An Ecological Framework for Compensatory Mitigation: Anticipating the Unexpected – Soil Compaction and Acid-S Conditions

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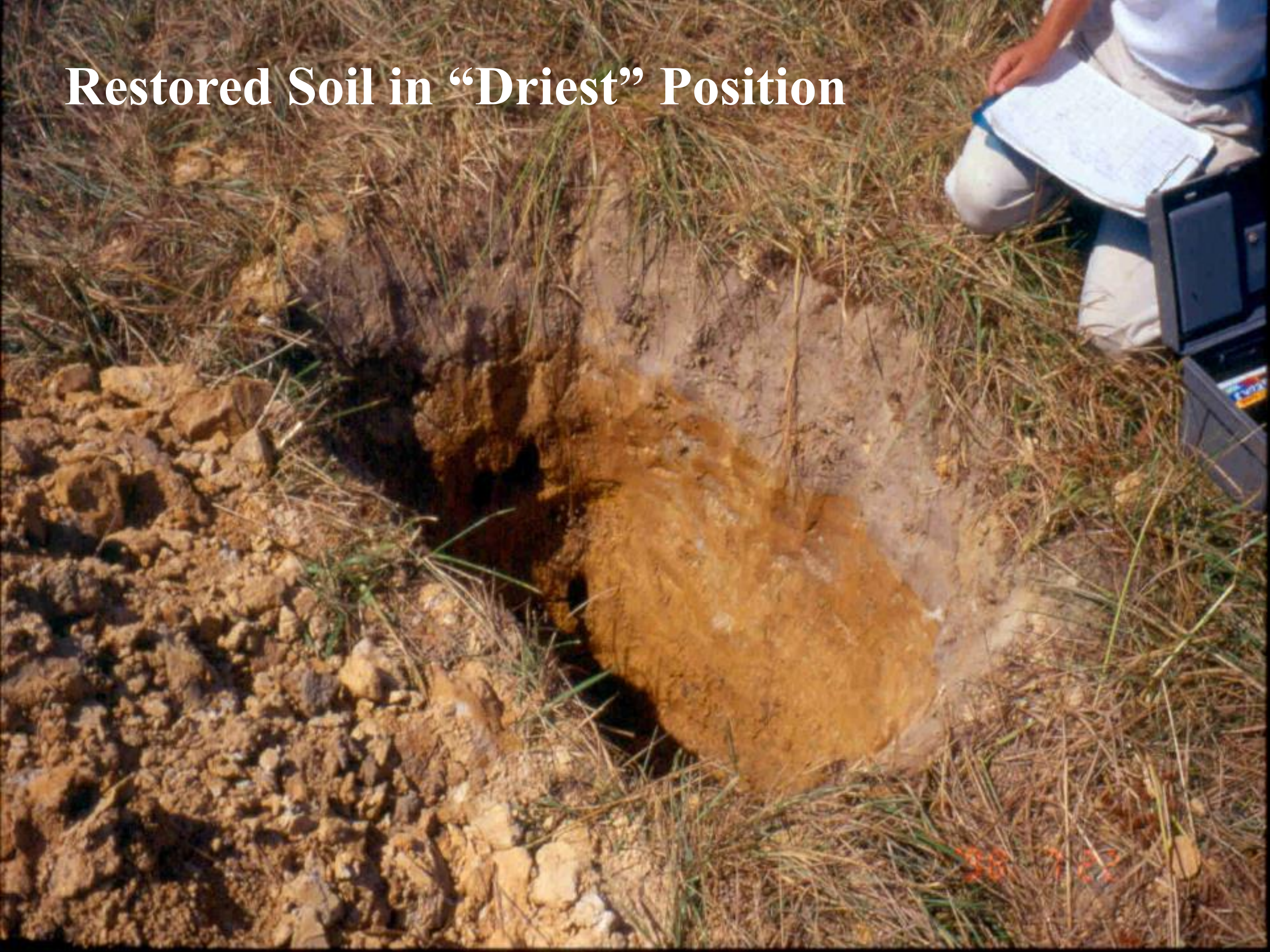
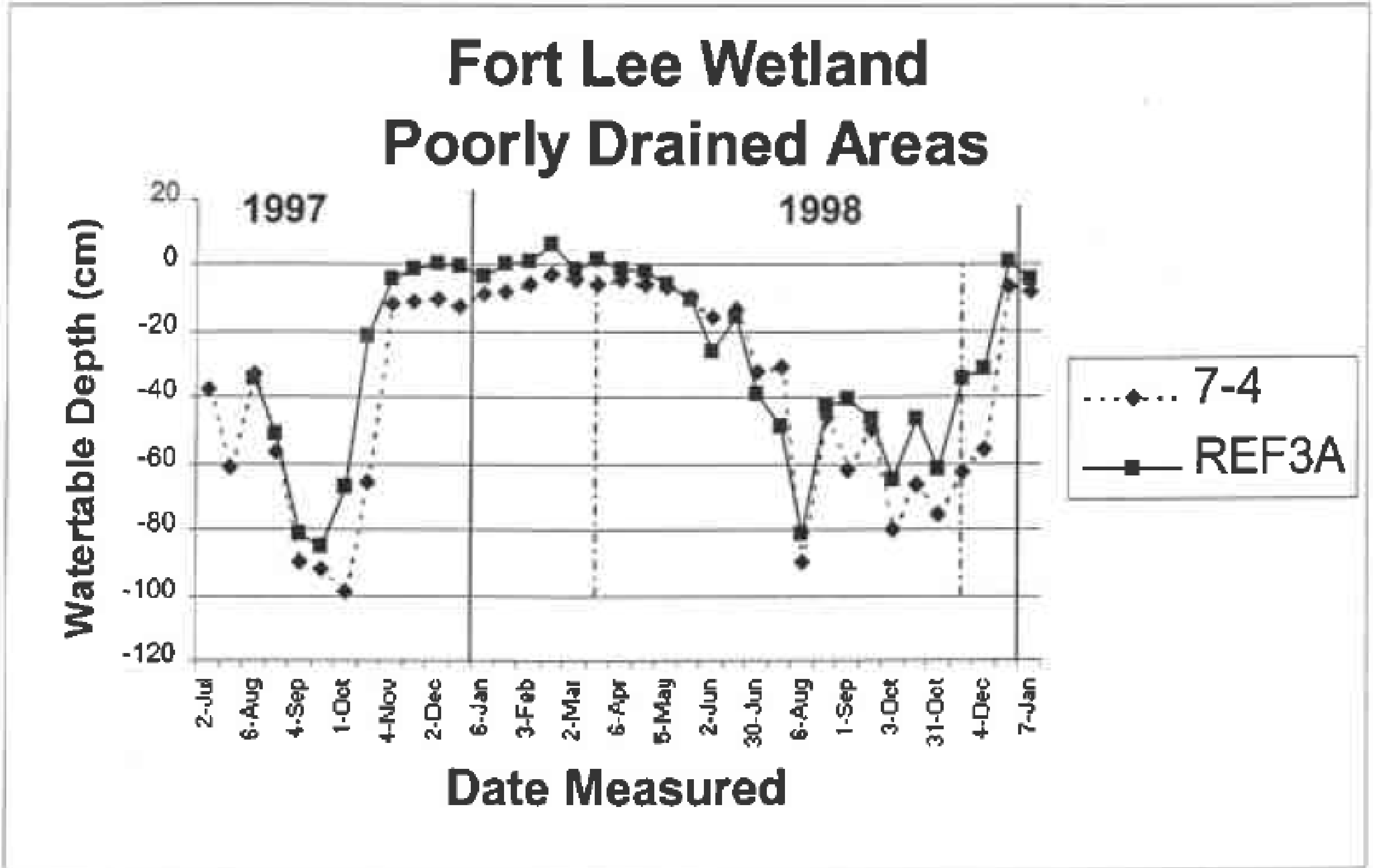
Fort Lee Drainage Gradient Studied by Cummings (a.k.a. Whitehead; 1999) and USGS/VT. One of 15 VDOT sites studied

Restored Soil in "Driest" Position





Hydroperiod of created soil vs native soil at Ft. Lee

Compacted Restored soil in intermediate drainage (poorly d.) class at Fort Lee. Many of these soils supported upland vegetation and showed no redox features.


Native soil < 75 m from previous profile. Similar elevation

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 g/cm^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 2006 report.

Why are Created Wetland Soils Compacted?

- **Historically, many designs and associated water budgets have intentionally compacted the subsoil to limit subsoil losses to local groundwater (seepage) and/or "perch" the saturated zone.**
- **Regardless of "design intentions", routine construction and grading operations often lead to high levels of compaction, particularly when soil materials are moved and placed in a moist to wet condition.**

How does a root penetrate soil?

- The active growing root tip is very small (often < 1 mm) and is pliable. It cannot and ***does not*** move soil particles out of its way!

- The extending root tip must find a route of continuous pores larger than itself to enter and grow. The tip will deflect or stunt if it cannot enter. “J-rooting”

- Once proliferating through a sequence of connected pores, the axial (spreading) pressure is much stronger and can widen and open up pores/cracks.

Critical Bulk Density

- **Root limiting (or critical) bulk densities in soils range from around 1.40 (g/cm^3) for massive (poorly structured) silty clays and clays to around 1.75 for sands.**

- **We are routinely at or above theoretical root limiting bulk density at many (most?) created/mitigation sites, particularly in the zone between – 20 and – 50 cm.**

Surface soil from 3-year old created wetland (CCW).

Note massive structure in surface breaking to firm plates at about 20 cm. This is the “traffic pan”.

Led to very wet winter conditions (perched or “epiaquic”), but very dry extended summer droughts and lack of persistence for wetland obligates.

Charles City Wetland (CCW); first built in 1997 & 1998 via excavation of upland landform; modified via tillage and OM amendments by VDOT several times thereafter.

What Mitigates High B.D.?

- **Moisture content**: in moist to wet soils, soil strength (rooting impedance) is lessened, so during the winter and spring, high B.D. may be less of a limitation. *So, this should help rooting in created wetlands?*

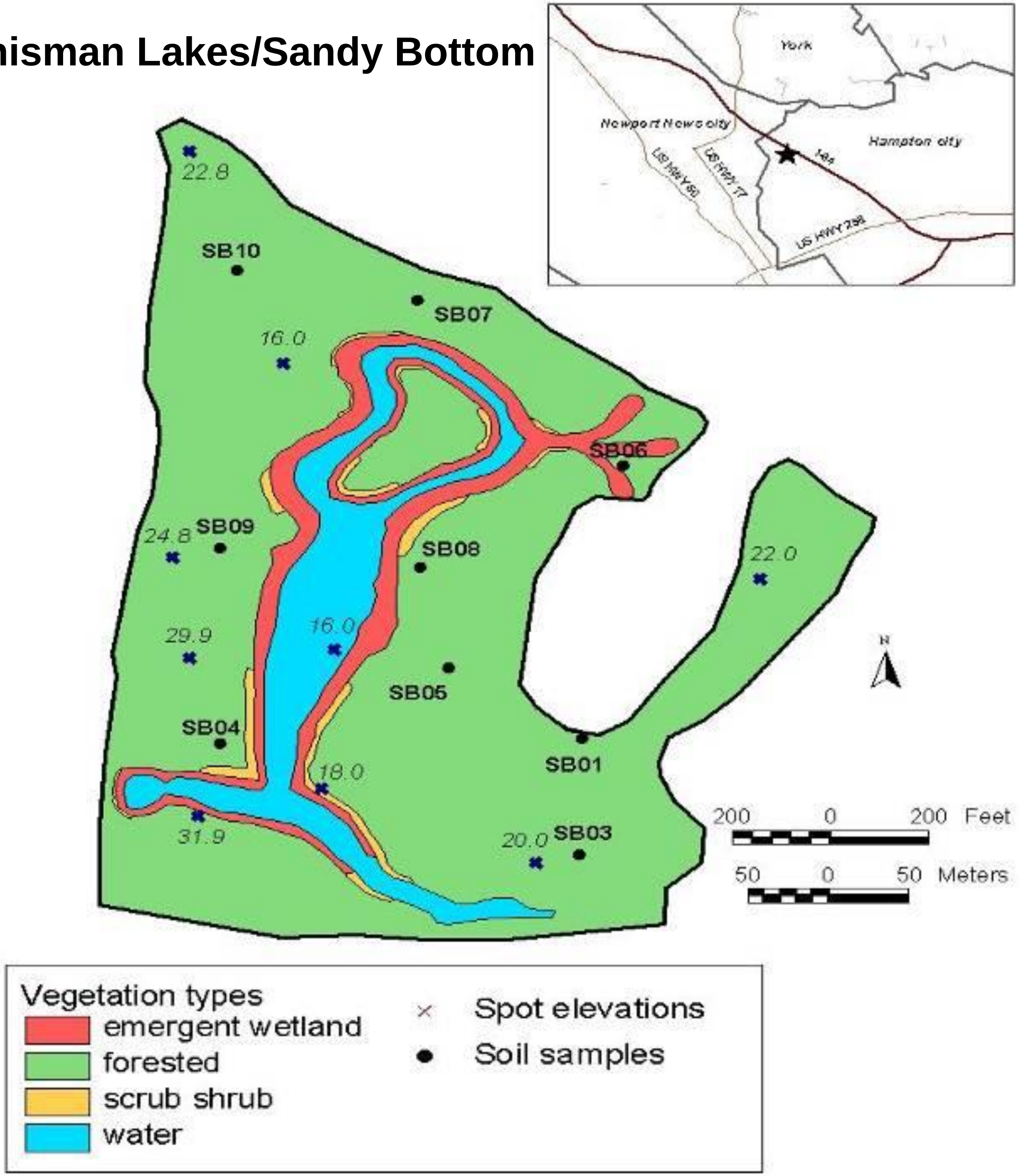
- **Soil structure (aggregates/peds)**: macropore development associated with soil structure allows root tips to penetrate otherwise massive and high strength soils. *However, most cut/fill soils in created wetlands have degraded or very limited aggregation.*

What Mitigates High B.D.?

- **Tillage/Ripping**: Offset disking can loosen to 4 to 6”; chisel plow or shank ripper need for deeper effects.
  - Must be done when soil is dry enough to shatter
  - Too dry – disk can’t cut or the ripper “pulls chunks”
  - Too wet – tractor ruts and/or shanks pull through like butter
  - So, seasonal timing vs. construction timing & schedule?

- **Soil Amendments**: Gypsum and other “magic amendments” *will not* loosen highly compacted soils without tillage and/or other wet/dry or deep freeze/thaw processes. OM additions help, but still need to be mixed into soil by tillage or natural/biotic processes.

Chisman Lakes/Sandy Bottom

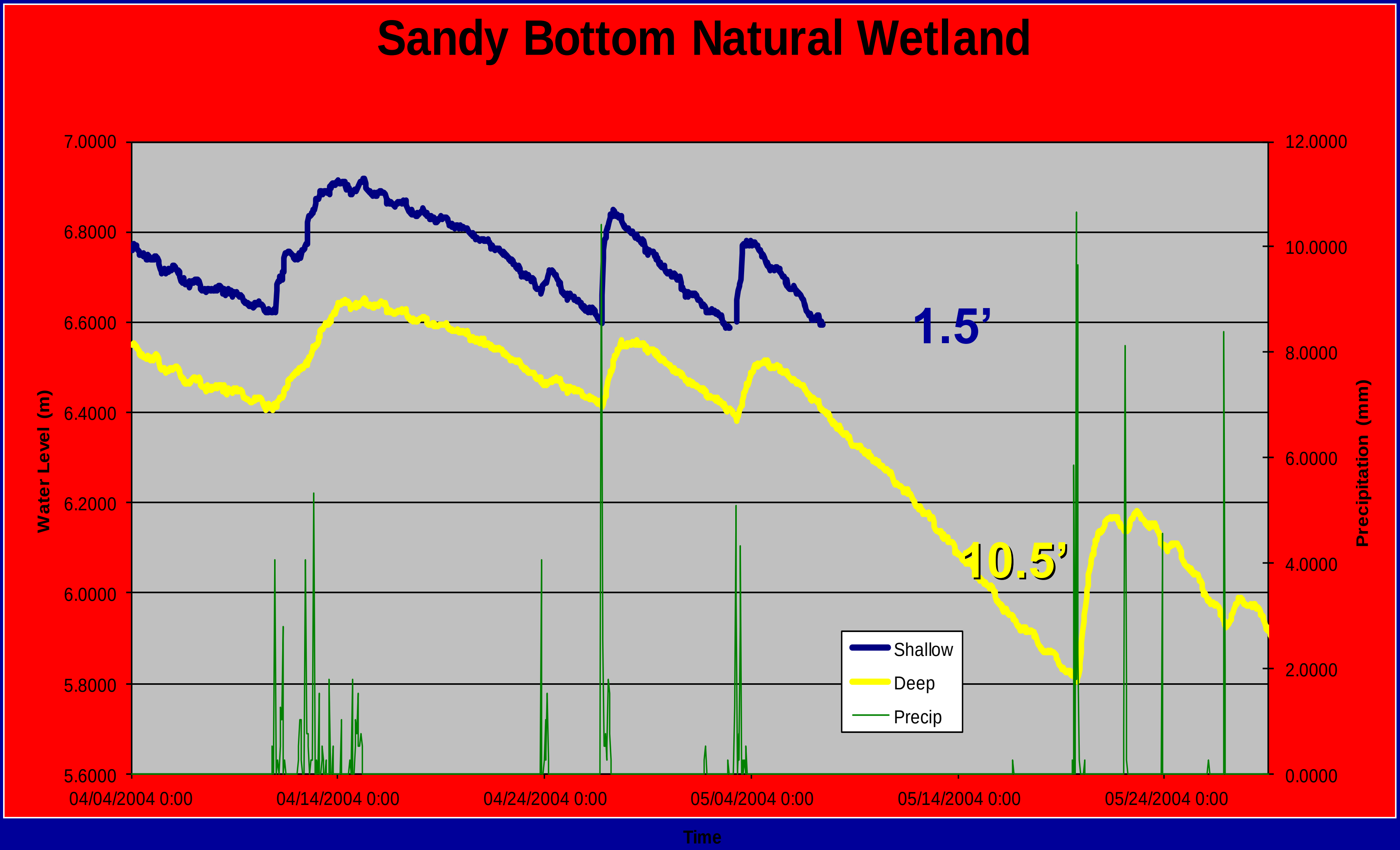


Chisman Lakes (Sandy Bottom NP) created wetland. One of ten VDOT sites studied in early to mid 2000's *following* efforts to improve soil conditions via OM additions, tillage, etc.

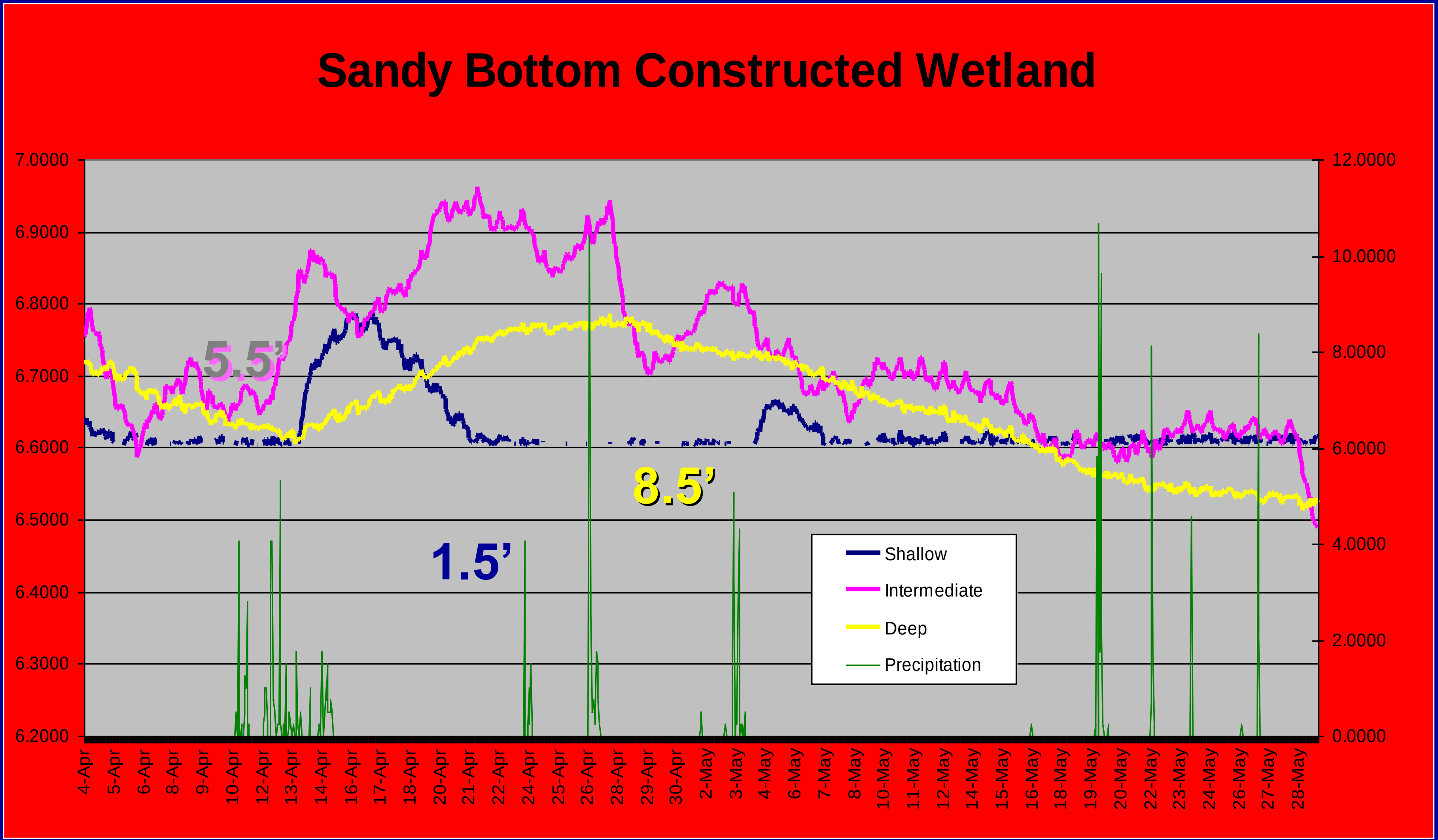
Sandy Bottom Wetland

Rich Whittecar (hydrogeology; VCU), Jim Perry (ecology; VIMS) and WLD on a cool day at Sandy Bottom. I can’t express enough how valuable it is to have other disciplines involved with site assessments!

Site	Total (%) C	Mass C (Mg/ha)	Bulk Density (g/cm^3)	pH	(%) Clay
	0-15 cm				
BCK	2.43 a	37.8 bc	1.29 f	5.3 e	12 d
CCW	**1.08 bc**	**19.0 f**	**1.42 de**	**5.3 e**	**28 a**
DC	0.76 c	16.4 f	1.61 b	5.5 de	15 cd
MAN	1.00 bc	21.9 ef	1.59 bc	5.7 cd	19 b
MATTA	**1.17 bc**	**33.1 bcd**	**1.68 b**	**6.2 b**	**8 e**
MTS	1.06 bc	29.2 cde	1.60 b	5.4 de	6 e
RCK	1.14 bc	25.2 def	1.36 ef	5.8 c	18 bc
SB	**1.42 b**	**40.5 b**	**1.82 a**	**6.6 a**	**12 d**
SCW	2.22 a	42.1 b	1.49 cd	5.3 e	12 d
SWS	2.28 a	56.7 a	1.46 d	6.4 ab	16 bcd

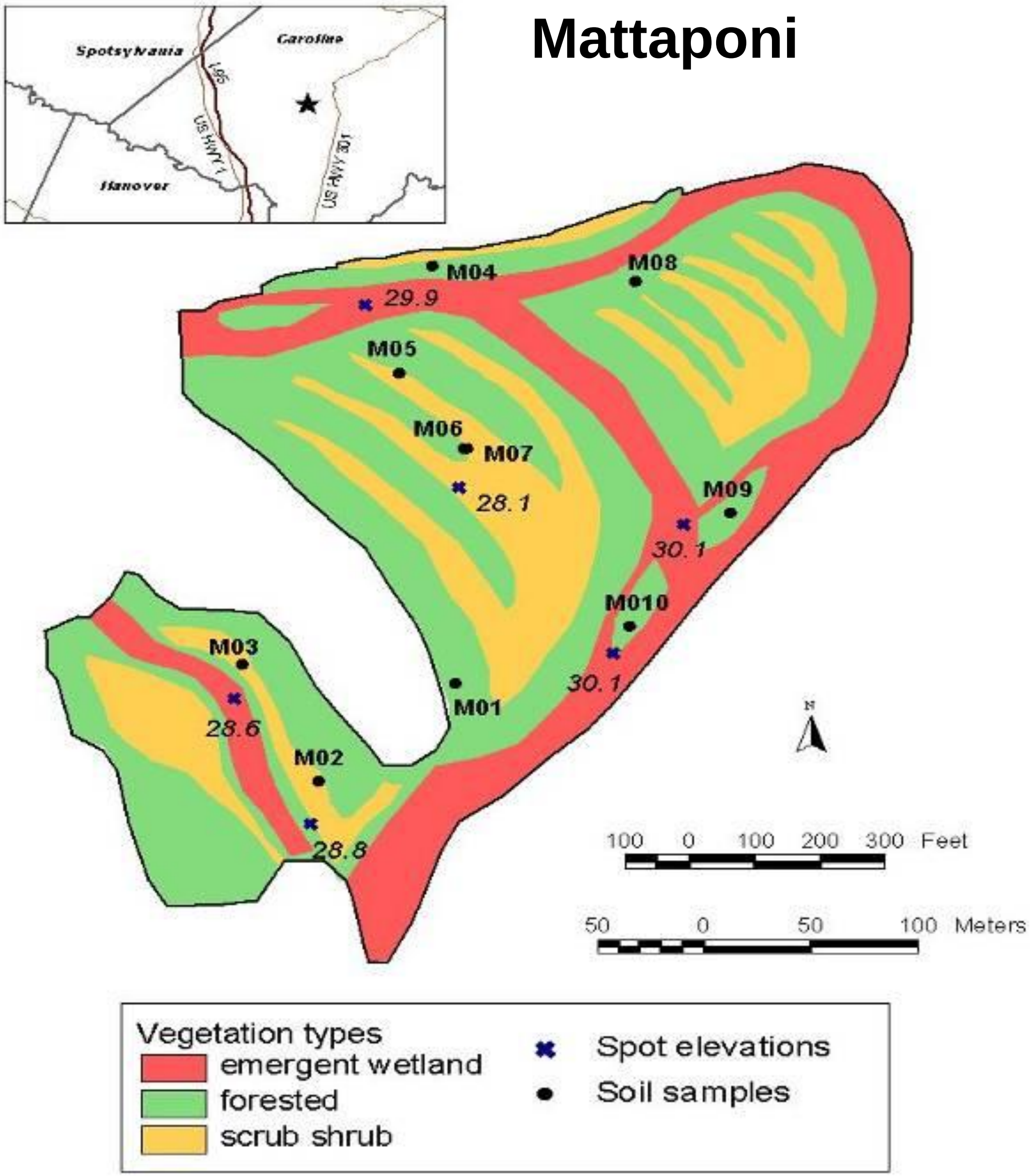


Water levels in nested piezometers in undisturbed wetland at SB. Note falling head with depth; indicative of GW recharge locally. This is a mineral flat landscape. Data from DesPres & Whittecar and DesPres (2004) M.S. thesis.



Same site x dates; nested piezometers in created wetland portion. Surface hydrology is clearly perched and disconnected from both intermediate and deeper strata. All depths here were in layered fill.

Mattaponi



Spotsylvania
Caroline
Hanover
95
US HWY 1
US HWY 301
M04
M08
29.9
M05
M06
M07
28.1
M09
30.1
M010
30.1
M01
M03
28.6
M02
28.8
N
100 0 100 200 300 Feet
50 0 50 100 Meters
Vegetation types
emergent wetland
forested
scrub shrub
Spot elevations
Soil samples

Mattaponi created wetland. Note barren slope (pH 3.5) in background after 2 years of revegetation. Site needed "hydrologic adjustment" to compensate for excess groundwater inputs, but also had acid-S soils in floor.

Site	Total (%) C	Mass C (Mg/ha)	Bulk Density (g/cm^3)	pH	(%) Clay
	30-45 cm				
BCK	0.54 bc	33.3 bc	1.74 c	5.5 b	21 bcd
CCW	0.19 d	13.4 c	1.58 d	4.5 c	44 a
DC	0.17 d	15.0 c	1.74 c	5.4 b	24 bc
MAN	0.18 d	10.4 c	1.80 bc	5.4 b	28 b
MATTA	0.39 bcd	55.9 a	1.59 d	***3.7 c***	16 de
MTS	0.33 cd	17.6 c	1.92 a	5.0 bc	12 e
RCK	0.18 d	15.3 c	1.61 d	5.4 b	27 b
SB	0.83 a	48.4 ab	1.89 a	6.7 a	21 cd
SCW	0.15 d	8.9 c	1.91 a	5.5 b	11 e
SWS	0.62 ab	30.3 bc	1.86 ab	5.0 bc	13 e

What are acid sulfate soils (ASS)?

- Soils formed from the weathering of sulfide-bearing parent materials, which results in extremely low pH (commonly < 4.0) and precipitation of sulfate salts.

- Active ASS are commonly pH 2.0 to 3.5 and very high in sulfates salts and soluble metals (Al, Fe, Mn, and others – As/Se).

- Post-active ASS will actually slowly increase in pH up to 3.7 to 4.3 due to Al^{3+} buffering.

- With few exceptions, any soil pH $\leq$ 3.8 is indicative of ASS and needs attention. Few (if any) adapted plant species.

Active pyrite (FeS_2) depositional environment in high C and sulfate input tidal marsh.

Sulfides occur in many other environments, including metamorphic mineral belts, black shales, etc.

$FeS_2 + 7/2O_2 + H_2O \rightarrow FeSO_4 + H_2SO_4$

$2FeSO_4 + H_2SO_4 \rightarrow Fe_2(SO_4)_3 + H_2O$

$1/2Fe_2(SO_4)_3 + 2H_2O \rightarrow 1/3HFe_3(SO_4)_2(OH)_6 + 5/6H_2SO_4$

OR $\rightarrow KFe_3(SO_4)_2(OH)_6$ (jarosite)

Summing it up all up:

$FeS_2 + 15/4O_2 + 7/2H_2O \rightarrow 2H_2SO_4 + Fe(OH)_3$

1 mole of pyrite produces 2 moles of sulfuric acid

Or 1% pyritic S in a soil or sediment will generate acidity to require addition of 32 tons of lime per acre 6 inches deep (or tons of lime per thousand dry tons soil).

Typical young acid-sulfate soil profile

Overlying oxidized material is typically a light yellowish brown with pH ~ 3. Yellow salt = jarosite; stable at pH $\leq$ 3.5. White = gypsum or Alum

Underlying reduced material is typically drab blue or gray, with pH > 6.0 and often 7 to 8. Called “blue marl” etc. by drillers. Usually will not react/acidify in routine lab processing time. Needs special testing called “acid-base-accounting”.

Extent of acid-sulfate forming materials in Virginia Coastal Plain of Virginia that are within routine excavation depths (2 to 10 m). The darker shaded tertiary aged marine sediments are the most extensive and damaging.

However, a belt of Piedmont materials just to the west of Fredericksburg and Stafford is actually much more problematic!

Example "ASS Risk Map"

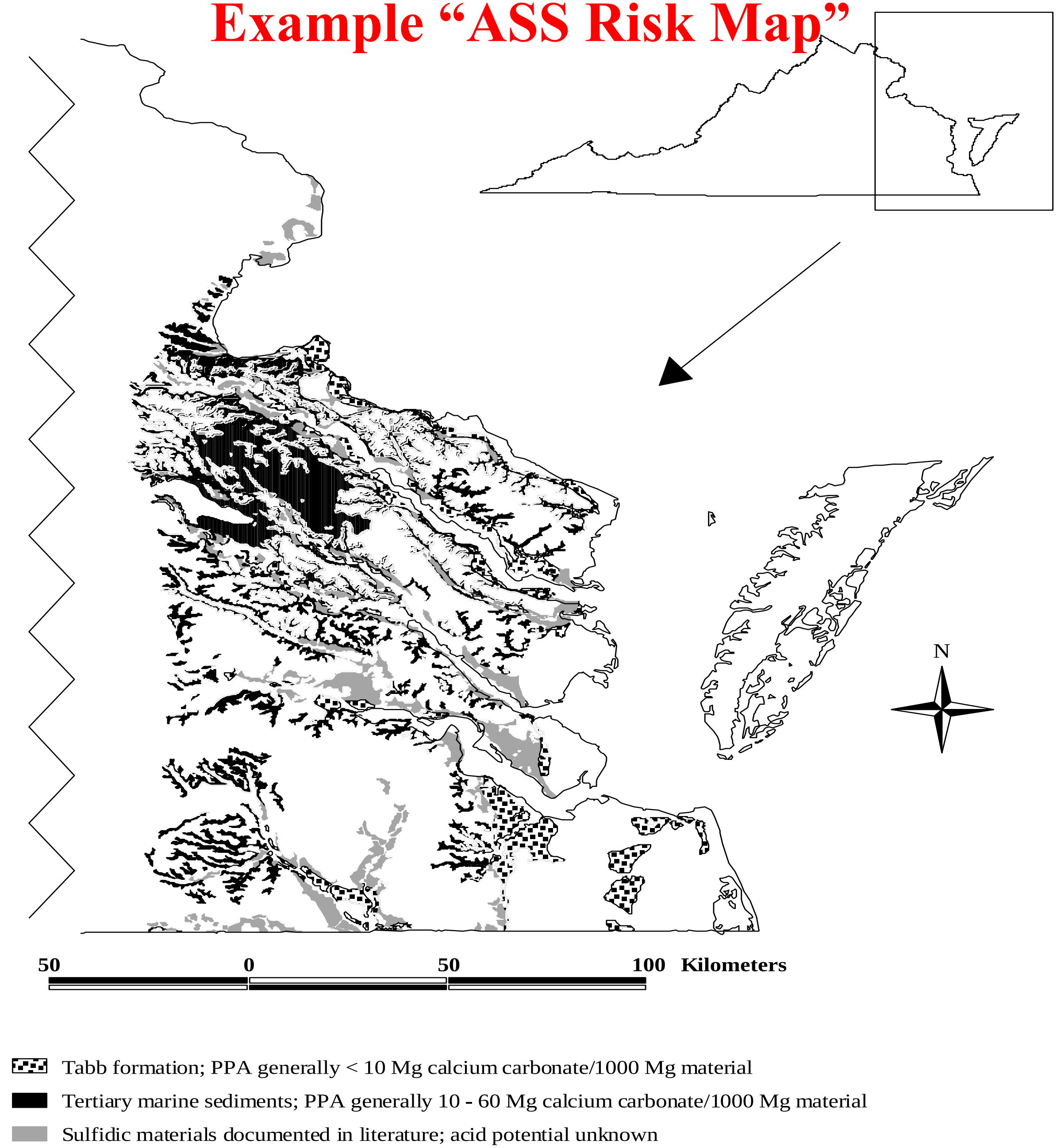
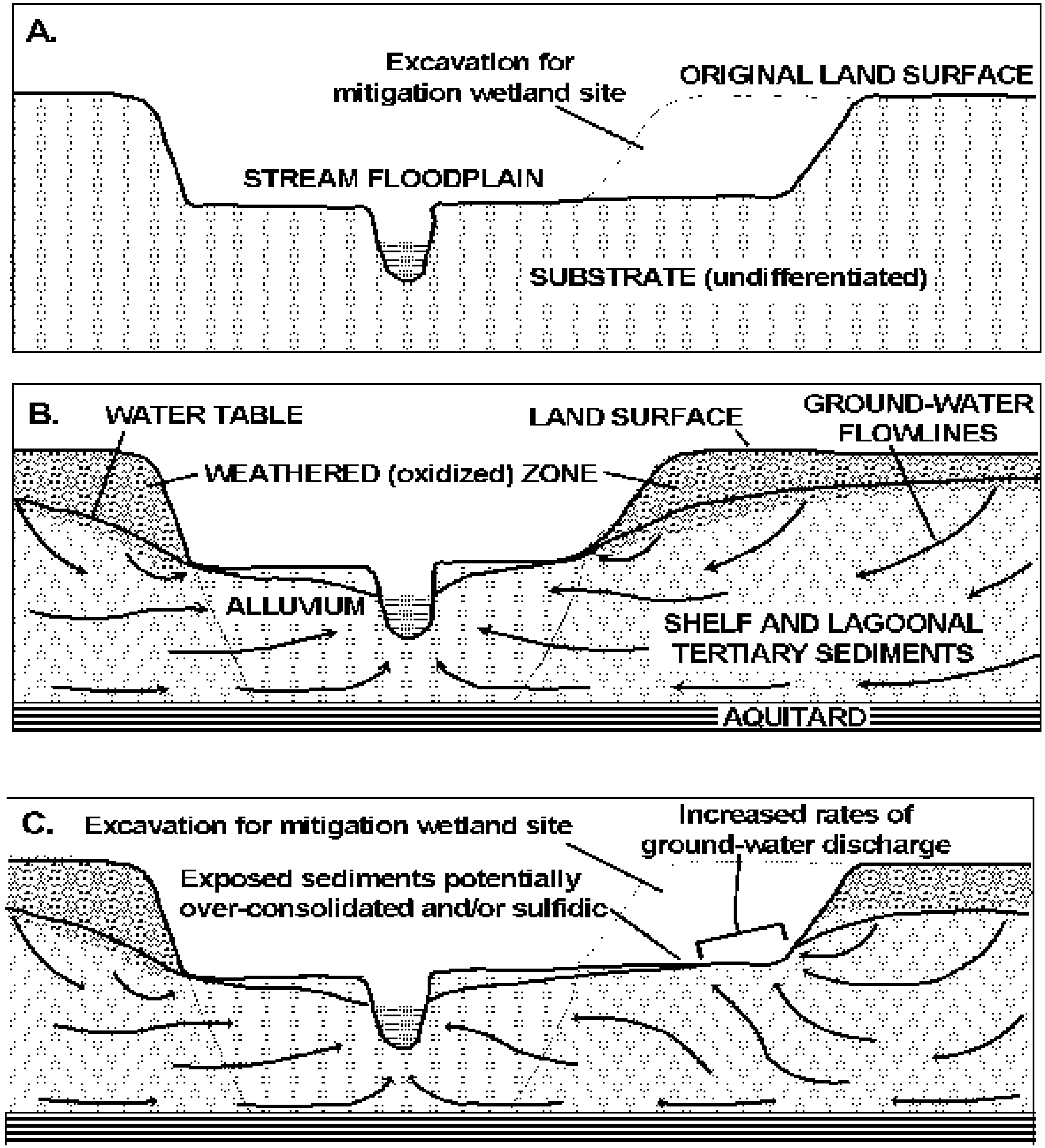
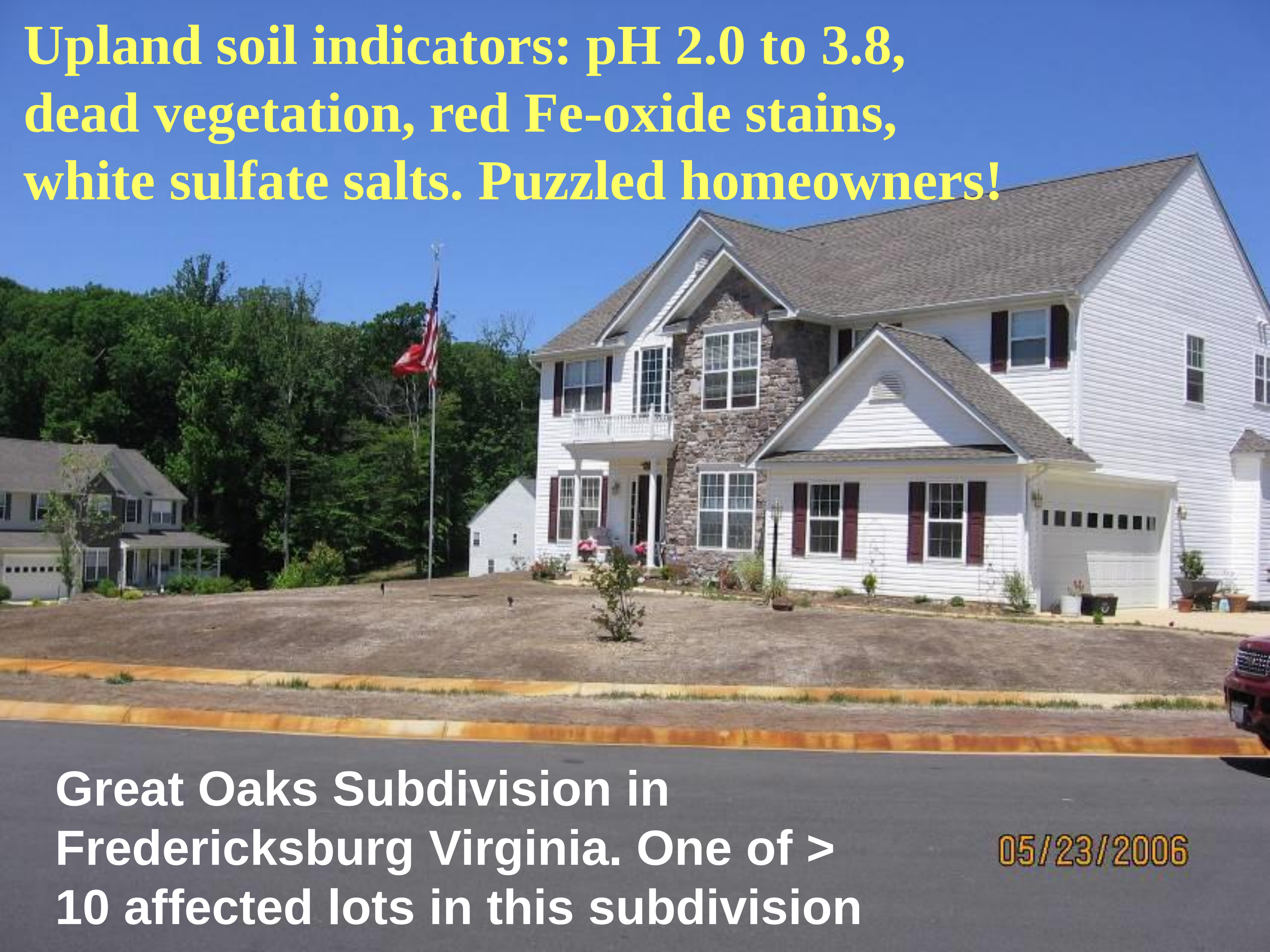


Figure adapted from Whittecar and Daniels (1999) indicating how excavations below pre-creation water table can (a) expose acid-forming materials and (b) fundamentally alter local groundwater discharge regimes.




Upland soil indicators: pH 2.0 to 3.8, dead vegetation, red Fe-oxide stains, white sulfate salts. Puzzled homeowners!
Great Oaks Subdivision in Fredericksburg Virginia. One of > 10 affected lots in this subdivision
05/23/2006


Stream
draining
Great Oaks.

Complete galvanized degradation in 9 mos.

Summary

- **All "risky materials" should be analyzed for total-S. If S is > 0.2%, analyze them for acid-base-accounting. Risk is based on geologic unit, depth and extent of weathering/oxidation.**
- **Near-surface brown to red materials (e.g. weathered soils) are usually much lower risk since the S probably oxidized long ago. Gray to blue/black materials increase risk.**
- **If you can't avoid them, you need to add agricultural lime to potential acidity levels or keep them under water. *<u>You will not stop pyrite oxidation</u>*; only slow it down.**
- **Liming rates commonly range from 10 tons per acre 6" deep to 40+ and the lime needs to be mixed and incorporated. Adding compost or other organic amendments also works synergistically will lime amendment.**

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