Development of Performance Standards for Wetland Soil and Hydrologic Reconstruction

W. Lee Daniels

and many more from many places!

Crop & Soil Environmental Sciences

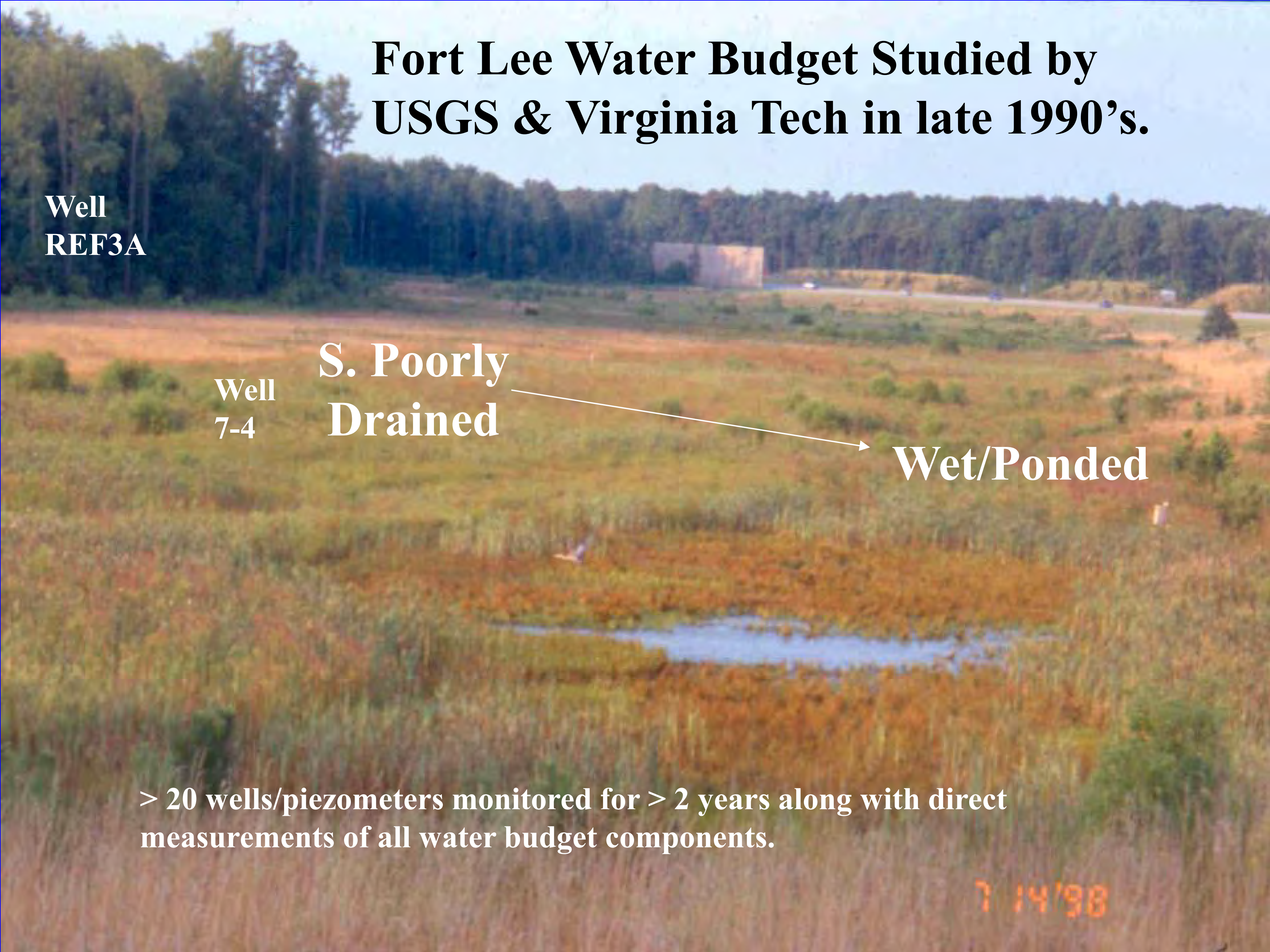
Virginia Tech
VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

http://www.landrehab.org

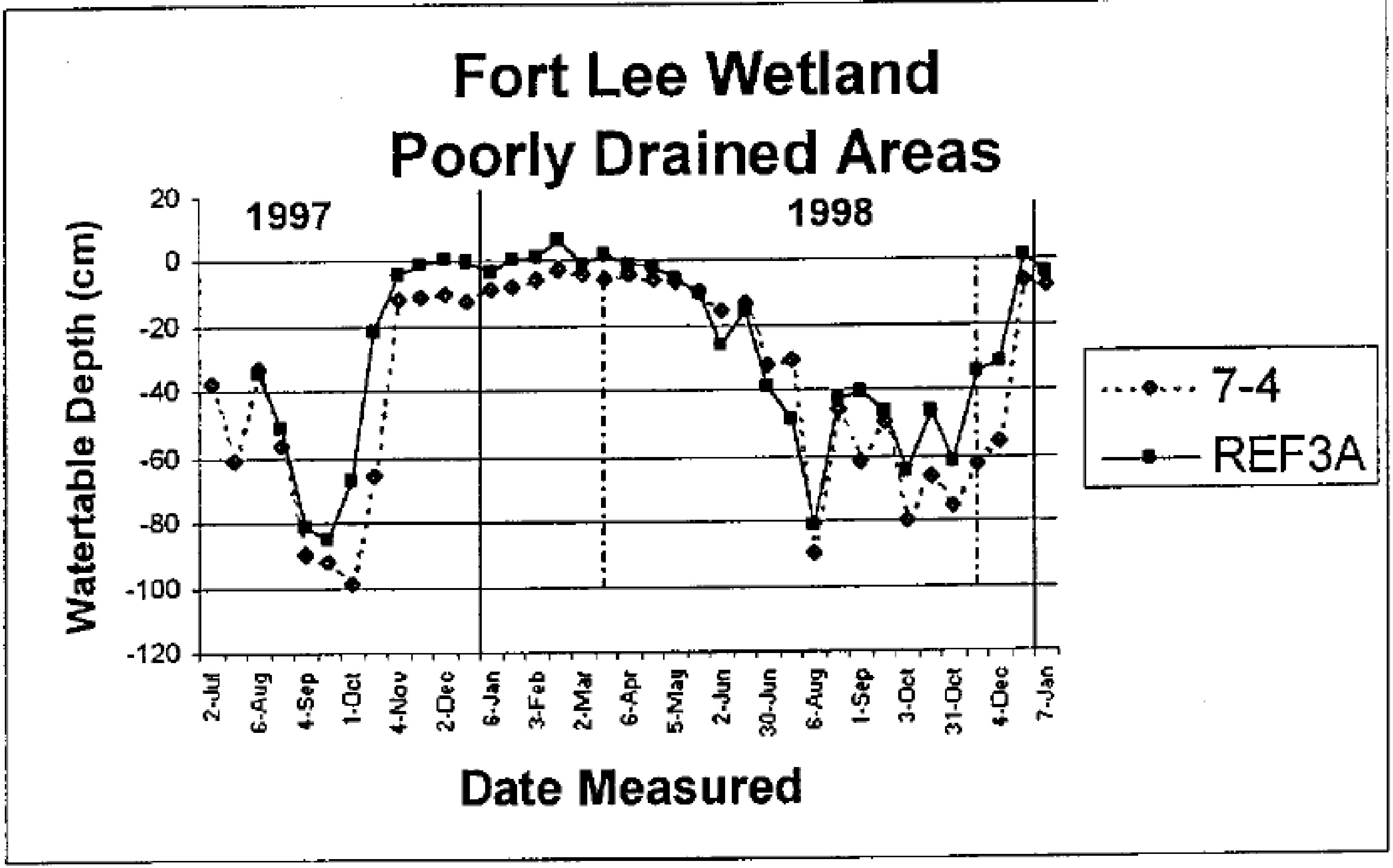
Objectives

- **Describe history of collaborative Virginia Tech, VDOT, and private sector research on created wetlands from the early 1990's to present.**
- **Focus on four primary areas:**
  1. ***Early comparisons of created vs. native (reference?) sites***
  2. ***Influence of OM additions on hydric soil development***
  3. ***Creation in sandy soils and micro-topography studies***
  4. ***A new "freeware" integrated water budget model - Wetbud***
- **Review the development of created wetland soil reconstruction guidance policy in place since 2005 in Virginia (Joint VDEQ and USCOE Norfolk District).**

Fort Lee Water Budget Studied by USGS & Virginia Tech in late 1990's.



> 20 wells/piezometers monitored for > 2 years along with direct measurements of all water budget components.



Hydroperiod of created soil vs native soil at Ft. Lee; the mitigation site soil was dominated by fac upland vegetation.

Compacted reconstructed soil in intermediate drainage (poorly d.) class at Fort Lee.

Most of these soils (~40% of site) supported fac. upland to upland obligate vegetation.

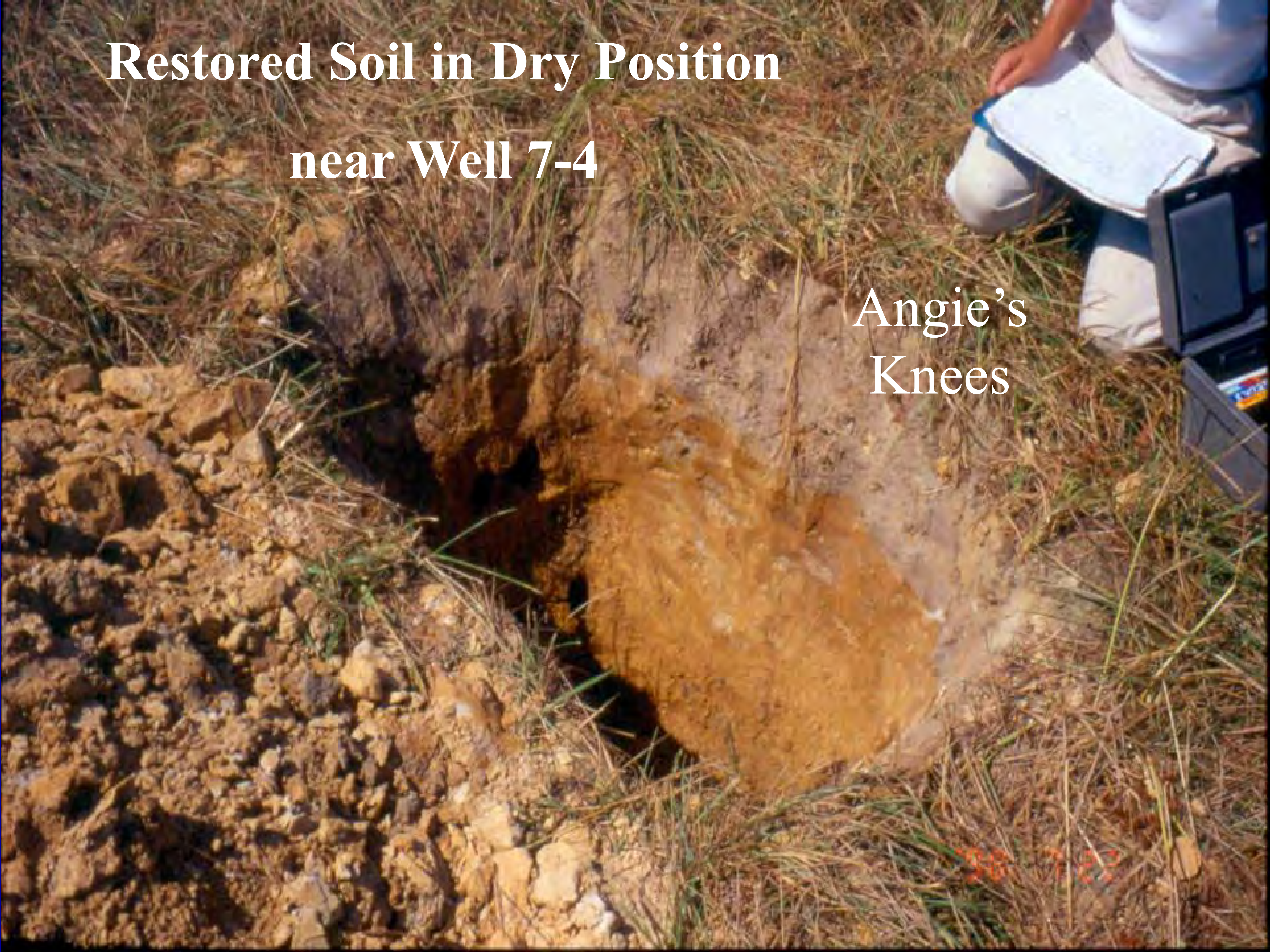
Differential Soil Properties at Fort Lee (Cummings, 1999)

0-15 cm	pH	% C	% N
Reference	4.76	2.89	0.18
Mitigation	5.31	0.82	0.07

Differential Soil Properties at Fort Lee (Cummings, 1999)

Bulk Density Mg/m^3	Surface (0-15 cm)	Subsurface (70 cm)
Reference	0.71	1.42
Mitigation	1.75	1.71

Similar findings also reported for 10+ VDOT sites statewide in journal articles and reports.


Restored Soil in Dry Position
near Well 7-4
Angie's
Knees

2

Quantifying Iron, Manganese, and Carbon Fluxes in Near-Surface Horizons of Palustrine Wetlands

M. H. Stolt

University of Rhode Island
Kingston, Rhode Island

M. H. Genthner, W. L. Daniels, V. A. Groover, and S. Nagle

Virginia Polytechnic Institute and State University
Blacksburg, Virginia

In: *Quantifying Soil Hydromorphology*, SSSA, 1998

Stolt's Buried Bag Study

Soil plus organic (~2.5% Acer rubrum leaves) amendments wrapped in nylon bag ready to go back into the ground.

Stolt's Buried Bag Study

- Old clod (+ C) removed after several years in the field, with the nylon bag carefully pulled away.
- Note: this drove several lab technicians into early retirement!

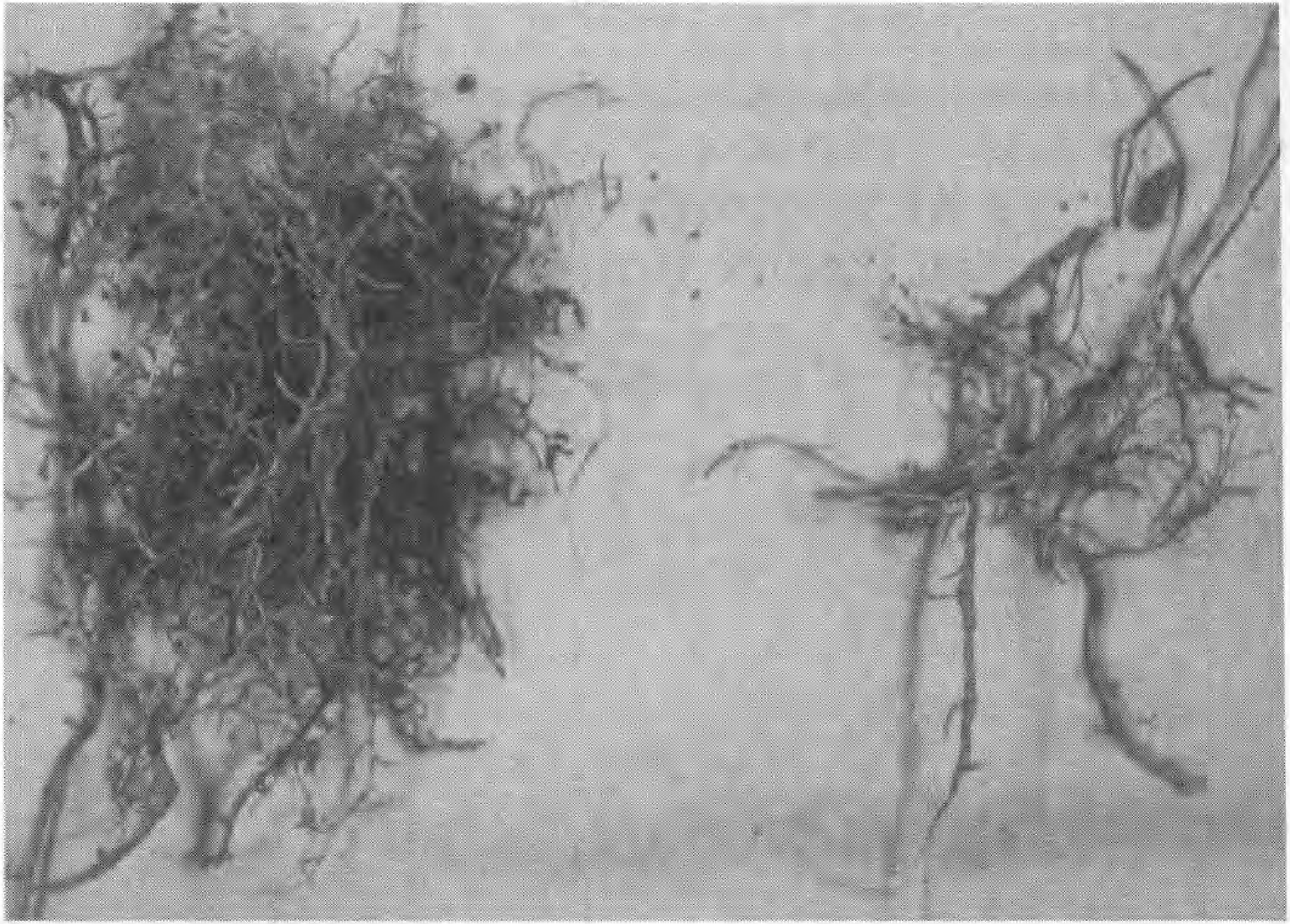


Fig. 2–5. Roots extracted from simulated peds amended with organic matter (*A*) and unamended (*B*) after 2 yr in a forested wetland (frame width is 5 cm).

Stolt et al. (1998) “Buried Bag Study”

- Peds amended with organic matter lost OM and DCB-extractable Fe at 0.5 to 1.0 g/kg/yr.
- Peds that were not amended with organic matter gained Fe at rates up to 2.0 g/kg/yr.
- Organic matter coatings, Fe-masses on ped exteriors, iron enriched pore linings, and depletions in ped interiors formed in 2 years in/around OM amended bags.

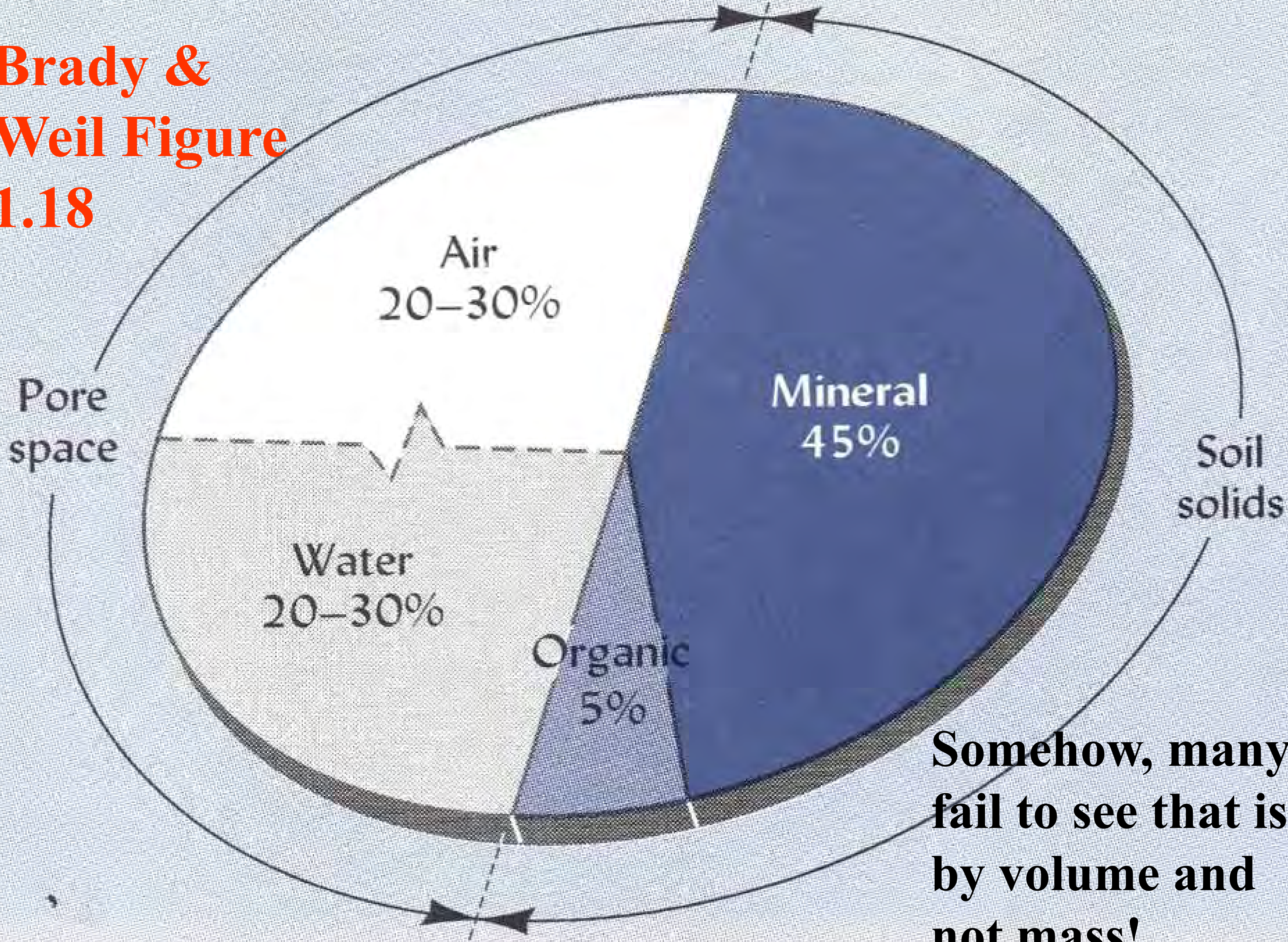
How Much and Which Organic Amendment?

Got me, and I'm supposed to know these things! **However, natural hydric soils in SE Virginia tend to contain anywhere from 3% to 10% humified OM in the upper 10 cm or so, and may contain as much as 2.5% to depths of 30 cm or more.**

Assuming 5% OM in the upper 15 cm, you need at least 50 tons per acre *<u>following turnover</u>* to mimic native soil conditions. Also, many field experiments in uplands indicate amendment rates of 50 tons per acre to be optimal on mining and highway sites.

Many advocate 5% soil OM as a target; why?

Brady & Weil Figure 1.18



Somehow, many fail to see that is by volume and not mass!

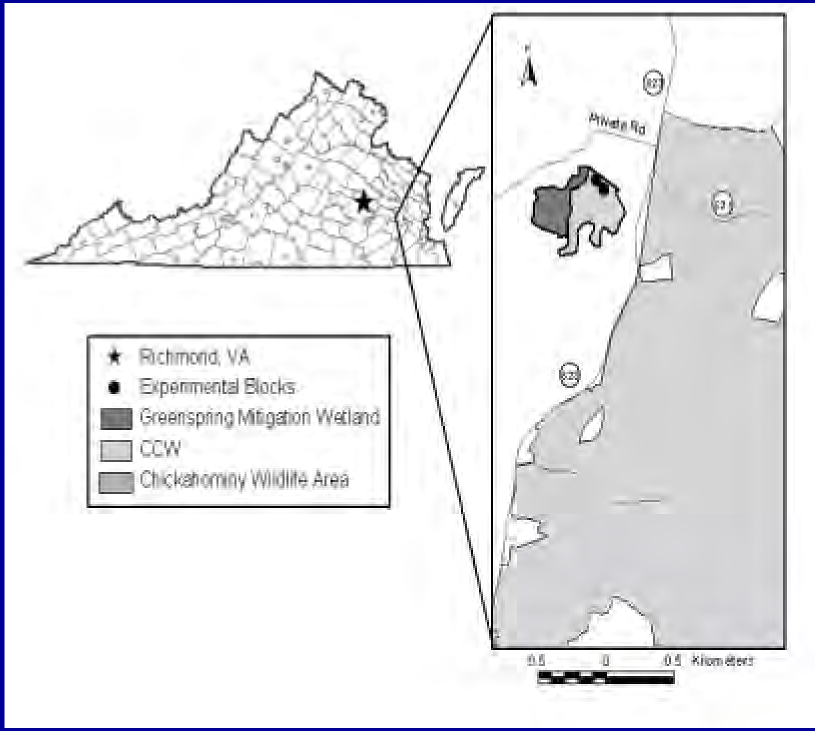
How Much and Which Organic Amendment?

- Assuming normal turnover rates and OM retention, you should expect no more than 30% of the added organic matter loaded to be retained as soil OM. So, the total amount you would have to add to get a total of 5% OM (50 tons per acre 6”) retained in soil is quite large (150 or more dry tons per acre)

- So, what we really need to sort out here is how much initial organic amendment we really need to induce sufficient redox conditions, etc., that will then allow OM to accumulate via natural additions.

Charles City Mitigation Wetland

- **Located in Charles City County, VA; Coastal Plain province**
- **VDOT mitigation wetland created in 1997**
- **21 ha with 18 ha compensating for bottomland hardwood wetland disturbance**



Designed to determine optimal OM loading rate. Agencies at the time specified 5%, which required very high OM loadings.

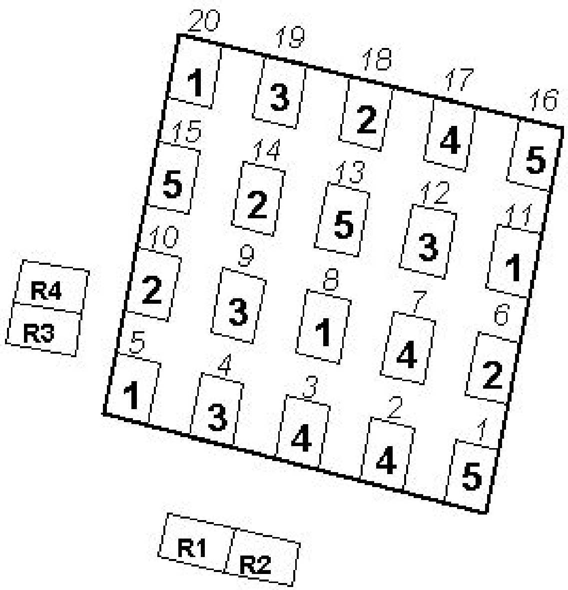

Site for Charles City Wetland (CCW) OM Loading rate experiment, first built in 1997 & 1998; modified by VDOT several times thereafter.
'99 1 28

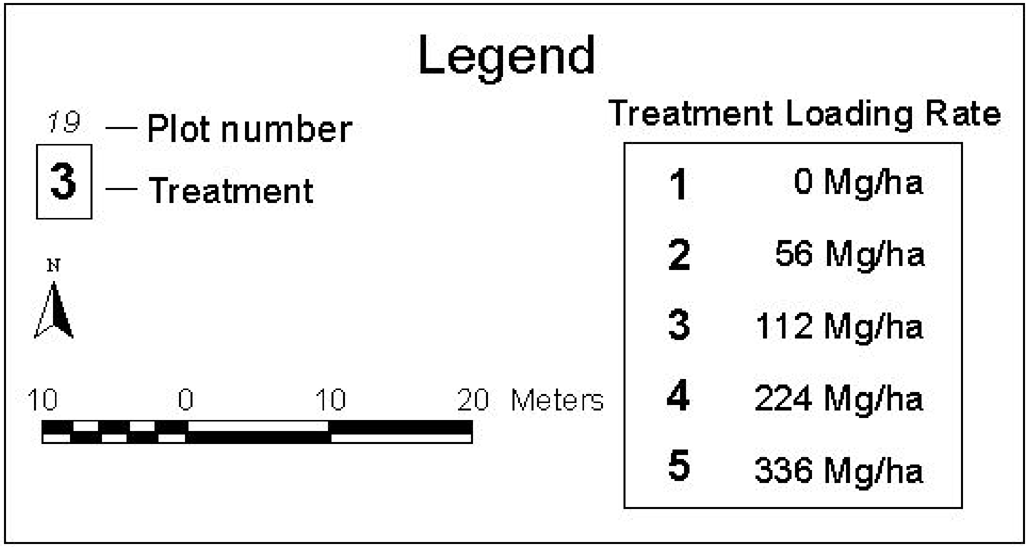
Surface soil at CCW in 2003.

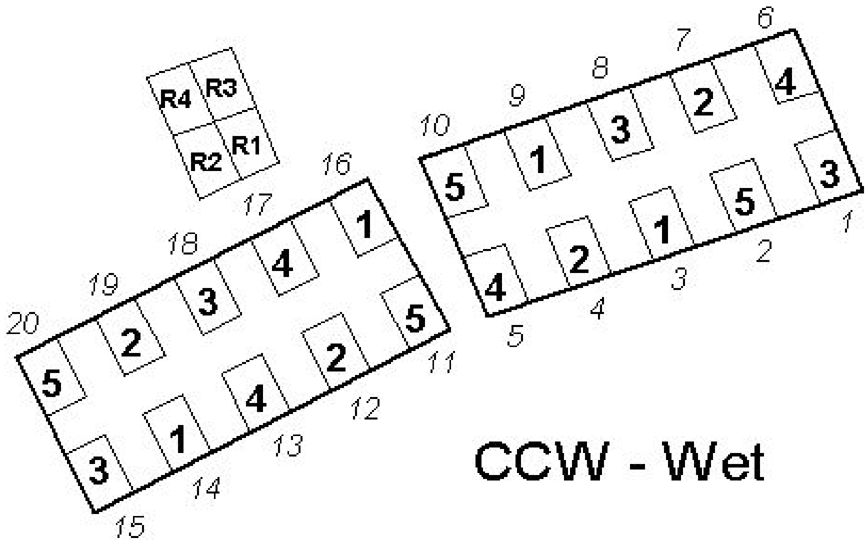
Note massive structure in surface breaking to firm plates at about 20 cm.

This is done intentionally at many sites to produce epiaquic conditions for the permit water budget.

CCW - Dry







CCW - Wet

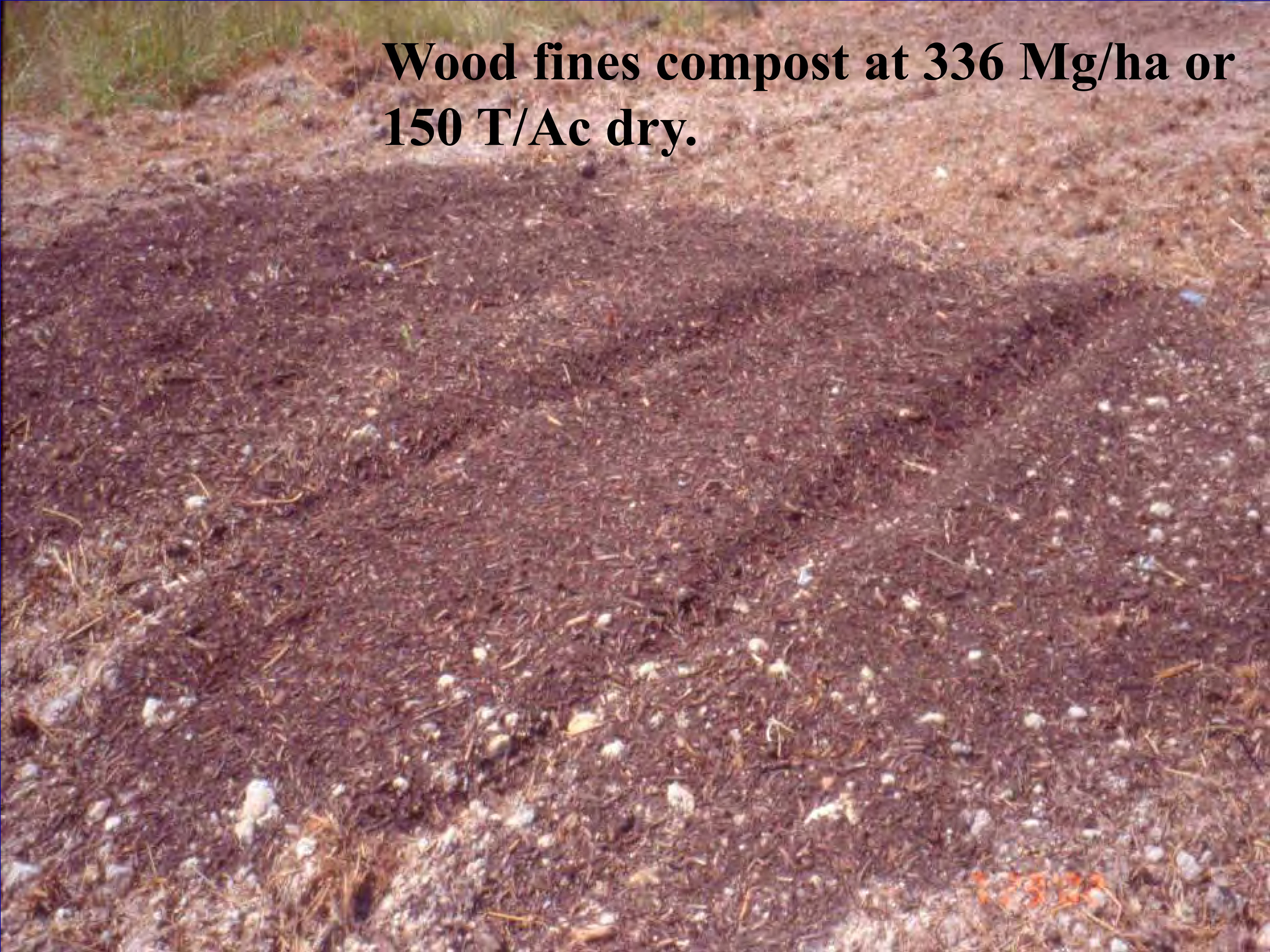
Loading rates in "English" were 25, 50, 100 and 150 dry tons per acre.

Methods: Installation of Experiments

- Vegetation on experiments mowed and soil deep ripped 15 cm with a root rake

- Organic matter (high quality wood waste compost) added to plots and incorporated into upper 15 cm soil in July 2002 with a roto-tiller followed by a forestry/bog disk. High rates were calculated to produce 5% OM following decomposition.


Wood fines compost at 56 Mg/ha
Or 25 T/Ac


Wood fines compost at 336 Mg/ha or
150 T/Ac dry.

Relict soil redox features at Charles City site. How do we determine if they have anything to do with current soil redox status?

Cara Bergschneider, 2005 MS Thesis

Described soil morphology, soil physical & chemical properties and vegetation response in 2003-2004; two years after treatment application.

Results: Pedogenesis

0 Mg/ha rate

56 Mg/ha rate

Results: Pedogenesis

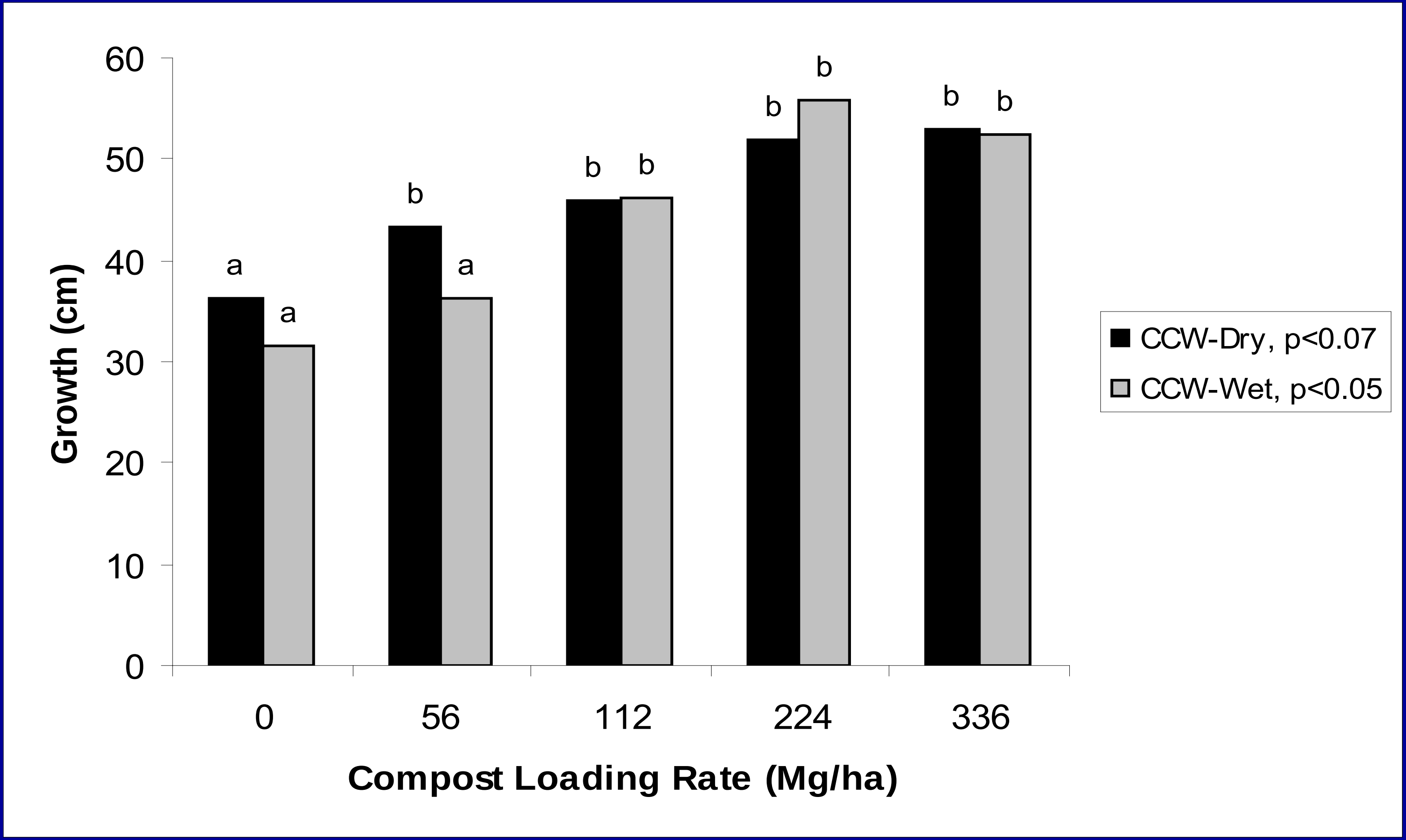
112 Mg/ha rate

224 Mg/ha rate

336 Mg/ha rate

Results: Tree growth

Average (n=4) *Betula nigra* (river birch) height growth as affected by compost loading rate. Significant differences by Wilcoxon rank sums. *Quercus palustris* did not respond.



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VEGETATION DYNAMICS IN RESPONSE TO ORGANIC MATTER LOADING RATES IN A CREATED FRESHWATER WETLAND IN SOUTHEASTERN VIRGINIA

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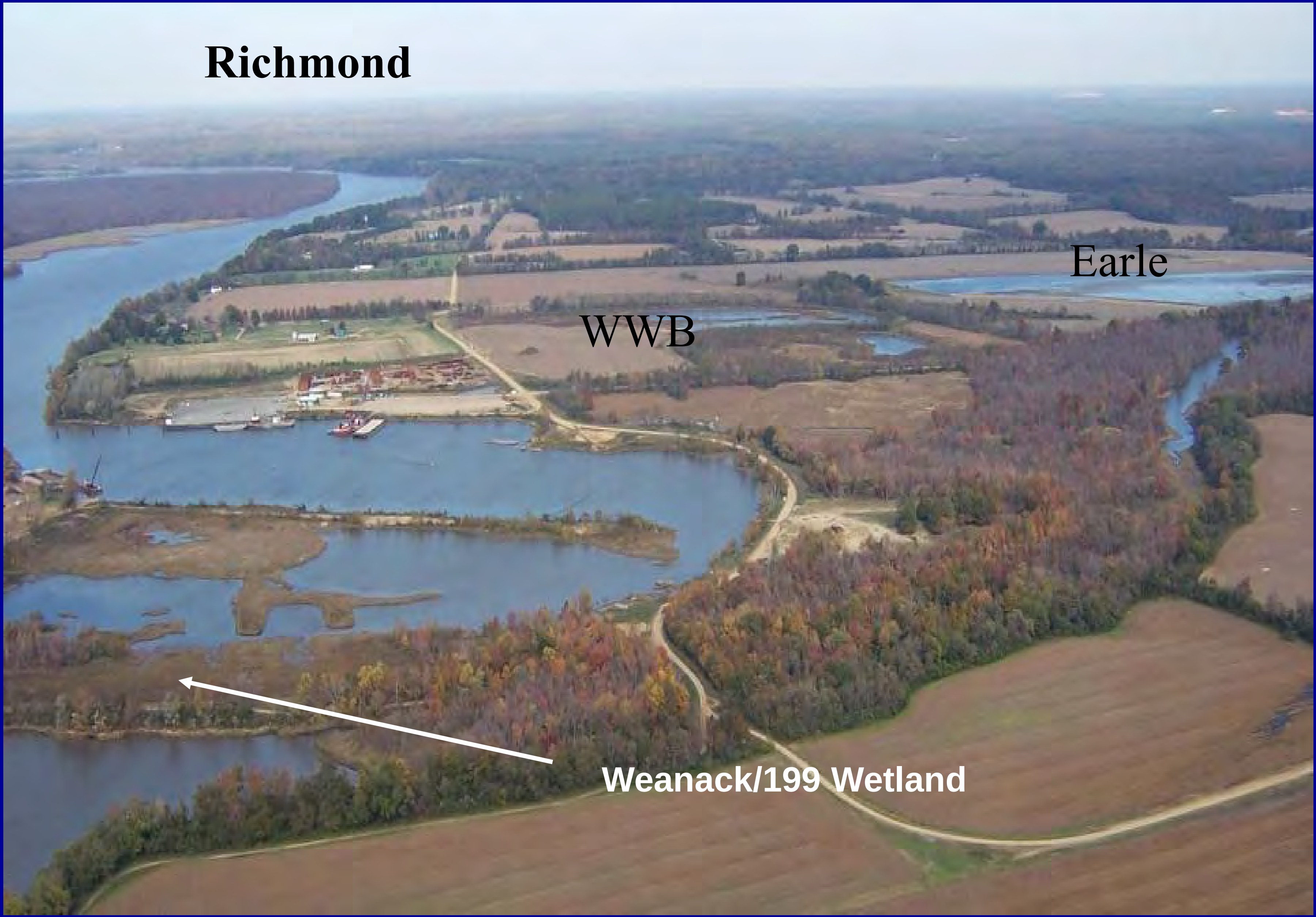
Blacksburg, Virginia, USA 24061

Bailey found that OM loadings had little effect on herbaceous vegetation, but did result in increased tree growth. Optimal addition was 112 Mg/ha (50 T/Ac).

Build it and they will **come**! Graduate students from VT (Bergschneider), Duke (Bruland and Winton working with Richardson) have sampled and published on these plots over time. All indicate that the intermediate OM rates are optimal for a range of soil and GH gas issues.

Emily Ott (VT) is currently working with John Galbraith now to determine long term changes in soil morphology, C storage, etc.

Long term effect of original compost loading (112 Mg/ha) at CCW dry experiment – Summer 2015.



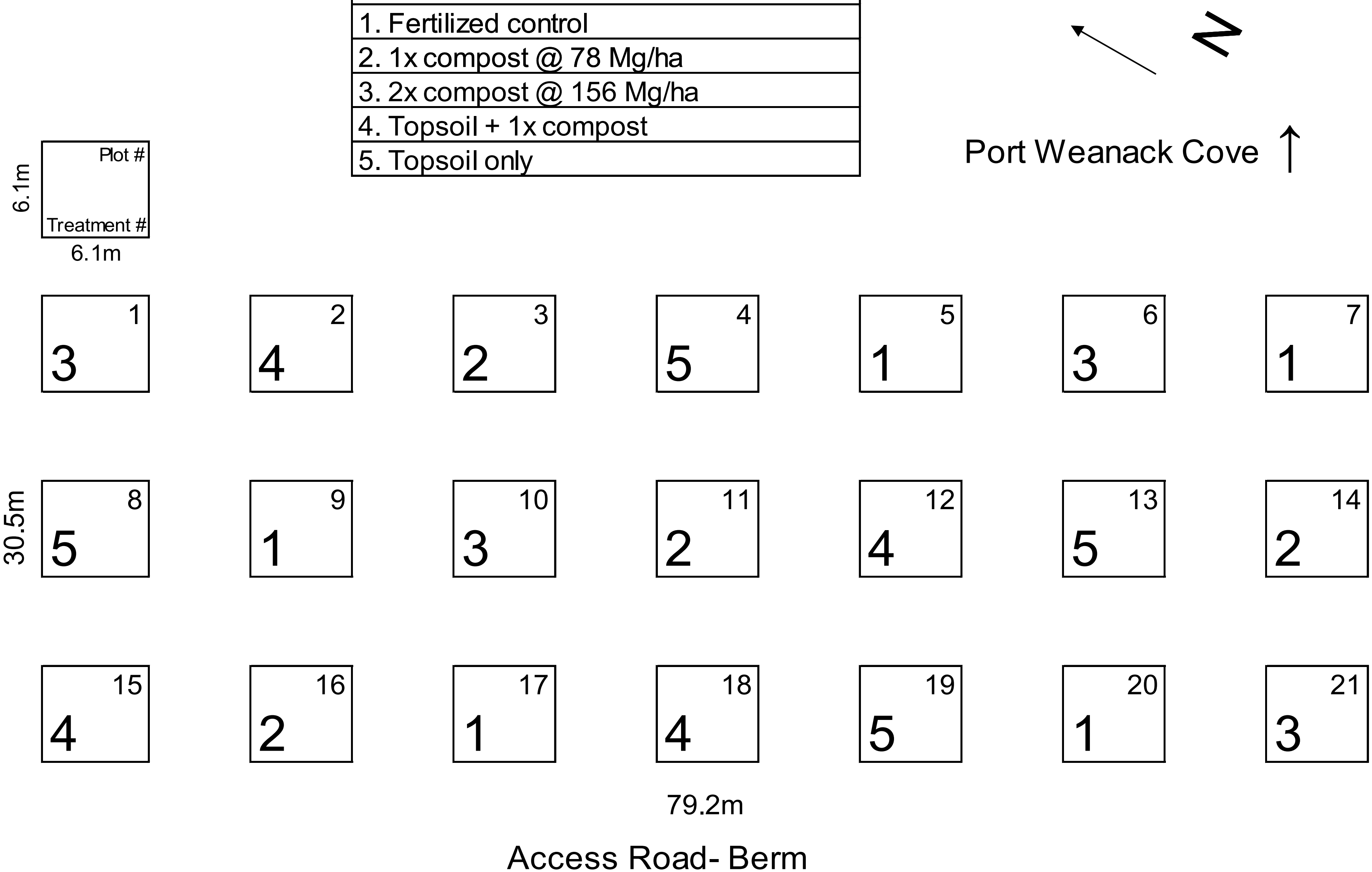
Aerial view of Weanack/VDOT 199 Wetland

Experimental site before any excavation; built by USCOE in 1960s and 1970s from dredging James River channels. Pre-existing mudflats and emergent wetlands were buried by ~7 m of medium sands.

Experimental area graded and flagged. This a created *tidal freshwater* forested wetland. Unique to our region.

Weanack/Shirley Wetland Experiment Plot

Treatments
1. Fertilized control
2. 1x compost @ 78 Mg/ha
3. 2x compost @ 156 Mg/ha
4. Topsoil + 1x compost
5. Topsoil only



A Powerful Quote

"In general, mitigation sites contained more sand and less clay than reference sites at 20 cm ……Whatever their origin, these textural differences may have important implications in the success of wetland creation projects as coarser textures are characteristically loose, well aerated and drained (Brady, 1984)". ***Bishel-Machung et al., 1996. Soil Properties of Reference Wetlands and Wetland Creation Projects in Pennsylvania. Wetlands 16(4): 532-541.***

Unfortunately, this was interpreted by many state and federal regulators in our region to mean that you could not build created wetlands in coarse textured substrates. Many sites were eliminated or forced to bring in finer soil covers. This was despite the fact that we had over 75,000 ha of coarse-loamy hydric soils in Virginia!

Compost was added to simulated pit floors and mounds working at low tide.

Experimental area after hummock installation and application of topsoil. Picture shot 3 hours after adjacent high tide. The site does flood on lunar high tides and in storms, occasionally to > +1.5 m.


20. 5. 2004


Mike Nester working at
Weanack wetland
03/08/2007

Distinct redox concentrations and depletions (F3; depleted matrix) formed in replaced upland topsoil within three years. Also note distinct band of concentrations at topsoil/sand contact.

Photo from 2009 of high compost addition treatment vs. original soil from berm.

Image of control plot soil (sand; fertilizer only taken 11/8/15. Note significant accumulation of OM in surface and low chroma below.

Detailed study by Emily Ott (PhD student) & John Galbraith is ongoing.

Bald cypress in pit (left) vs. mound (right). Note other woody stems invading.

Contents lists available at ScienceDirect

Ecological Engineering

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Microtopographic effects on growth of young bald cypress (*Taxodium distichum* L.) in a created freshwater forested wetland in southeastern Virginia

CrossMark

Marcin Pietrzykowski[a,*], W. Lee Daniels[b], Sara C. Koropchak[b]

[a] *Department of Forest Ecology & Reclamation, Institute of Ecology & Silviculture, University of Agriculture in Krakow, Al. 29 Listopada 46, 31-425 Krakow, Poland*

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Pietrzykowski et al. found no effects of original soil treatments on any tree growth parameter, but trees growing in pits were taller, larger and had more butt swell. Trees in pits also had more competition from other invaders like *Salix nigra* and *Acer rubrum.*

Recommendations for Reconstructing Hydric Soils (*assuming* hydrology is correct!)

- Regrade the subsoil layer of the site, making all efforts to minimize compaction and limit rutting and smearing.

- Rip and/or chisel plow the subsoil layer to attain a non-limiting soil bulk density (e.g. 1.35 for a clayey subsoil and 1.75 for a sand).

Recommendations for Reconstructing Hydric Soils

- Whenever possible, salvage and direct haul natural hydric or other native topsoil layers to form the new soil's A horizon.

- Supplement non-hydric soil materials with sufficient suitable organic amendments at 35 to 50 dry tons per acre (~75 to 100 Mg/ha) and thoroughly incorporate the materials to 15 cm.

How Much and Which Organic Amendment?

- In general, the more similar an organic amendment is to natural leaf fall, etc., the better it will serve as a wetland soil amendment. I favor yard/wood waste composts.
- High nutrient (biosolids), or salty (some mill sludges), or partially stabilized organic amendments should probably be avoided.
- However, we do not have a good comparative study on this question to rely upon.

Recommendations for reconstructing Hydric Soils

- Disk and/or rip the replaced hydric soil or the manufactured soil zone to remediate any grading associated compaction.
- Wherever possible/feasible/economic, rebuild hummocks, pits and mounds, etc., to recreate micro-topographic variability.
- Apply any available leaves, wood chips, or other debris as a surface mulch.

Avoid sulfidic materials at all costs! Mattaponi Wetland; bare ground in rear is pH 3.1 as is the wetland floor when it dries down in the summer. Around 25% of VDOT Coastal Plain sites hit sulfidic materials

Soil bulk density, organic matter content and overall soil reconstruction procedures are specified in the following policy:

COE/DEQ, Norfolk District Corps and Virginia Department of Environmental Quality Recommendations for Wetland Compensatory Mitigation Including Site Design, Permit Conditions, Performance and Monitoring Criteria - July, 2004

http://www.nao.usace.army.mil/Portals/31/docs/regulatory/guidance/Annotated_Corps-DEQ_Mit_7-04.pdf

Created Wetland Water Budgeting

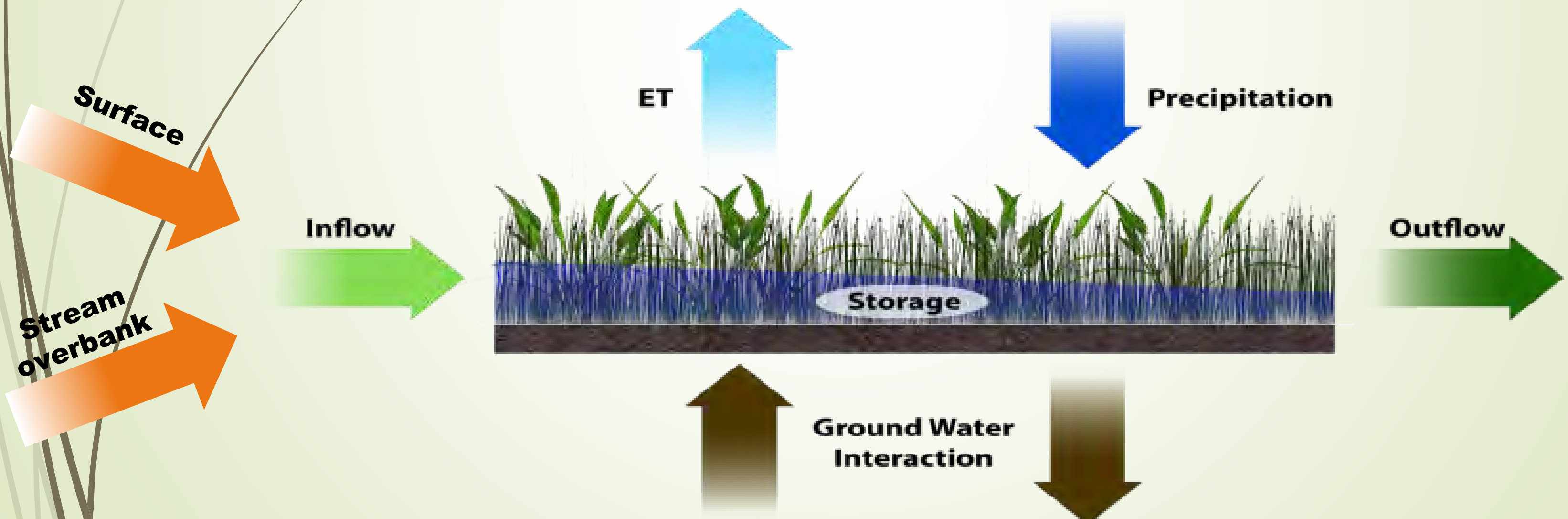
- **Wide variation in water budgeting approaches among agencies and consultants.**

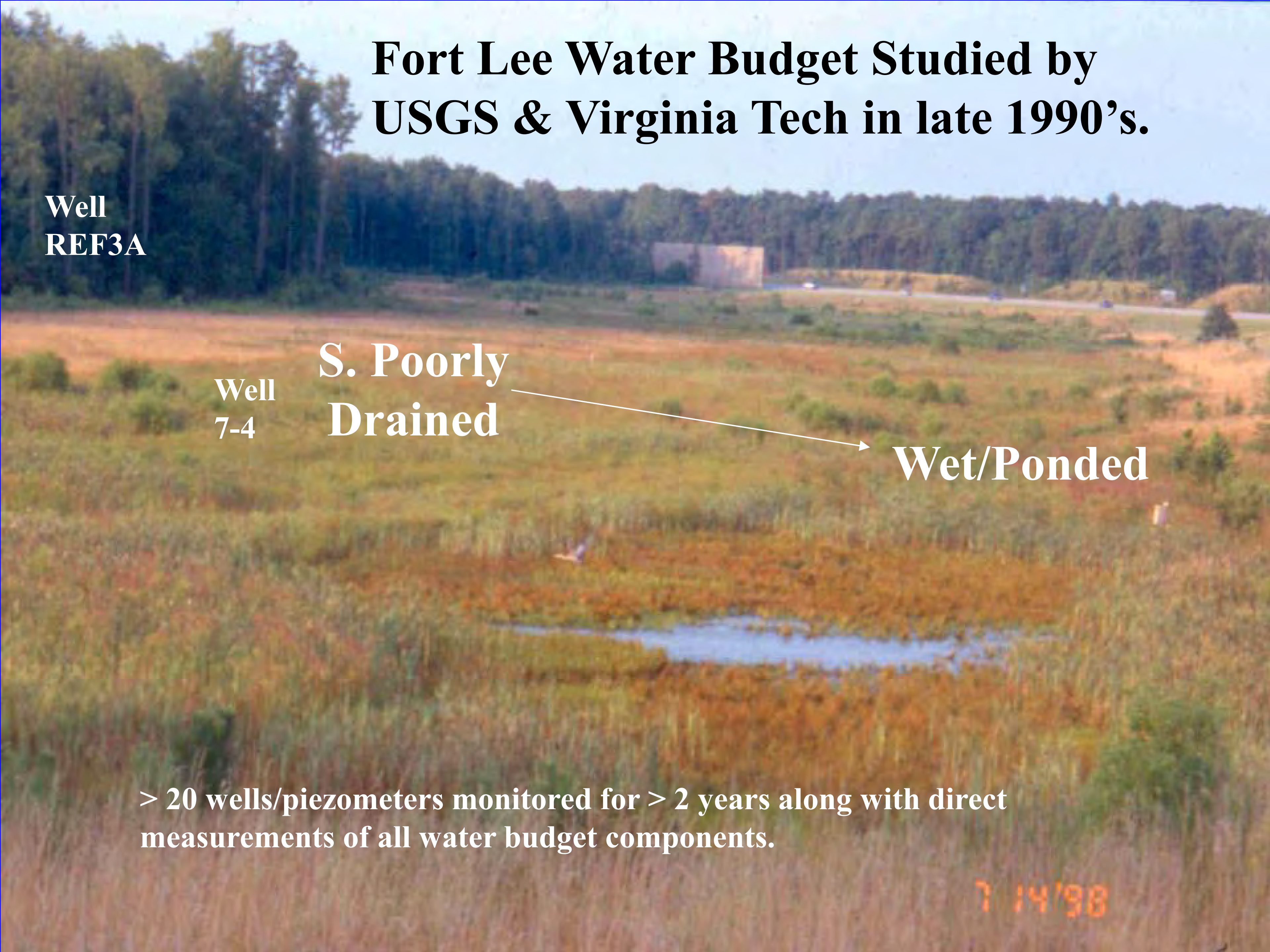
- **Many agencies follow and/or recommend variations of the "Pierce Approach" whereby ground water flux is presumed minimal, ET is estimated via Thornthwaite, runoff additions are estimated via SCS/NRCS Runoff Curve Number Method, water is presumed to be detained over the site via a berm, and water level is controlled via an outlet, etc. *Note: Gary Pierce was one or our original collaborators on Wetbud.***

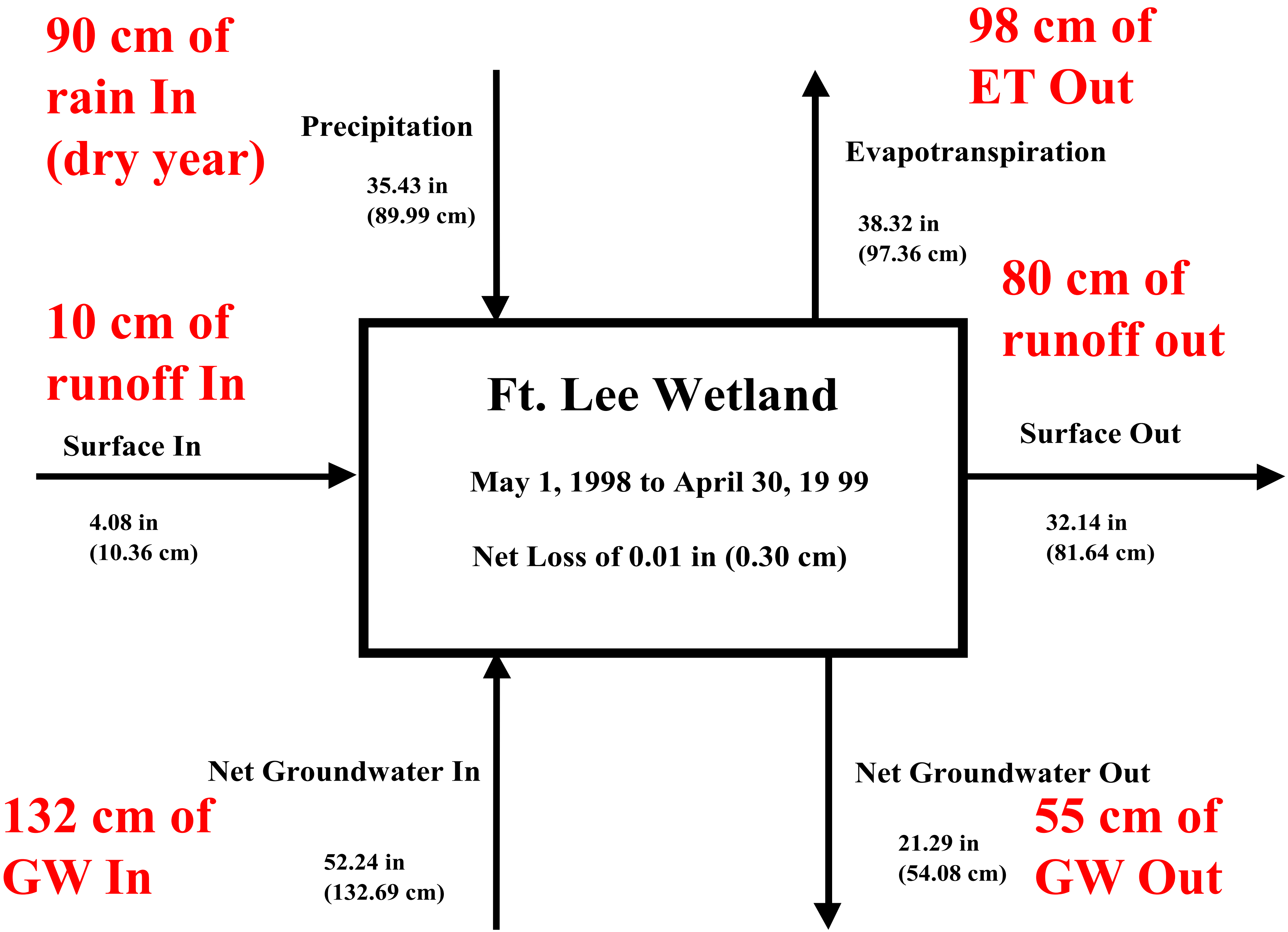
- **Virginia Tech, ODU and U. of Ky have collaborated with Wetland Studies and Solutions Inc. to develop a new water budget software program called Wetbud.**

Water Budget Model Issues

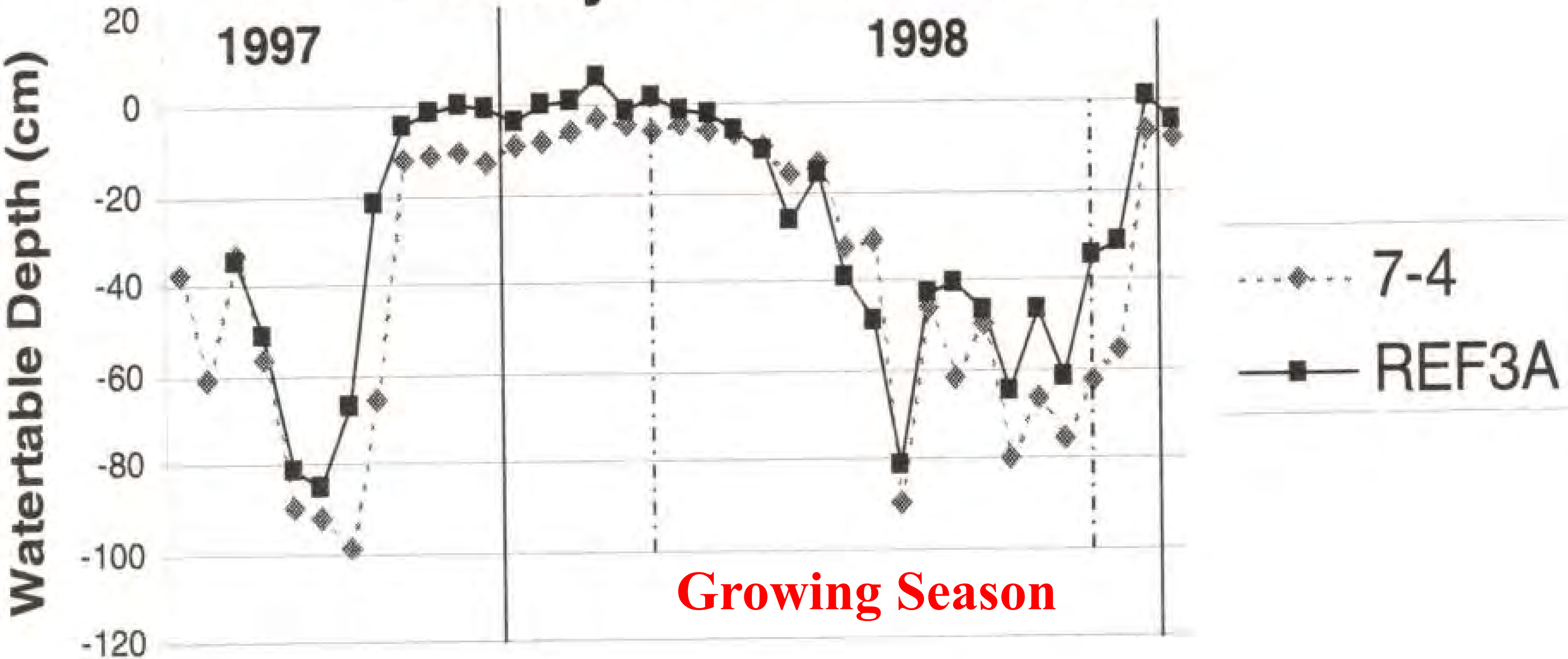
- “Bath Tub” vs. Sloped Systems
- Vegetative Flow Resistance
- Groundwater Inputs vs. data?
- Overbank Flow Contribution
- Which Precipitation Data?
- Variations in ET Estimators
- Complex topography




Fort Lee Water Budget Studied by
USGS & Virginia Tech in late 1990's.
Well
REF3A
Well
7-4
S. Poorly
Drained
Wet/Ponded
> 20 wells/piezometers monitored for > 2 years along with direct
measurements of all water budget components.
7 14'98


90 cm of rain In (dry year)
Precipitation
35.43 in (89.99 cm)
98 cm of ET Out
Evapotranspiration
38.32 in (97.36 cm)
80 cm of runoff out
10 cm of runoff In
Surface In
4.08 in (10.36 cm)
Ft. Lee Wetland
May 1, 1998 to April 30, 19 99
Net Loss of 0.01 in (0.30 cm)
Surface Out
32.14 in (81.64 cm)
Net Groundwater In
132 cm of GW In
52.24 in (132.69 cm)
Net Groundwater Out
21.29 in (54.08 cm)
55 cm of GW Out

Fort Lee Wetland
Poorly Drained Areas



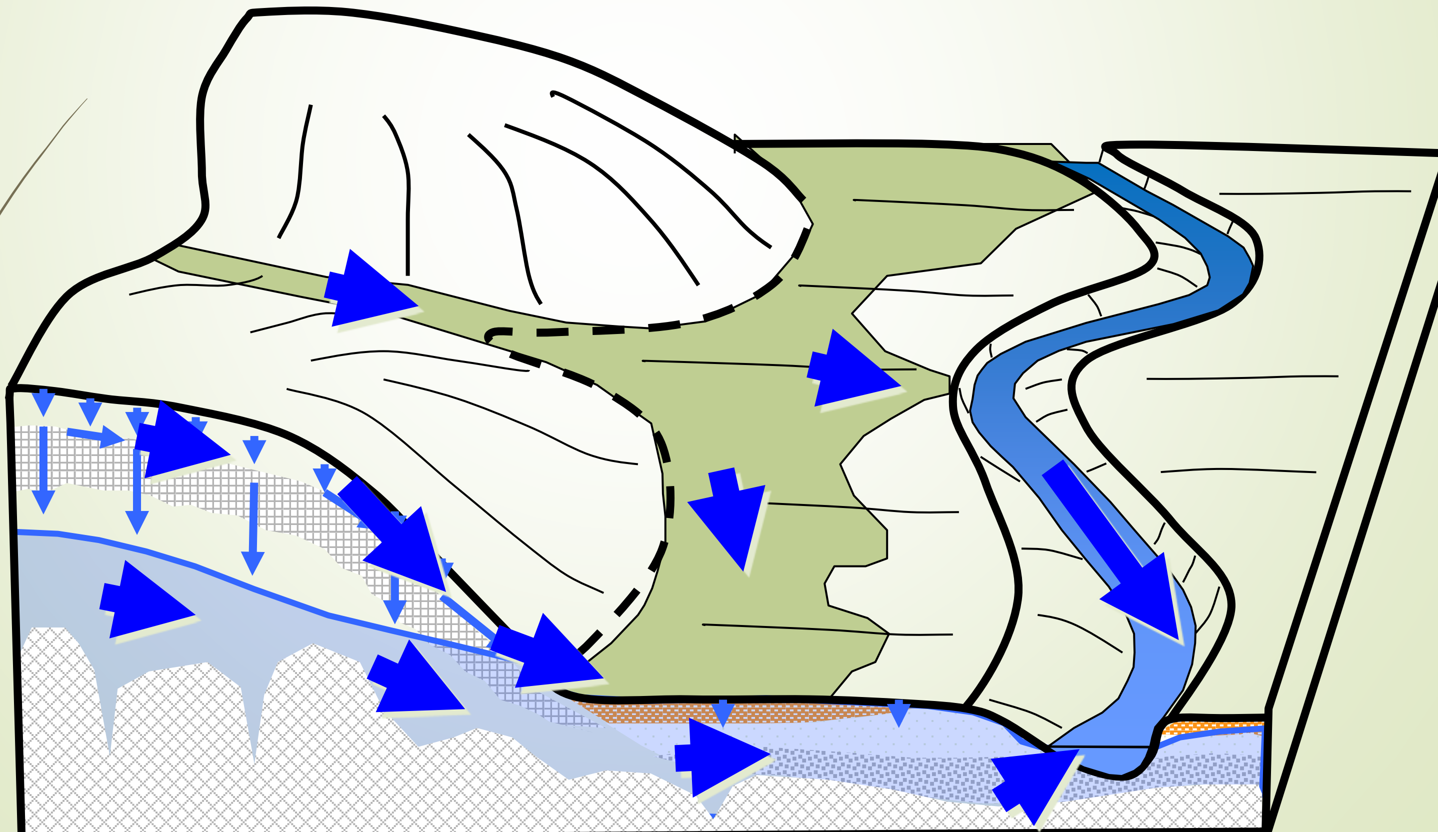
Hydroperiod for one zone in Fort Lee wetland (7-4) vs. adjacent natural wetland (REF3A). How do we pick a design target? Here it was just lucky.

Date Measured

Less than 20% of this site exhibited a hydroperiod similar to well 7-4. Around 40% was much drier and the rest was much, much wetter.

Piedmont Wetlands: the interface between uplands, groundwater, and surface water. Primary original focus of research funds for new water budget model, ***Wetbud***. The model also functions very well in the Coastal Plain.

Wetland creation in any landscape must understand the HGM context of both the impact and proposed creation site and particularly account for groundwater.

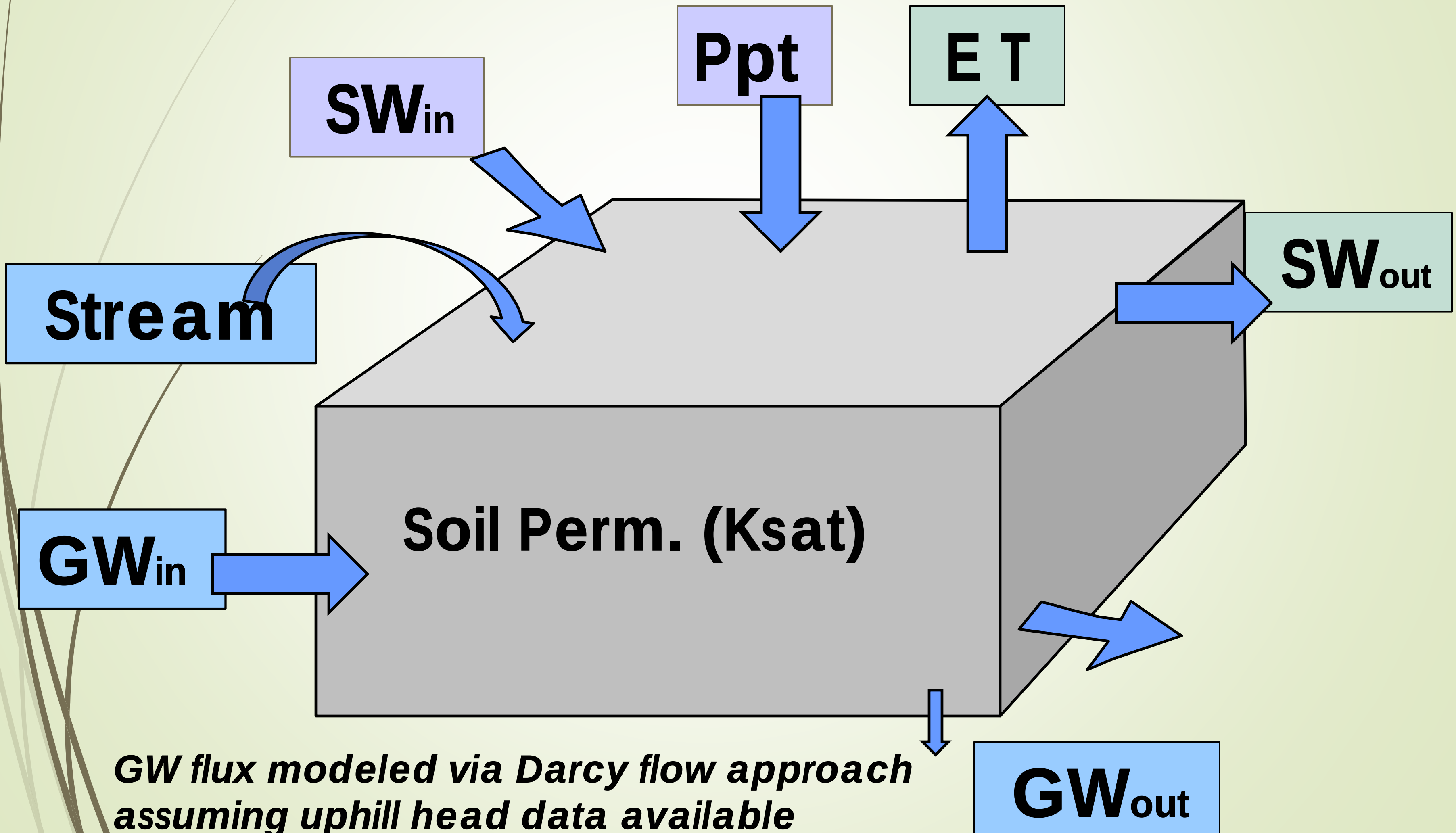


Wetbud is <u>freeware</u> and available for download at www.landrehab.org/WETBUD

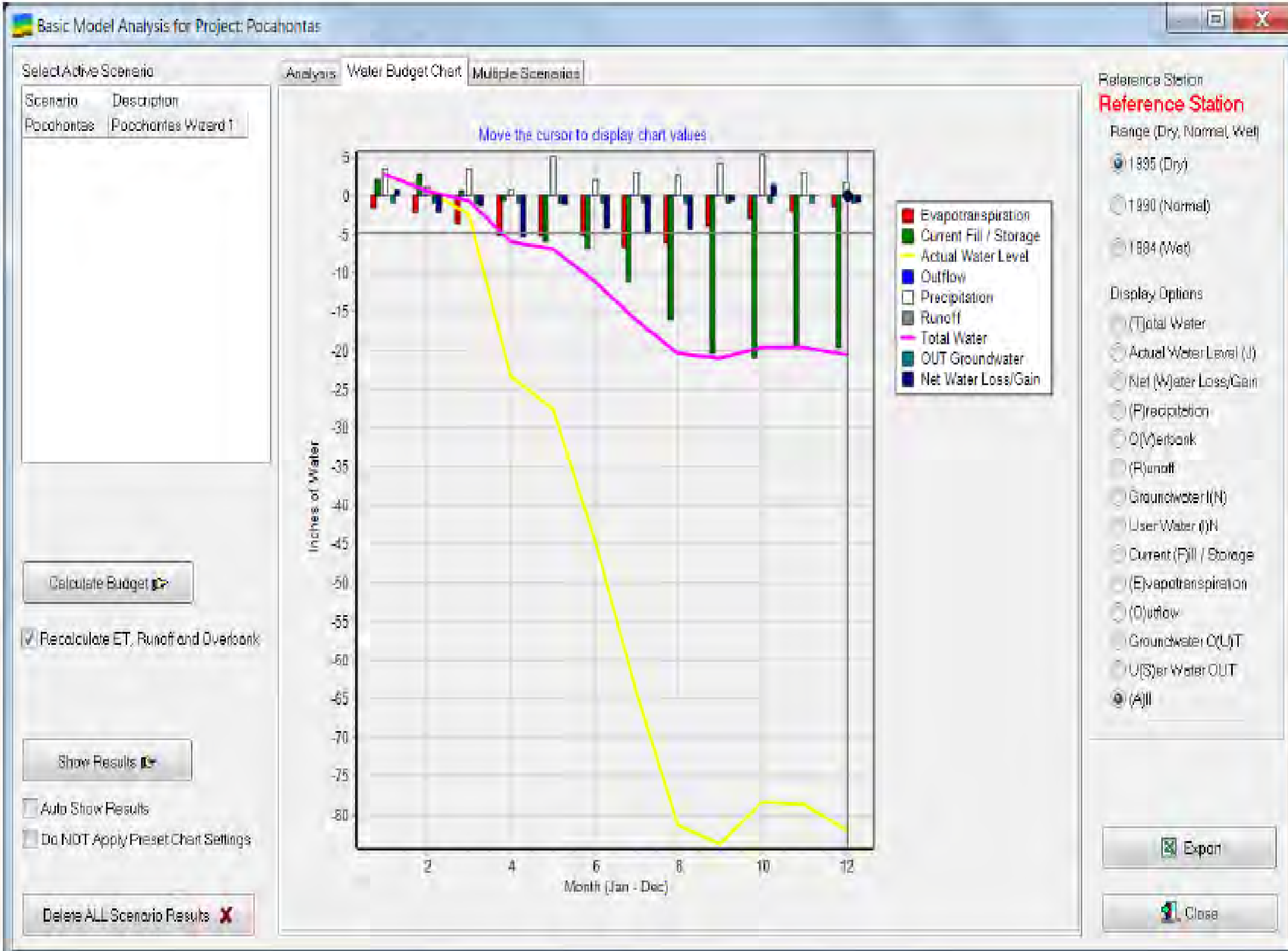
Current Project: None
01.04.00.69 c:\wetbud\wetbud2.fdb

Wetbud Basic Version

Wetbud is a design tool for wetland creation



GW flux modeled via Darcy flow approach assuming uphill head data available

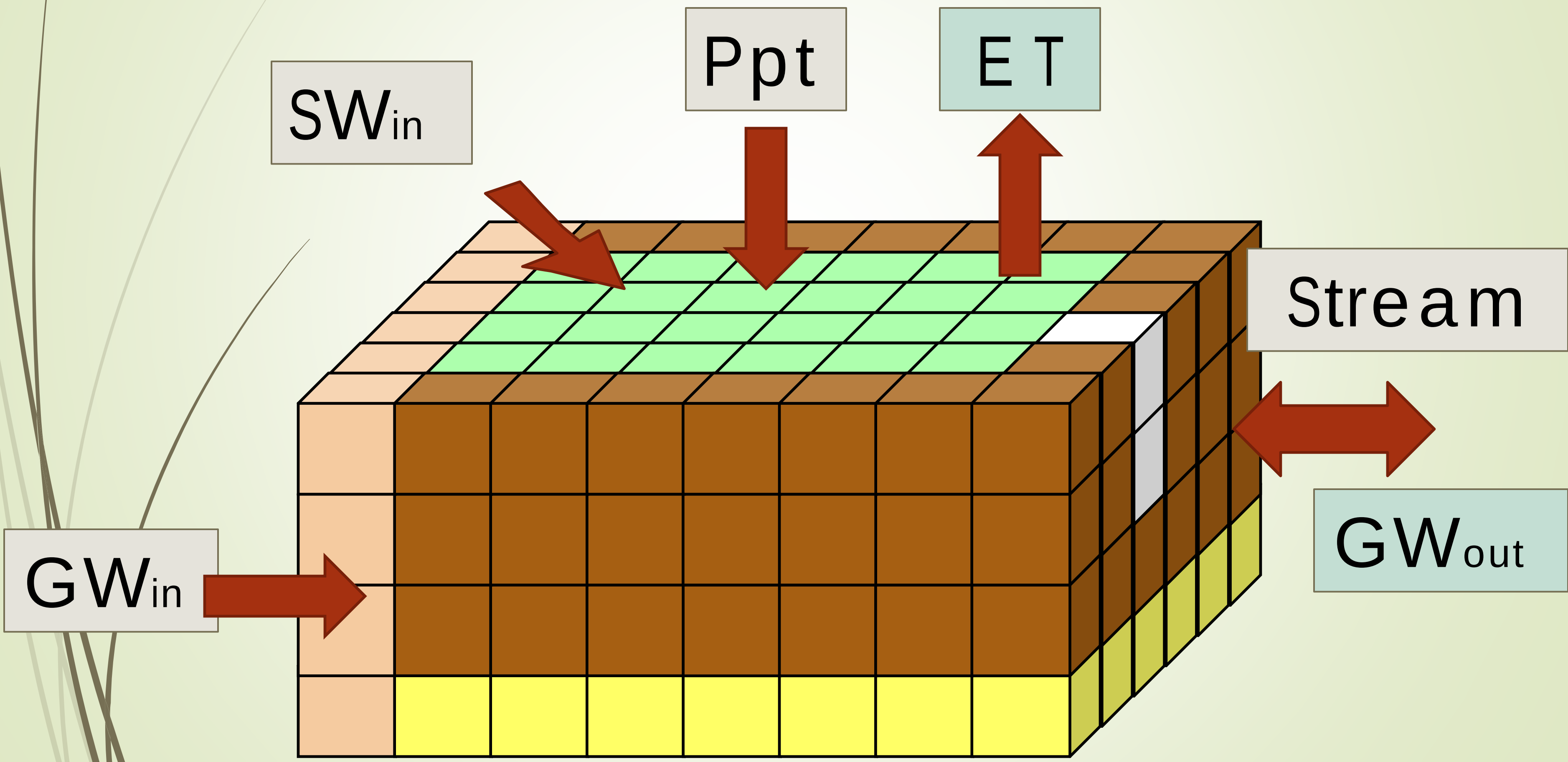

Basic Model Analysis for Project: Pocahontas
Select Active Scenario
Scenario
Description
Pocahontas
Pocahontas Wizard 1
Calculate Budget
Recalculate ET, Runoff and Overbank
Show Results
Auto Show Results
Do NOT Apply Preset Chart Settings
Delete ALL Scenario Results
Analysis
Water Budget Chart
Multiple Scenarios
Move the cursor to display chart values
Inches of Water
Month (Jan - Dec)
Evapotranspiration
Current Fill / Storage
Actual Water Level
Outflow
Precipitation
Runoff
Total Water
OUT Groundwater
Net Water Loss/Gain
Reference Station
Reference Station
Range (Dry, Normal, Wet)
1995 (Dry)
1990 (Normal)
1984 (Wet)
Display Options
(T)otal Water
Actual Water Level (J)
Net (W)ater Loss/Gain
(P)recipitation
O(V)erbank
(R)unoff
Groundwater I(N)
User Water (I)N
Current (F)ill / Storage
(E)vapotranspiration
(O)utflow
Groundwater O(U)T
U(S)er Water OUT
(A)ll
Export
Close

Wetbud Advanced Version

Allows for 3-D modeling including multiple water/soil/substrate layers, slopes, variable wetland topography, etc.

Incorporates more rigorous groundwater flux modeling via MODFLOW (basic model uses a simplified Darcy approach)

WetBud – Advanced Version



Model and Component Validation & Calibration

Huntley Meadows – Fairfax
(detailed ET x 4 and GW studies)

Northfork Bank – Haymarket
(basic model + overbank flow)

Cedar Run 3 – W. of Quantico

Others at Julie Metz, Bender Farms, Pocahontas, etc.

Wetland Studies and Solutions, Inc. a DAVEY company

Design Standards Development

Precipitation

- Statistically based analysis for wet, normal, and dry rainfall years
- Recommended weather stations for VA/MD
- Tools for auto download of any USA station

Evapotranspiration

- Calculates both Penman and Thornthwaite
- For W-N-D years selected by precipitation
- Options for input of pan data, Bowen Ratio, etc.

Groundwater

- Measurement protocol recommendations
- Wem: Projection of long term hydroperiod
- Soils data import for Ksat for all VA map units

Hydroperiod "Library"

- Developing VA and MD Regional Collection of "typical hydroperiods"
- What is targeted design Hydroperiod for PFO, PSS, PEM?

Acknowledgments

- **Funds for various portions of this research were provided by VDOT, Weanack Land LLLP and Wetland Studies and Solutions Inc.**

- **Thanks to all the students, post-docs and research staff cited in this talk. Too many to list!**

- **I particularly want to thank Jim Perry (VIMS) and Rich Whittecar (ODU) for their input over the past 20 years.**