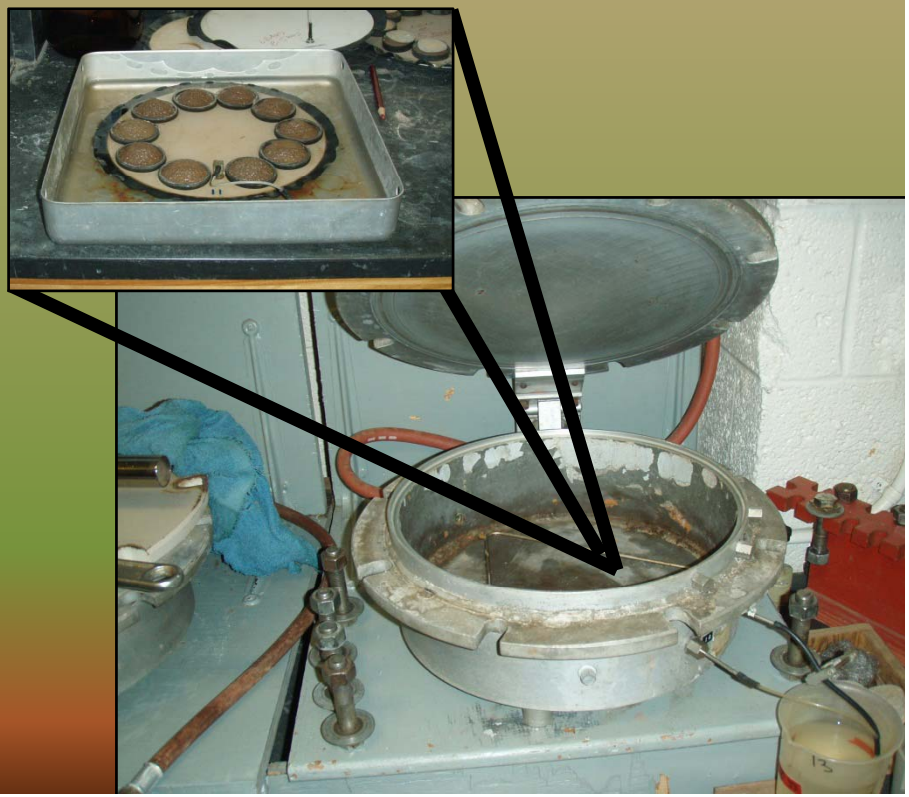
Low Pressure Suction Chamber, Klute (1986)

BJ: 0 cm (saturation), -3.6 cm, -13.6 cm, -23.6 cm, -33.6 cm, -43.6 cm, -53.6 cm, -63.6 cm, -83.6 cm, -103.6 cm, -123.6 cm, -153.6 cm, -203.6 cm, -253.6 cm, and -403.6 cm pressures

PF: 0 cm (saturation), -3.6 cm -7.5 cm, -13.6 cm, -33.6 cm, -63.6 cm, --103.6 cm, --203.6 cm, -303.6 cm, and -403.6 cm pressures

High Pressure Suction Chamber, Cassel and Nielsen (1986)

-1000 cm, -5000 cm, -10000 cm, and -15,000 cm (wilting point) suctions



Methods - Soils

- **Lateral Saturated Hydraulic Conductivity ($Ksat_L$)**

Auger-hole Method, (Van Beers, 1958)



- **Vertical Saturated Hydraulic Conductivity ($Ksat_V$)**

Constant and Falling Head Laboratory Methods, Klute and Dirksen (1986)



Results – BJ Soil Physical Properties

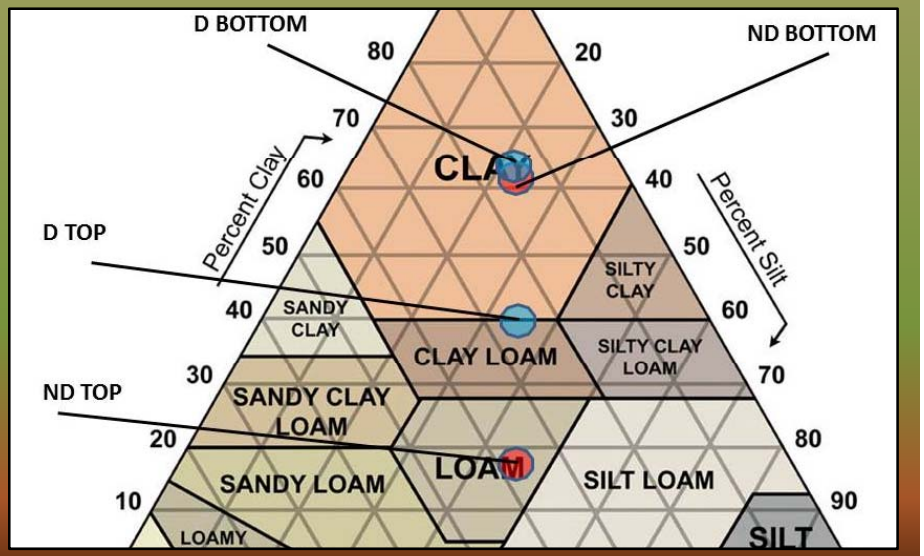
	N	ND Top	ND Bottom	D Top	D Bottom
Sand%	10	38.6 (6.3)	13.0 (2.0)	27.4 (10.0)	15.1 (3.5)
Silt%	10	42.8 (3.4)	25.3 (3.8)	32.6 (7.2)	21.3 (5.2)
Clay%	10	18.5 (7.8)	61.7 (5.6)	40.0 (16.8)	63.6 (5.3)
SOM%	10	5.0 (4.1)	4.6 (1.3)	5.4 (0.5)	4.6 (0.5)
D_b (g/cm^3)	4	1.56 (0.4)	1.28 (0.07)‡	1.45 (0.18)‡	1.22 (0.04)
TP(%)	4	36.7 (1.7)	53.6 (1.7)‡	42.6 (8.3)‡	54.9 (1.2)
AWC (%)	4	24.1 (1.6)	22.7 (0.8)‡	15.8 (3.7)‡	21.8 (0.2)
$Ksat_v$(cm/hr)	4	4.169 (7.569)	0.006 (0.007)‡	0.670 (1.307)‡	0.001(0.002)‡
$Ksat_L$(cm/hr)	4	12.5 (13.6)*	0.003 (.003)	0.0002	(.0004)†

- Standard deviations are given in parenthesis.

† = 7; ‡ N = 5; § N = 11; ¶ N = 9

ND – Nondisturbed Area

D – Disturbed Area



Results – PF Soil Physical Properties

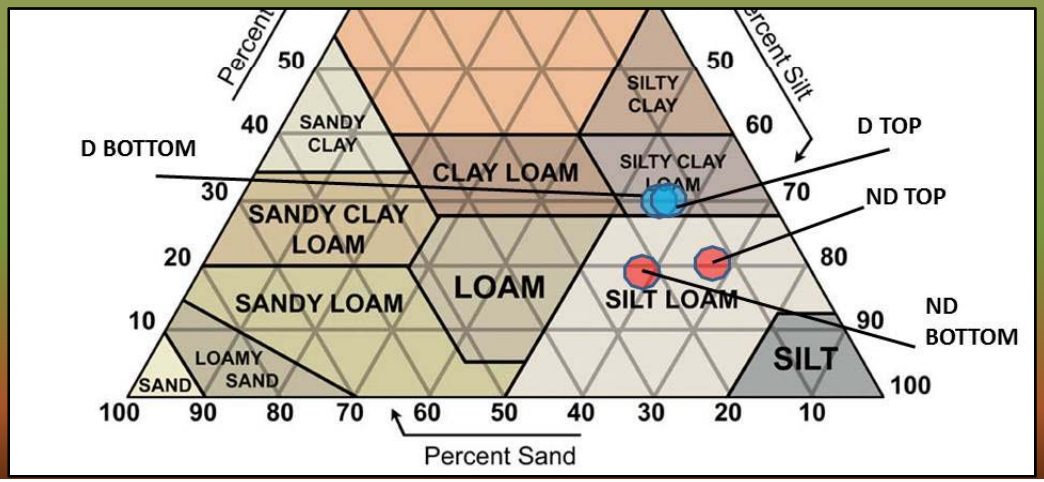
		ND Top	ND Bottom	D Top	D Bottom
Sand%	10	11.8 (2.6)	22.4 (8.0)	14.7 (6.0)	15.6 (6.1)
Silt%	10	68.1 (2.9)	59.3 (6.8)	53.8 (9.1)	53.7 (6.9)
Clay%	10	20.1 (1.1)	18.4 (1.5)	31.5 (5.9)	30.7 (4.0)
SOM%	10	3.3 (0.4)	3.1 (0.2)	3.3 (0.3)	3.7 (0.3)
D_b (g/cm^3)	4	1.52 (0.06)‡	1.59 (0.20)‡	1.67 (0.09)‡	1.64 (0.07)‡
TP(%)	4	37.2 (2.3)‡	34.0 (2.5)‡	40.2 (5.0)‡	40.2 (5.0)‡
AWC (%)	4	21.6 (2.4)‡	20.7 (2.2)‡	17.6 (9.4)‡	16.3 (5.3)‡
$Ksat_v$(cm/hr)	4	0.054 (0.099)‡	6.325 (14.017)‡	0.255 (0.530)‡	0.386(0.703)‡
$Ksat_L$(cm/hr)	4	2.71(2.48)§		0.017(0.026)¶	

_- Standard deviations are given in parenthesis.

† = 7; ‡ N = 5; § N = 11; ¶ N = 9

ND – Nondisturbed Area

D – Disturbed Area



Results – Water Content (θ)

	Pressure Head (-cm)	ND Top	ND Bottom	D Top	D Bottom
	N=	4	5	5	4
BJ	0 cm	0.367(0.017)	0.536(0.017)	0.471(0.087)	0.549(0.012)
	-13.6	0.359(0.020)	0.532(0.018)	0.467(0.090)	0.549(0.012)
	-63.6	0.347(0.022)	0.531(0.018)	0.462(0.098)	0.549(0.012)
	-103.6	0.337(0.024)	0.337(0.024)	0.458(0.100)	0.548(0.011)
	-203.6	0.322(0.027)	0.547(0.013)	0.402(0.101)	0.527(0.018)
	-403.6	0.303(0.027)	0.515(0.015)	0.439(0.109)	0.540(0.011)
	-1000	0.301(0.005)‡	0.485(0.031)	0.444(0.093)	0.521(0.012)‡
	-5000	0.166(0.013)‡	0.375(0.026)	0.328(0.102)	0.410(0.018)‡
	-10000	0.144(0.012)‡	0.340(0.013)	0.296(0.094)	0.370(0.017)‡
	-15000	0.126(0.011)‡	0.309(0.016)	0.266(0.088)	0.334(0.015)‡
	N=	5	5	5	5
PF	0 cm	0.372(0.023)	0.351(0.029)	0.401(0.050)	0.399(0.028)
	-13.6	0.336(0.027)	0.317(0.034)	0.366(0.050)	0.365(0.033)
	-63.6	0.309(0.028)	0.289(0.038)	0.338(0.044)	0.340(0.036)
	-103.6	0.298(0.029)	0.280(0.038)	0.330(0.042)	0.331(0.036)
	-203.6	0.283(0.030)	0.266(0.038)	0.317(0.041)	0.266(0.038)
	-403.6	0.270(0.031)	0.249(0.039)	0.304(0.038)	0.306(0.040)
	-1000	0.375(0.026)	0.315(0.019)	0.435(0.024)	0.414(0.020)
	-5000	0.209(0.012)	0.174(0.008)	0.284(0.025)	0.282(0.023)
	-10000	0.174(0.011)	0.146(0.009)	0.248(0.035)	0.240(0.034)
	-15000	0.156(0.010)	0.133(0.009)	0.225(0.036)	0.237(0.034)

Results – BJ ANOVA

	Sand %		Silt%		Clay%		SOM%	
Adjusted R2	0.731		0.719		0.77		0.58	
	F	Sig	F	Sig	F	Sig	F	Sig
Horizon	92.2	**	79.8	**	110.4	**	0.7	N/S
Treatment	5.4	*	19.3	**	13.6	**	0.1	N/S
Treatment*Horizon	11.3	**	3.7	N/S	9.4	**	0.0	N/S

	D_b		TP%		$Ksat_V$ cm/hr		$Ksat_L$ cm/hr		AWC%	
Adjusted R2	0.594		0.717		0.048		0.27		0.691	
	F	Sig	F	Sig	F	Sig	F	Sig	F	Sig
Horizon	26.0	**	4.1	*	2.0	N/S	-	-	4.9	*
Treatment	3.1	N/S	2.7	N/S	1.1	N/S	4.7	N/S [+]	20.3	**
Treatment*Horizon	0.3	N/S	1.1	N/S	1.1	N/S	-	-	13.2	**

* $P \leq 0.05$; ** $P < 0.005$

[+] One way ANOVA conducted between nondisturbed bottom horizon and effective $Ksat_L$ of disturbed soil profile.

cm of Pressure:	0		-13.5		-63.5		-103.5		-203.5		-403.5		-1000		-5000		-10000		-15000	
Adjusted R2	0.717		0.714		0.706		0.710		0.711		0.718		0.736		0.767		0.772		0.755	
	F	Sig	F	Sig	F	Sig	F	Sig	F	Sig	F	Sig	F	Sig	F	Sig	F	Sig	F	Sig
Horizon	44.1	**	43.6	**	41.9	**	42.4	**	42.3	**	43.2	**	36.1	**	41.3	**	40.9	**	38.2	**
Treatment	2.7	N/S	3.0	N/S	2.9	N/S	3.0	N/S	3.5	N/S	4.2	N/S	16.5	**	19.1	**	20.0	**	17.3	**
Treat*Horizon	1.1	N/S	1.0	N/S	1.0	N/S	1.1	N/S	1.2	N/S	1.4	N/S	5.7	**	8.06	*	9.3	*	8.7	*

* $P \leq 0.05$; ** $P \leq 0.005$

Results – PF ANOVA

	Sand %		Silt%		Clay%		SOM%	
Adjusted R2	0.261		0.408		0.722		0.307	
	F	Sig	F	Sig	F	Sig	F	Sig
Horizon	9.2	*	4.3	*	1.2	N/S	2.4	N/S
Treatment	1.1	N/S	21.4	**	103.1	**	11.0	N/S
Treatment*Horizon	6.5	*	4.2	*	0.1	N/S	6.9	N/S

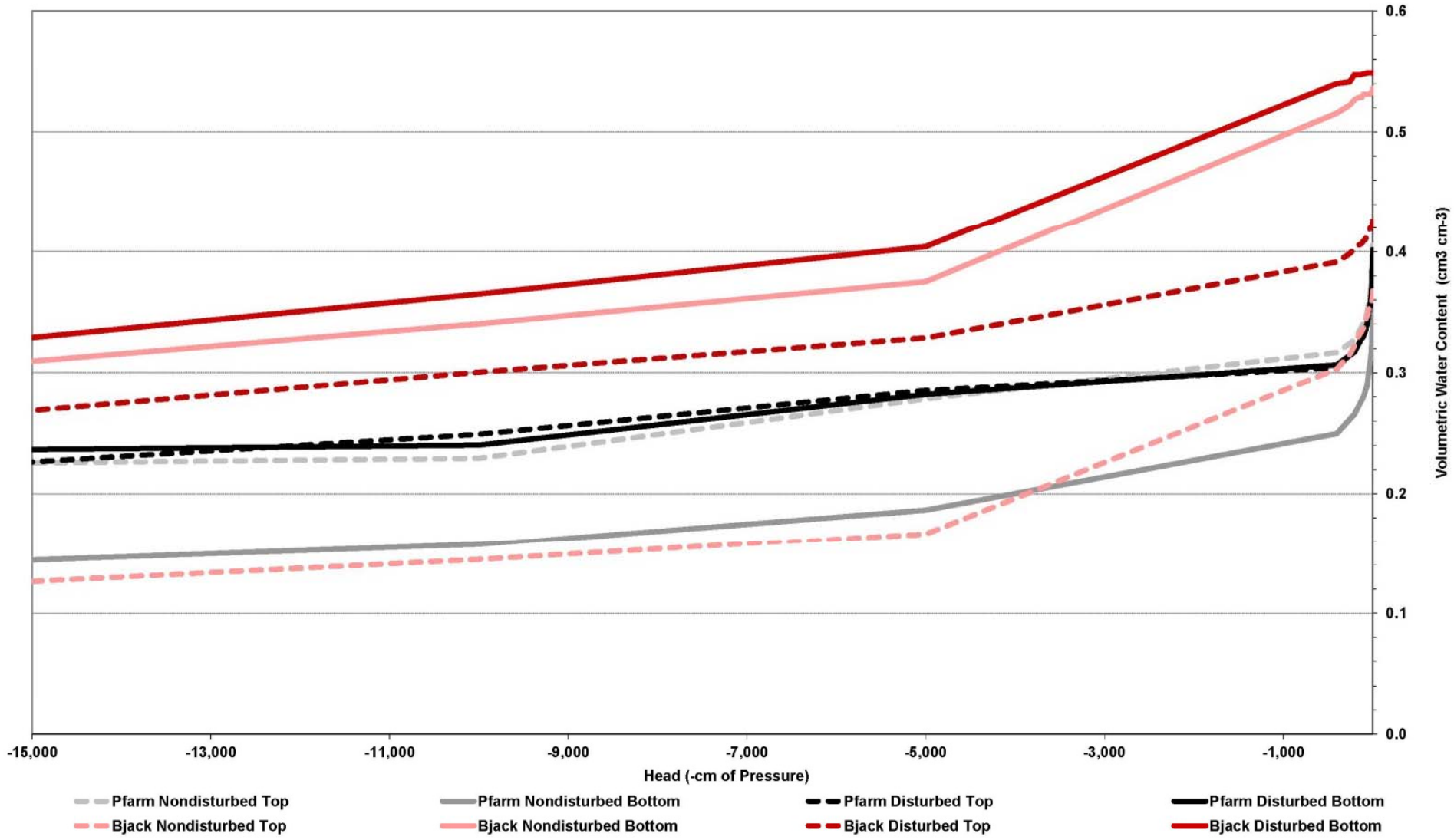
Sand %	D_b		TP%		$Ksat_V$ cm/hr		$Ksat_L$ cm/hr		AWC%	
Adjusted R2	0.078		0.304		0.009		0.334		0.004	
	F	Sig	F	Sig	F	Sig	F	Sig	F	Sig
Horizon	0.1	N/S	1.3	N/S	0.8	N/S	-	-	0.2	N/S
Treatment	3.7	N/S	9.0	*	1.0	N/S	10.5	**	36.2	**
Treatment*Horizon	50.8	N/S	1.0	N/S	1.0	N/S	-	-	0.0	**

* $P \leq 0.05$; ** $P \leq 0.005$

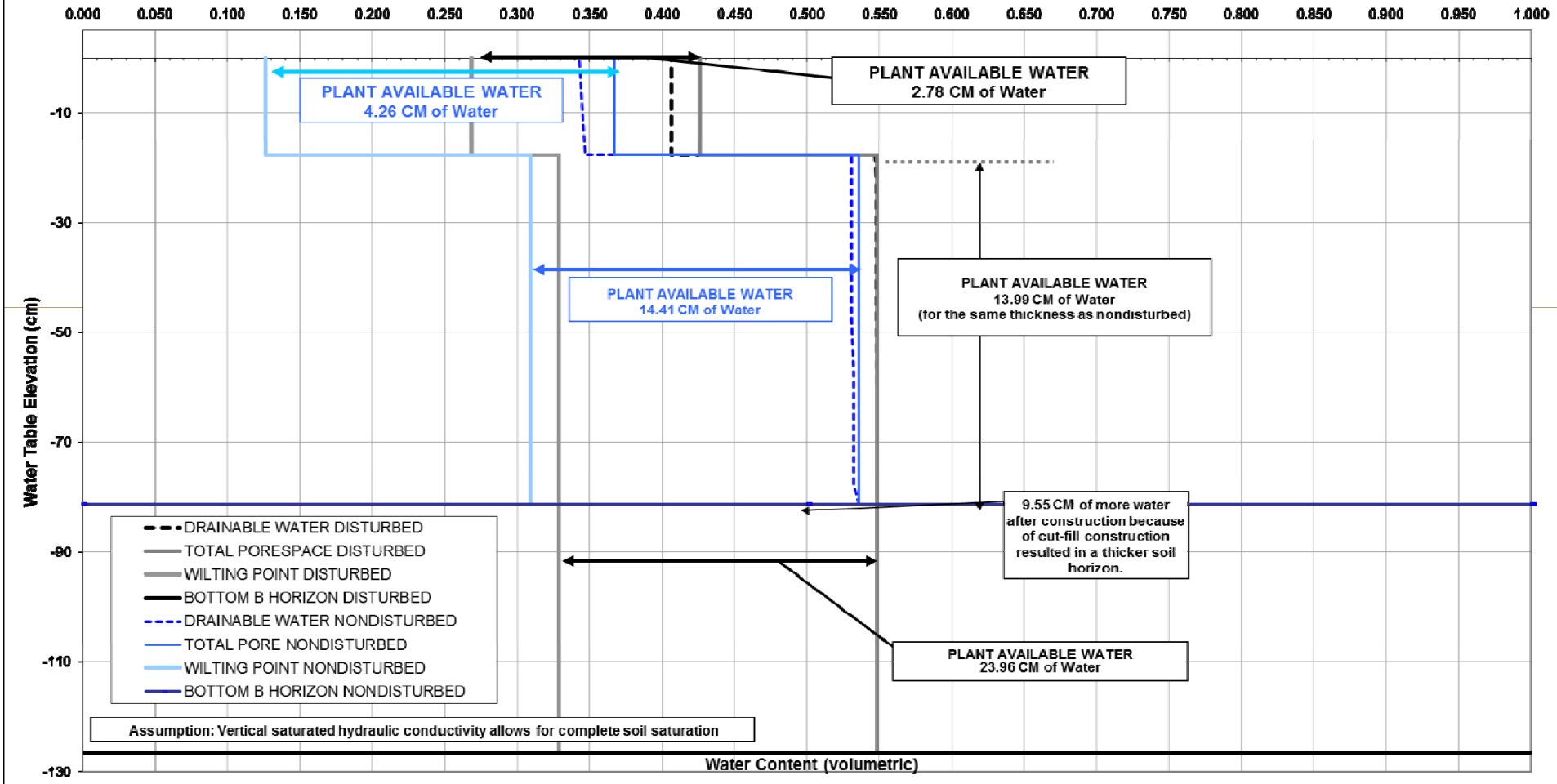
cm of Pressure:	0		-13.5		-63.5		-103.5		-203.5		-403.5		-1000		-5000		-10000		-15000	
Adjusted R2	0.191		0.139		0.158		0.179		0.180		0.216		0.807		0.873		0.742		0.755	
	F	Sig	F	Sig	F	Sig	F	Sig	F	Sig	F	Sig	F	Sig	F	Sig	F	Sig	F	Sig
Horizon	0.6	N/S	0.3	N/S	0.3	N/S	0.3	N/S	0.3	N/S	0.3	N/S	16.4	**	5.3	*	2.3	N/S	0.2	N/S
Treatment	6.6	*	5.4	*	5.9	*	6.6	*	6.6	*	7.4	*	62.2	**	123.8	**	54.4	**	57.2	**
Treat*Horizon	0.4	N/S	2.8	N/S	0.4	N/S	0.3	N/S	0.3	N/S	0.5	N/S	4.1	**	4.1	N/S	0.8	N/S	2.2	N/S

* $P \leq 0.05$; ** $P \leq 0.005$

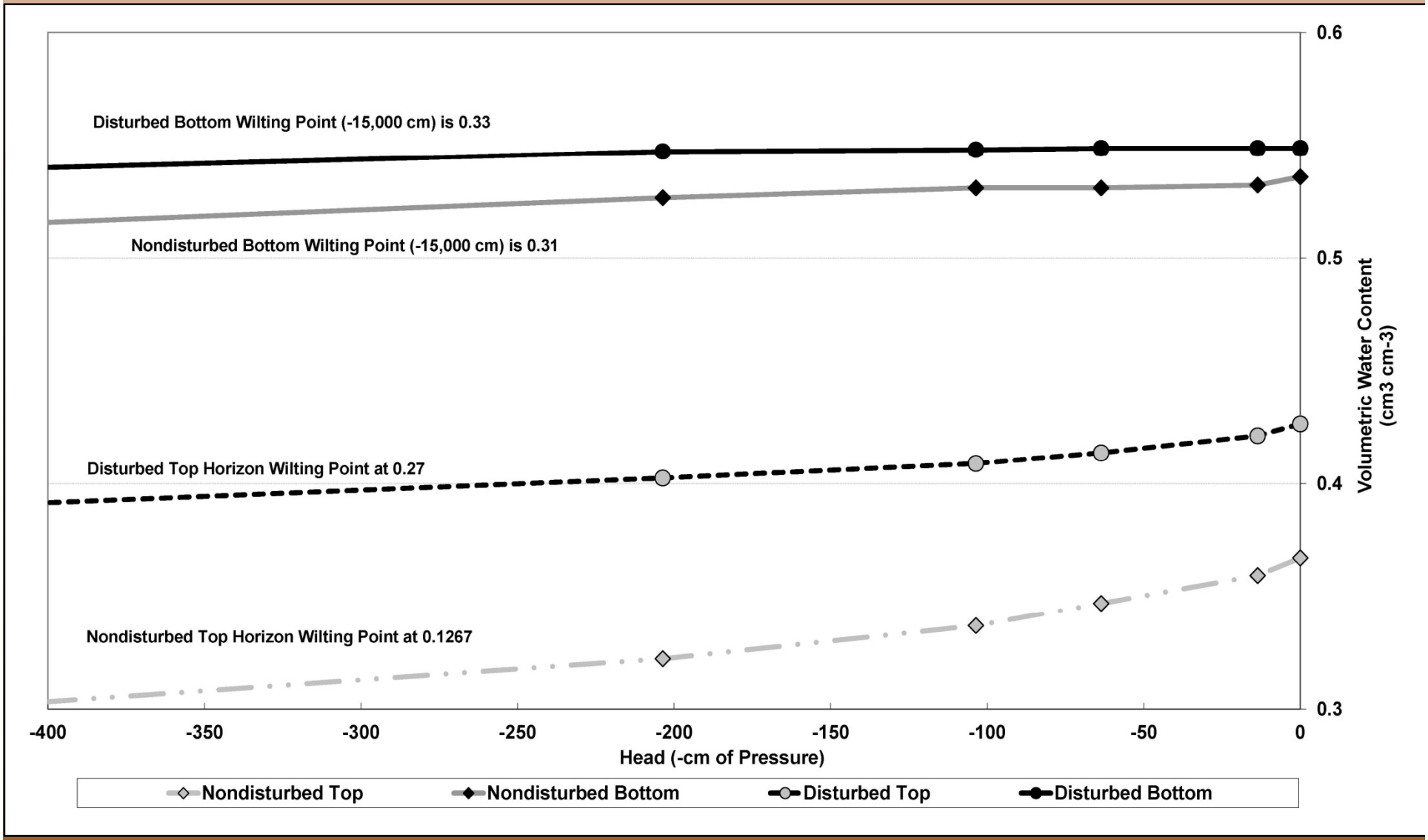
Blackjack and Peters Farm Soil Water Characteristic Curves



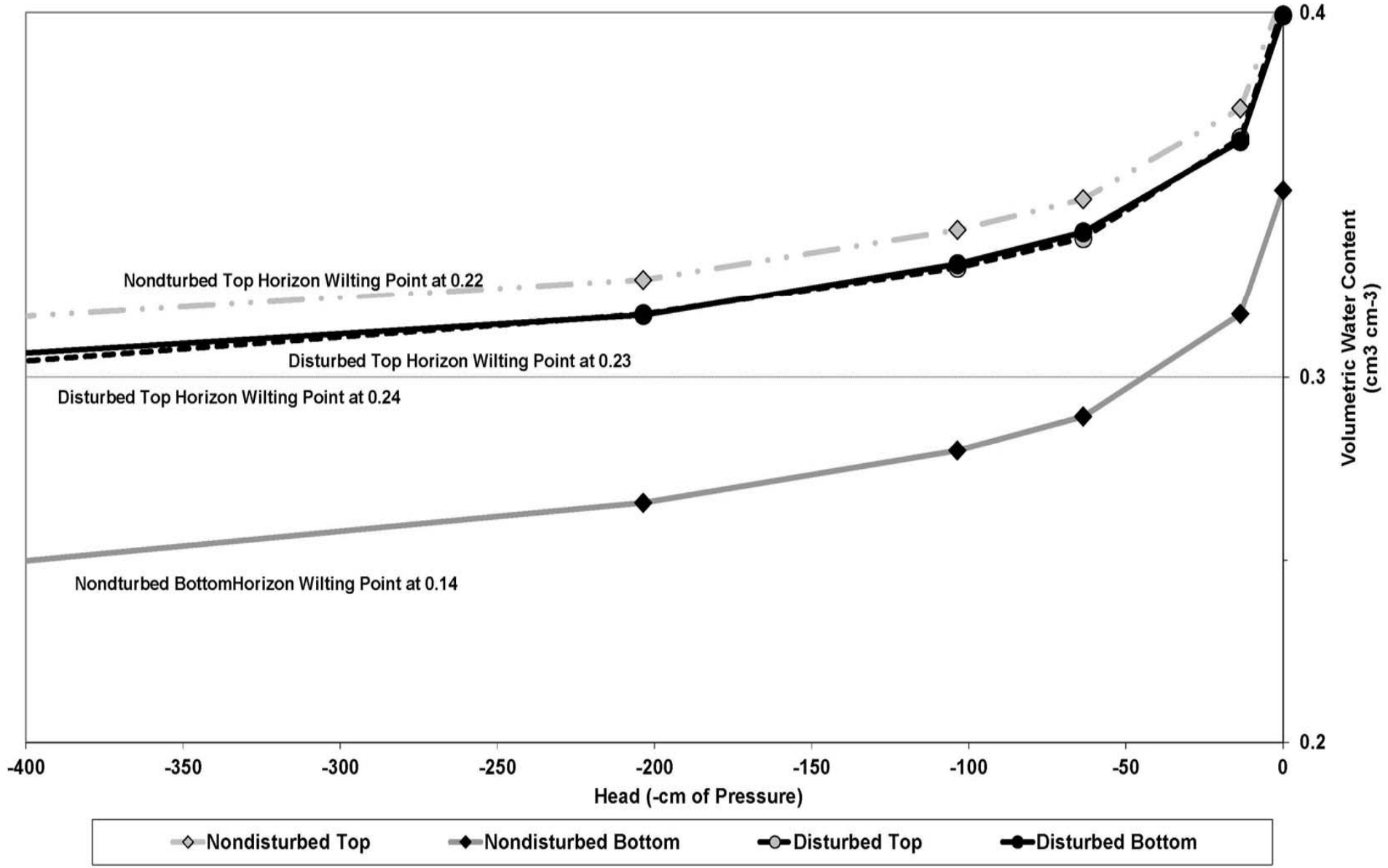
Soil Water Distributions When the Water Table is Lowered to the Bottom of the B Horizon of Both Study Locations at the Blackjack Study Area



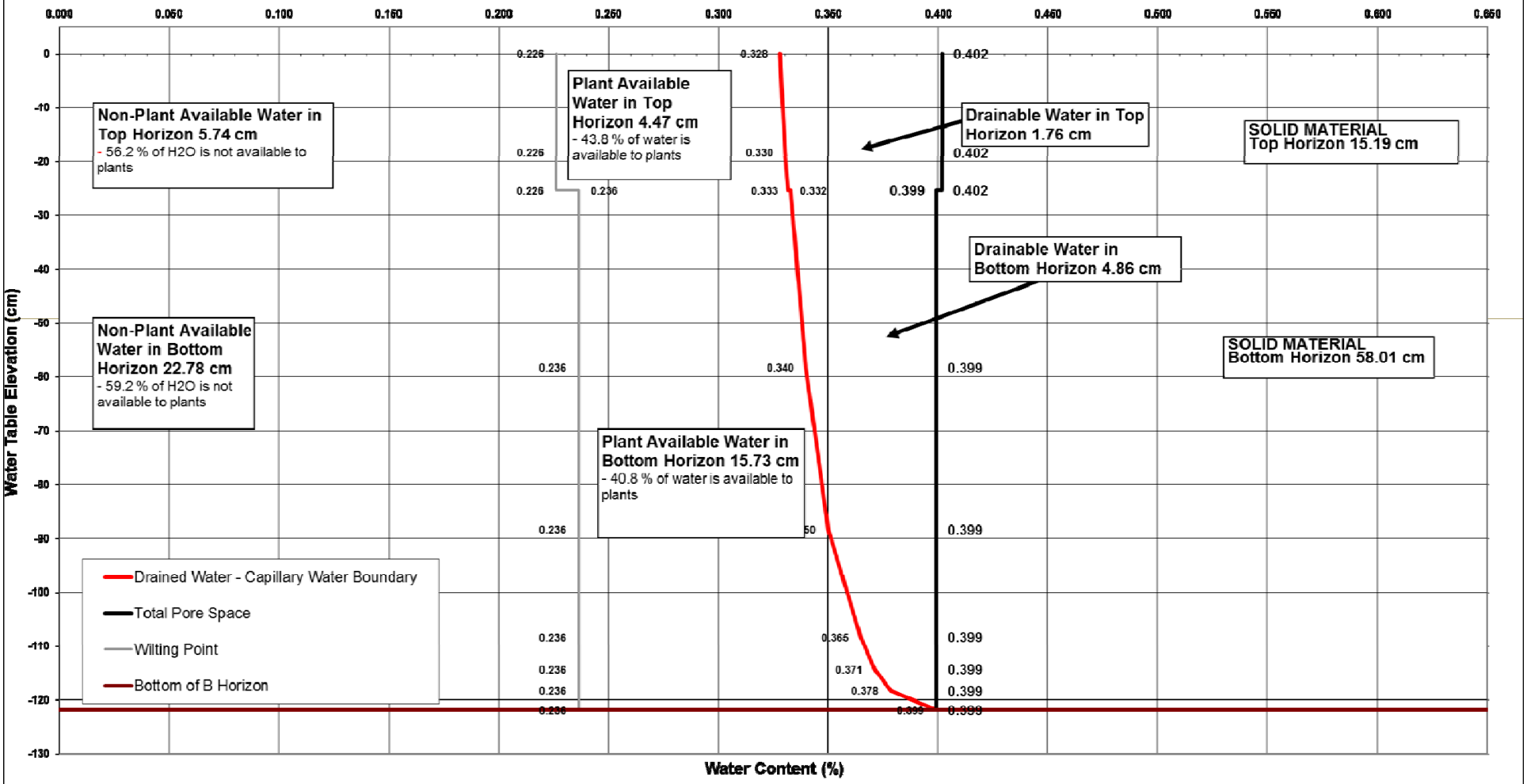
SWCC – Blackjack Study Area



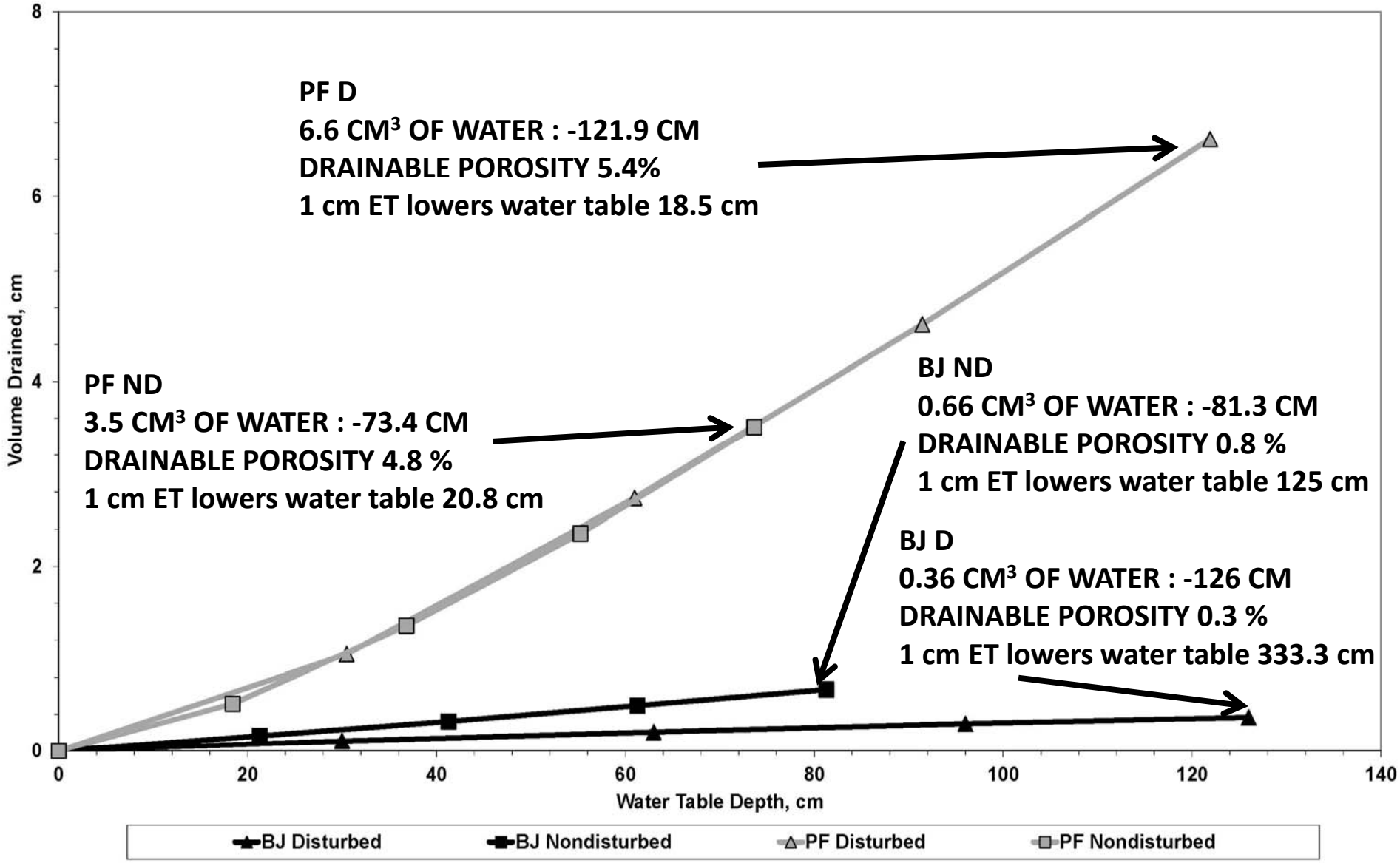
SWCC – Peters Farm Study Area



Soil Water Distribution of the Disturbed Soil Profile at the Peters Farm Study Location When the Water Table is Lowered to the Bottom of the B Horizon (121.92 cm below the surface)



Volume Drained versus Water Table Depths



Implications of Study - Soils

- Construction practices changed soil hydraulic properties at both study areas.
- Organic matter content did not help drainable water content.
- There is a point at which increased clay content has negative impact on plant available and drainable water. Particularly smectitic clay.
- PF contains a bulk density and an organic matter content outside the recommendations for constructed wetlands (Daniels and Whittecar, 1999). BJ contains a bulk density and an organic matter within acceptance of recommendations. But PF has more drainable water.
- A large portion of the total pore space in BJ disturbed area is not available for plant consumption.
- Spatial variability of alluvial settings makes it difficult to predict the subsurface extent of homogeneous soil units.

Acknowledgments

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Thank you!!


Questions?