Understanding and Reconstructing Soil Conditions at Remediation Sites

W. Lee Daniels

Crop & Soil Environmental Sciences

Virginia Tech
Virginia Polytechnic Institute and State University

http://www.cses.vt.edu/revegetation/

Overview of Seminar

- Introduction to site disturbance, terminology, and important soil functions
- Chemical and physical properties of wastes and reconstructed soils
- Case studies on smelter wastes, sulfidic soils and constructed mitigation wetlands

2

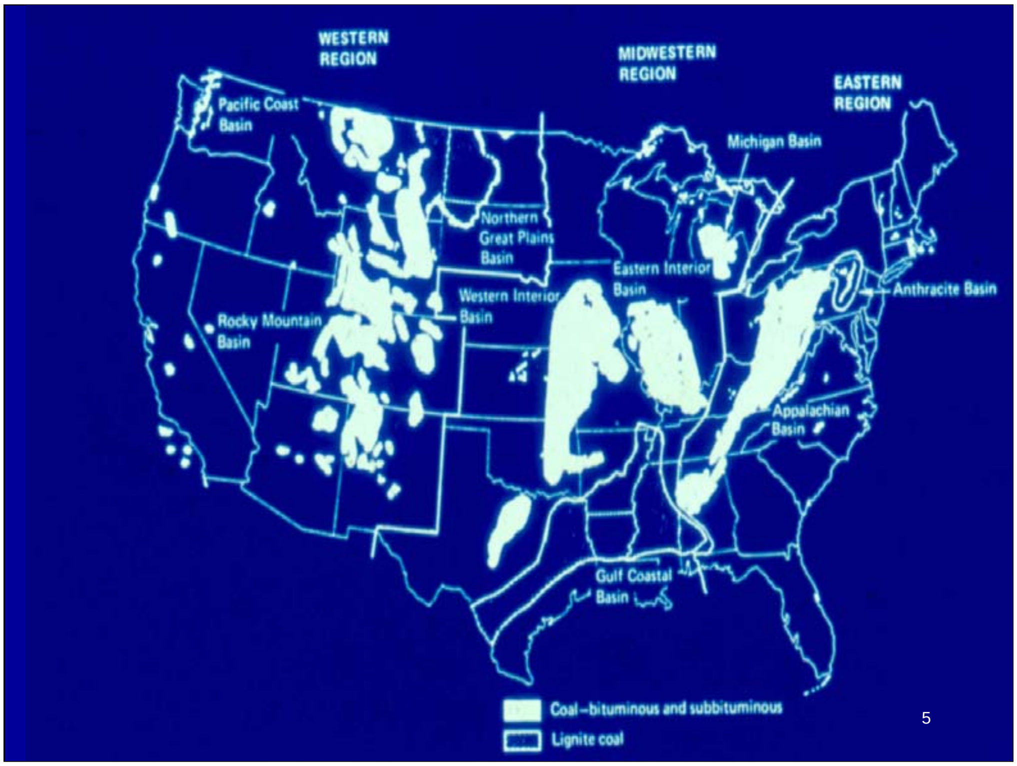
Our “Disturbing History”

- Land Clearing/Erosion (1600’s on)
- Surface Mining (1800’s on)
- Urbanization (minor before 1950’s)
- Suburbanization (1940’s on)
- Road Building (Expansion in 1950’s)
- Utility Corridor Development

3

Modern Contour Coal Mine

4


WESTERN REGION
MIDWESTERN REGION
EASTERN REGION
Pacific Coast Basin
Michigan Basin
Northern Great Plains Basin
Eastern Interior Basin
Anthracite Basin
Western Interior Basin
Rocky Mountain Basin
Appalachian Basin
Gulf Coastal Basin
Coal–bituminous and subbituminous
Lignite coal
5

Coal Processing Waste Pile

6


Metal mine tailings at
Anaconda, Montana
7

Off-Road Effects of Acid Drainage and Sediment Losses

8

The Four “R Words”

<u>Reclamation</u> is the term used broadly in the USA for stabilization and revegetation of mined lands. However, the term has also been used historically to describe the conversion of salty soils in the West to agricutural production.

<u>Restoration</u> is a term favored by biologists, which necessarily implies/requires return of the disturbed area to its natural and undisturbed state.

9

The Four "R Words"

Revegetation is the term used broadly in to describe the establishment of vegetation on any disturbed or non-vegetated area. Used in a broad way by highway engineers to describe the entire right-of-way stabilization process.

Rehabilitation is the term favored by the Australians and many Europeans, particularly where a specific land-use or ecosystem is not intended to be restored.

10

Another “R Word”

- **Remediation specialists applying similar technologies to Superfund and Brownfields sites have now begun to call this “<u>Revitalization</u>” to clearly separate it from restoration or reclamation.**

11

One of our underlying principles in any remediation/restoration setting is the importance of creating soil conditions appropriate for the intended plant and microbial community.

What are the important functions that the soil profile provides?

Soil/Plant Relations

- Physical support
- Ventilation/gas exchange/aeration
- Temperature moderation
- Water holding
- Plant protection/growth regulation
- Buffering Acidity/Metals & Nutrient supply

13

In a native forest soil, annual added leaf litter and roots are “bio-processed” and decomposed to form humus, which is the dark black material seen coloring this topsoil layer. In the process, nutrients and energy are released in the food chain.

However, the soil provides a wide array of support and benefits beyond simple nutrition to the plant community.

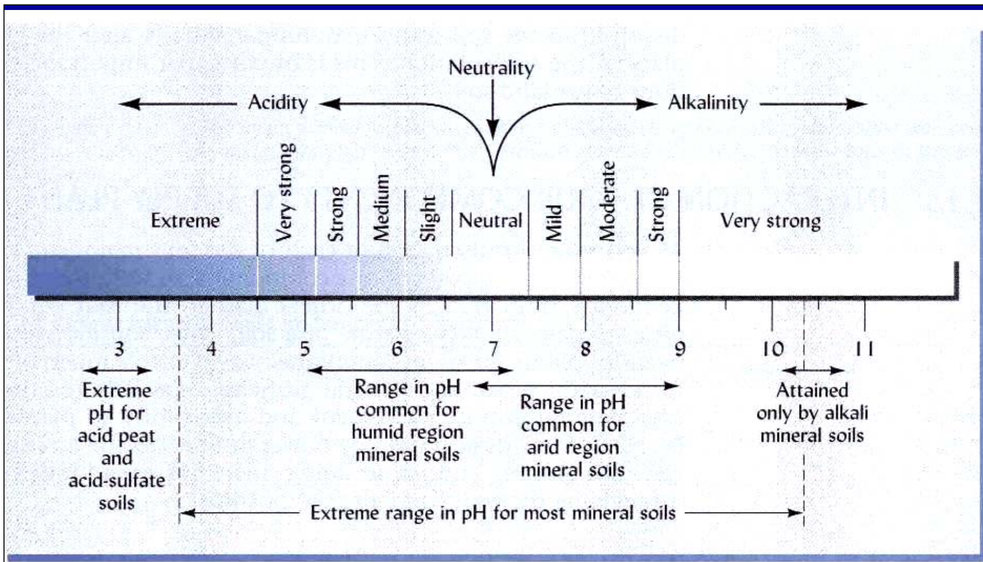
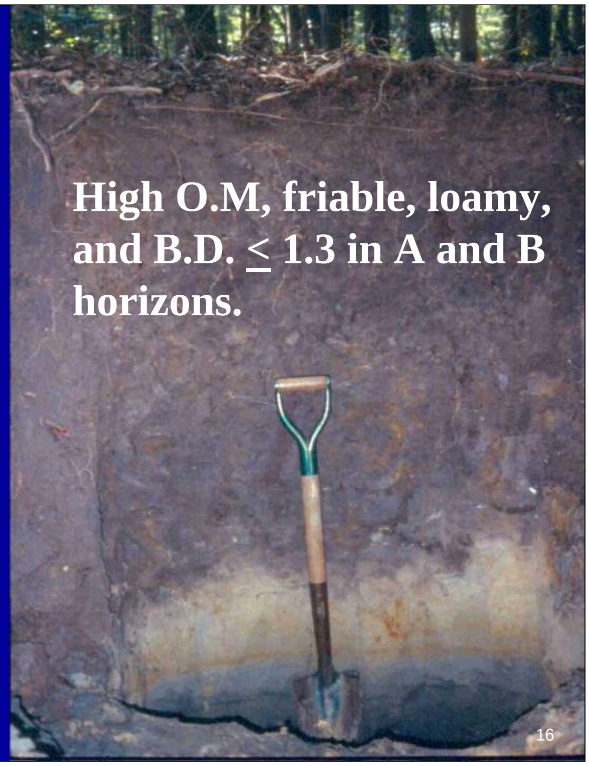


Figure 1.23. Note that the common range of soil pH under natural conditions is from 5.0 to 9.0. For each pH change of 1 unit, the concentration of H^+ changes 10X. So, how much more acidic is a pH 4.0 soil when compared with a pH 7.0 soil?

15

Even though this soil is naturally acidic (pH 5.3), the high levels of organic matter bind toxic Al and other metals, making the soil more hospitable.

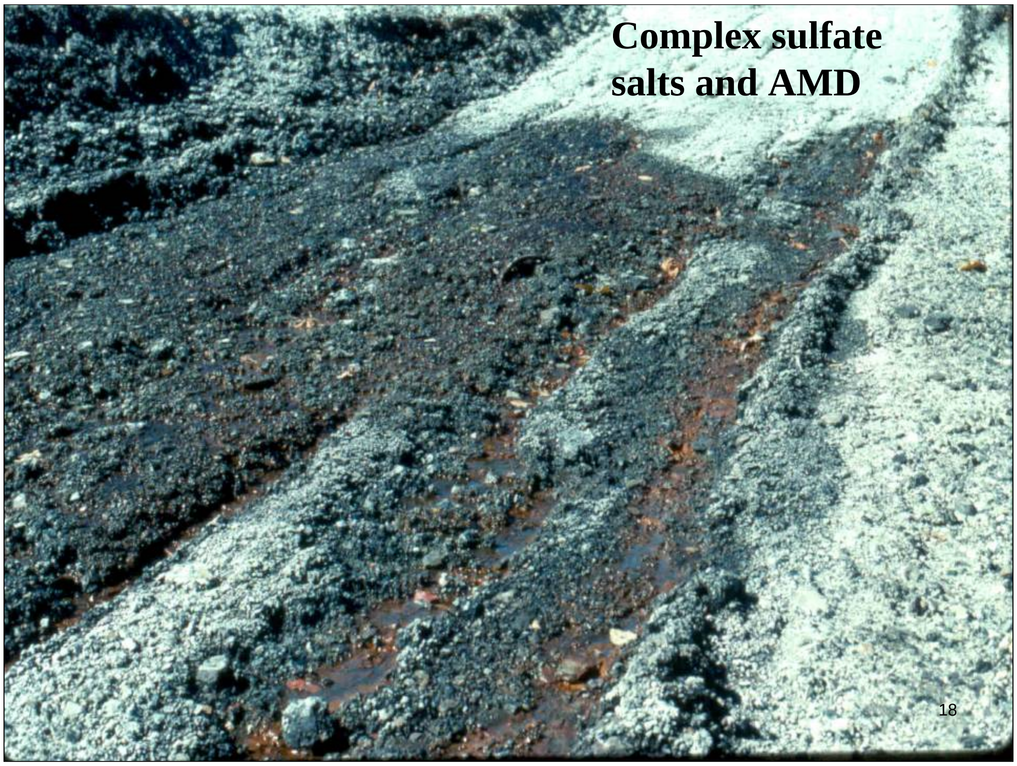
Calcium cycling and mineralization to solution by the forest litter turnover process also offsets Al phytotoxicity



Four Things That Limit Reclamation Success!

1. **Sulfidic/Pyritic acid forming materials must be avoided or neutralized for any successful stabilization project. Worldwide, there is no doubt that acid-sulfate weathering processes are the major risk to environmental quality from any drastic land disturbance.**

17


Complex sulfate
salts and AMD
18


AMD impact in northern WV. Picture by Jeff Skousen, WVU
19

Prediction of Net Acid Release

- **Potential Acidity** is the total amount of acidity that a given pyritic material can theoretically generate over time after complete oxidation.

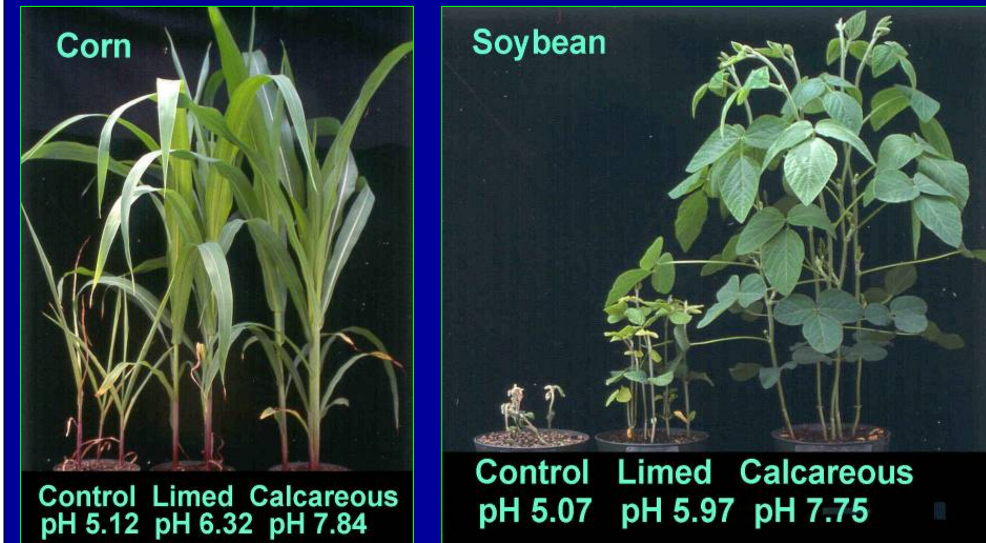
- **Most commonly, this is estimated stoichiometrically based on total pyritic-S in a given sample.**

20

Toxic Heavy Metals

- **Pyrite oxidation commonly produces high concentrations of Fe, Mn, Zn, Cu, Pb and occasionally Ni, As and Mo in the weathered mine spoil and in receiving waters.**
- **The low pH generated by pyrite oxidation commonly enhances the solubility and mobility of many metals.**

21



Amelioration of nickel phytotoxicity in smelter impacted soils by liming. Slide courtesy of Kukier and Chaney, USDA.

22

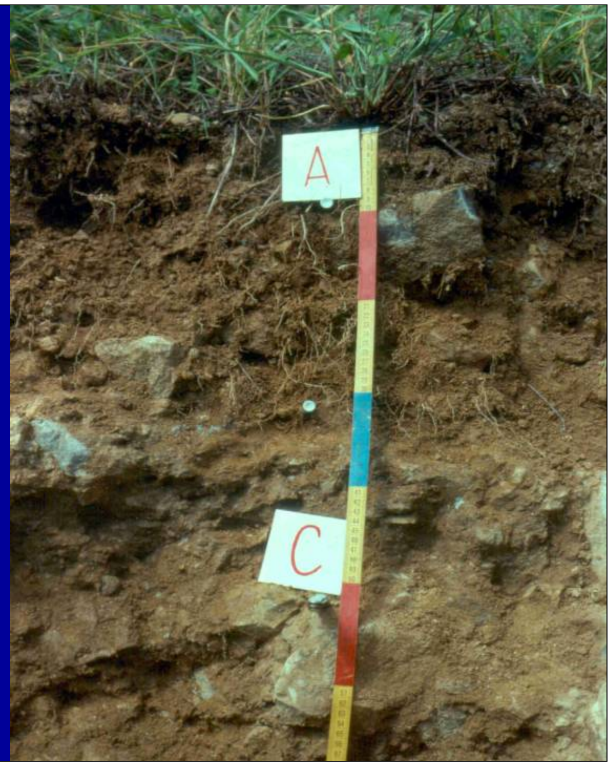
Four Things That Usually Limit Reclamation Success!

2. **Compaction is the most common limiting factor in disturbed lands worldwide. Many mine soils with otherwise suitable chemical and physical properties are of very low quality due to severe compaction.**

3. **Very coarse textures (sands) or high rock contents limit the water holding and effective rooting volume of many disturbed land soils.**

23

Regardless of their overall acidity and fertility status, the number one limitation to plant growth in disturbed soils worldwide is ***severe compaction.***



Benefits of Topsoil

Whenever it is economically feasible, native topsoils should be salvaged and re-applied to final reclamation surfaces.

In general, native soil materials will be much higher in organic matter, available N and P, and perhaps most importantly, beneficial microbial populations than any topsoil substitute materials.

25


Mixed Topsoil + Weathered
Overburden (A+B+C+R)
Rocky (15% fines),
High pH (7.5)
Sandstone Spoil
26

Four Things That Limit Reclamation Success!

4. Assuming you've avoided acid forming materials, compaction, and excessively sandy/rocky materials, the last thing you really have to be concerned about is slope/aspect/albedo effects. For example, black coal waste on a 35% south-facing slope is going to be very, very difficult to stabilize without significant soil amendments due to heat loads and drought stress.

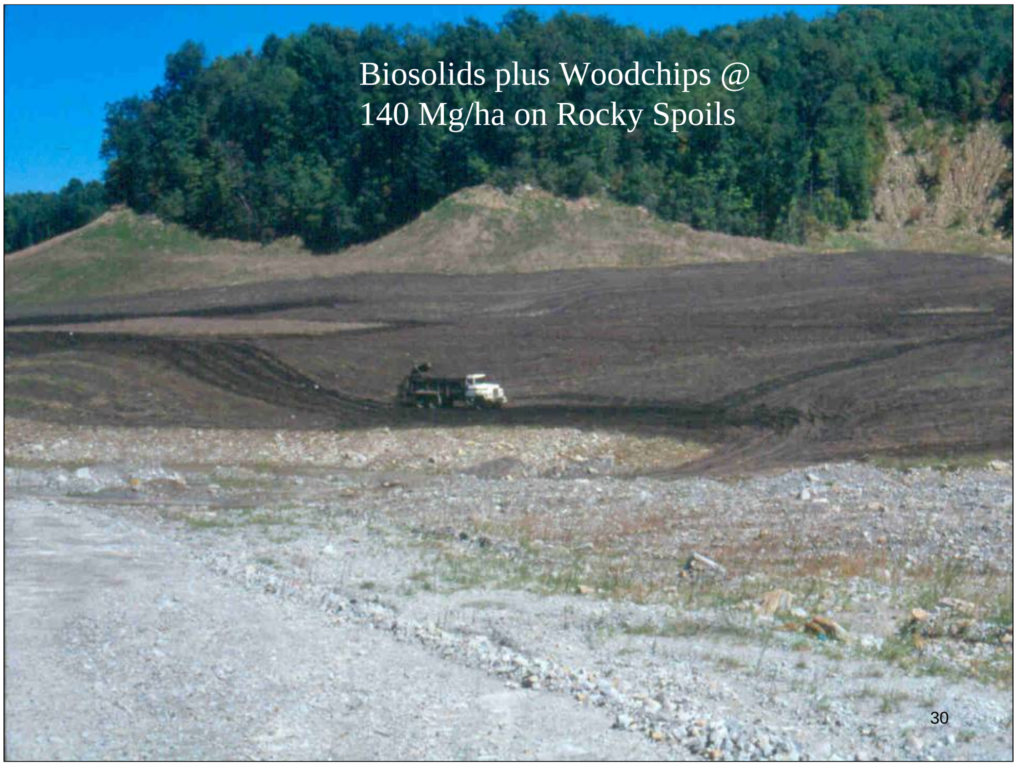
27

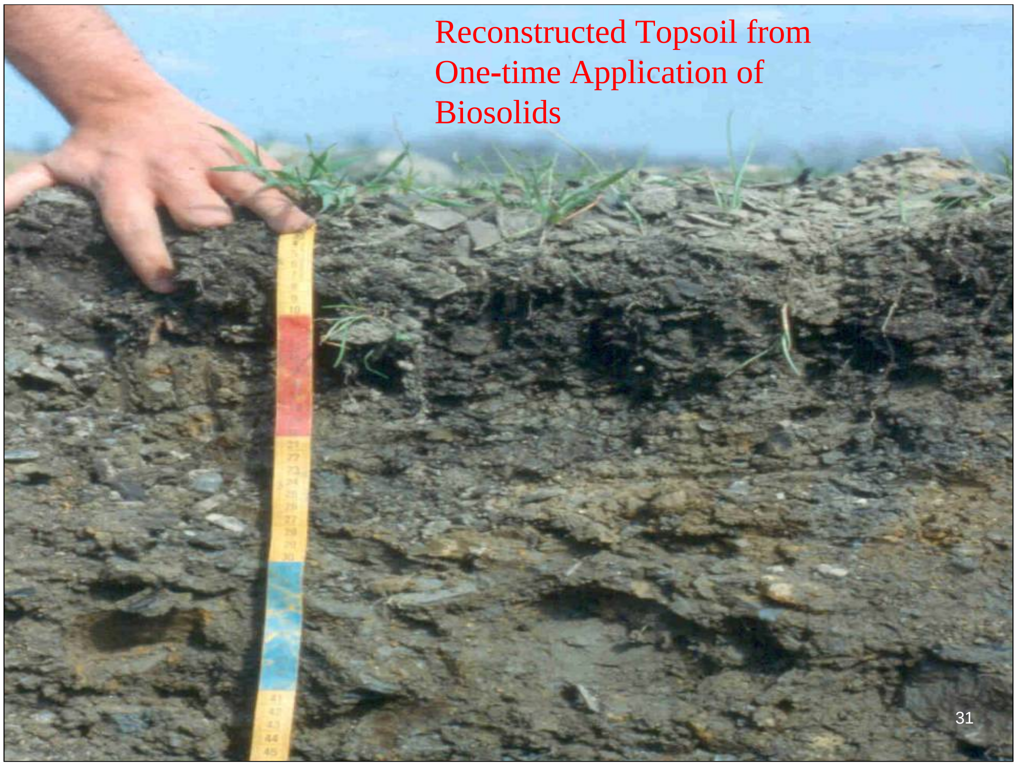

Incorporation of 45 Mg/ha lime on sulfidic coal waste materials.
28

Soil Amendments

Once you take care of the four basic challenges pointed out earlier, you can start working towards really improving the quality of drastically disturbed soils via the addition of appropriate soil amendments such as compost, manures, biosolids, waste limes, alkaline fly ash, etc..

29


Biosolids plus Woodchips @
140 Mg/ha on Rocky Spoils
30


Reconstructed Topsoil from
One-time Application of
Biosolids
31


100 Mg/ha Yardwaste Compost + Deep Ripping, + 400 kg/ha P, + 8 Mg/ha Lime applied to Mineral Sands Tailings/Slimes
30 cm of Topsoil over Ripped/Limed Tailings/Slimes
32
10 13 '95

Other Important Chemical Properties

- Salinity (estimated by EC)
- Sodium content (estimated by ESP or SAR)
- Toxic Metals/Oxyanions

33

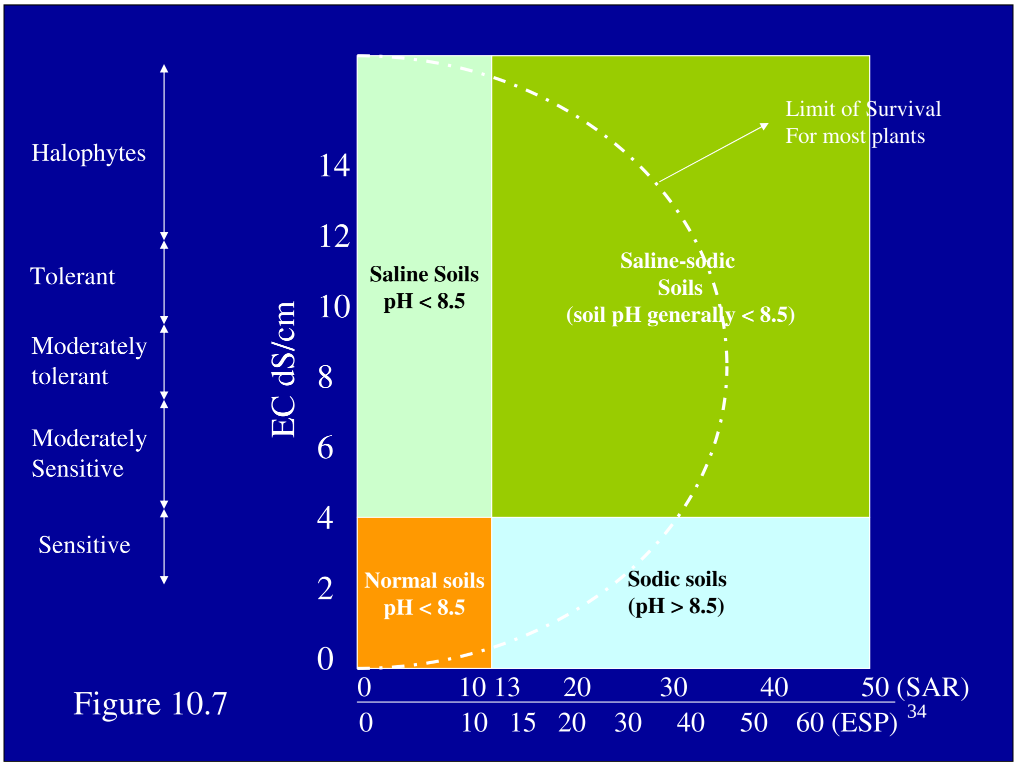

Halophytes
Tolerant
Moderately tolerant
Moderately Sensitive
Sensitive
EC dS/cm
14
12
10
8
6
4
2
0
Saline Soils
pH < 8.5
Saline-sodic Soils
(soil pH generally < 8.5)
Limit of Survival
For most plants
Normal soils
pH < 8.5
Sodic soils
(pH > 8.5)
0 10 13 20 30 40 50 (SAR)
0 10 15 20 30 40 50 60 (ESP)
34

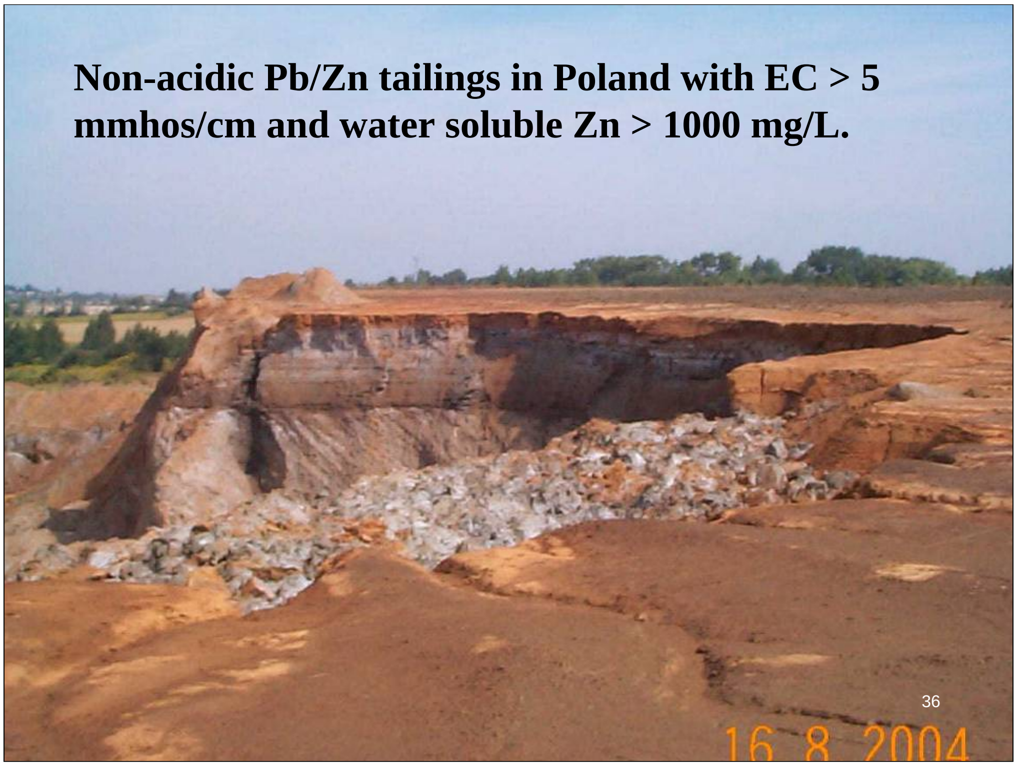
Figure 10.7

Salinity in Mine Soils and Wastes

- Generally tends to be due to sulfates from pyrite oxidation or sulfuric acid processing.
- EC values (based on KCl standards) underestimate the total "salt load" in most mine soils since sulfates do not conduct as well as chlorides!
- EC can be $\geq$ 15 mmhos/cm or ds/m in smelter wastes; commonly > 5 in actively oxidizing pyritic materials or recent fly ash amended systems.

35

Non-acidic Pb/Zn tailings in Poland with EC > 5 mmhos/cm and water soluble Zn > 1000 mg/L.



Three Important Principles

In order to develop appropriate reclamation protocols for any site, we must develop a detailed understanding of:

1. Soil, biotic and water quality conditions before disturbance or in an appropriate reference area.

37

Three Important Principles

2. We must thoroughly understand the nature of the site development process and how it impacts soil and site conditions during and after disturbance.

3. We must be able to predict how soil, site, and vegetation conditions will change with time after reclamation is initiated.

38

Summary

- Virtually any mine waste or overburden material can be successfully reclaimed and revegetated once the appropriate suite of analyses have been conducted.

- Sulfidic wastes (> 0.3% pyritic-S) must be isolated away from the final reclamation surface, or very high rates of suitable liming materials must be utilized and incorporated.

39

Summary

- Assuming sulfidic materials are eliminated, long term revegetation success in mine soils is most commonly limited by compaction in most mining environments, and excessive rockiness in certain mining environments.

- Waste products such as biosolids and fly ash can have great utility for enhancing mine soil physical and chemical properties.

40

Part II – Recreating Soil Chemical and Physical Properties Important for Remediation and Revegetation

“Simple” Pyrite Oxidation

(Singer & Stumm 1970; Nordstrom, 1982)

$FeS_2 + 7/2O_2 + H_2O \longrightarrow Fe^{II} + 2SO_4^{2-} + 2H^+$ (1)

$Fe^{II} + ¼\ O_2 + H^+ \longrightarrow Fe^{III} + ½\ H_2O$ (2)

(Direct oxidation; relatively slow)

$Fe^{III} + H_2O \longrightarrow Fe(OH)_3 + 3\ H^+$ (3)

$FeS_2 + 14Fe^{III} + 8H_2O \longrightarrow 15Fe^{II} + 2SO_4^{2-} + 16H^+$

(Oxidation by Fe^{III}; very fast under pH < 4.5) (4)

42

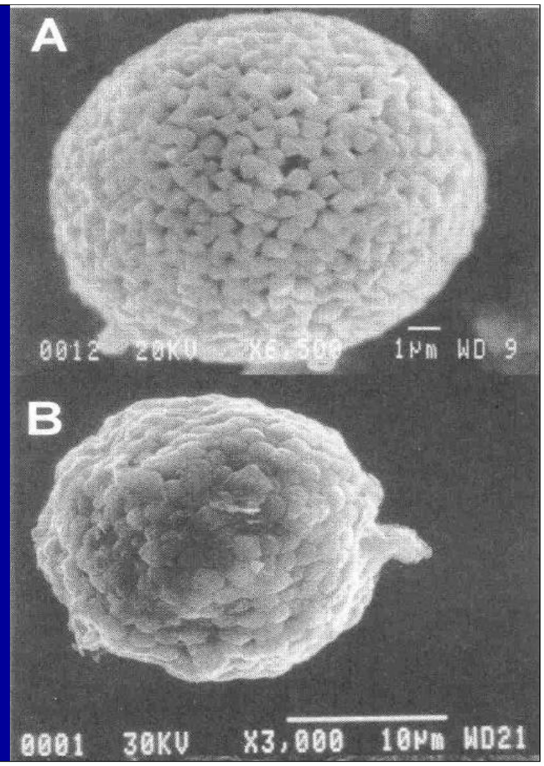
Potential Acidity Estimators for Water Quality Prediction

Acid-Base Accounting - *Smith et al., 1976* - WVU

ABA is the most commonly used technique worldwide to estimate the tendency of a given material to generate acid soil conditions and associated drainage. The resultant estimate is termed "*Potential Acidity*", and hopefully gives a conservative estimate of how much lime demand a given strata or waste will require to fully mitigate or neutralize over extended periods.

43

Framboidal pyrite forms from Fanning et al. (2002). Finely divided framboidal pyrite is much more reactive than larger and more crystalline forms.



44

Theoretical Maximum Potential Acidity (MPA) via Carbonate Neutralization *(Skousen et al., 2002)*

$$FeS_2 + 2CaCO_3 + 3.75O_2 + 1.5H_20 \longrightarrow$$

$$2SO_4^{\ 2-} + 2Ca^{\ 2+} + 2CO_2$$

Result: ***1000 Mg of waste at 1% pyritic-S requires 31.25 Mg of CCE to neutralize.***

45

ABA Interpretation and Issues

Strata with net acidities in $\leq$ -5 Mg per 1000 are generally regarded as <u>potentially toxic</u>. Strata $\geq$ 0 are presumed not to be acid forming. Predicting between 0 and –5 is something of an art. ***<u>Note: we use the parts per thousand unit because it = tons of lime per acre 6 inches deep.</u>***

ABA “assumes” complete reaction of acid-forming components with neutralizers. However, pyrite oxidation kinetics are much faster than carbonate dissolution!

ABA Interpretation and Issues

Carbonates may become "coated" with Fe, Mn and other metals, greatly restricting reactivity and alkalinity release.

Carbonate species vary widely in their dissolution rates and in the subsequent solubility of their sulfate salt reaction products.

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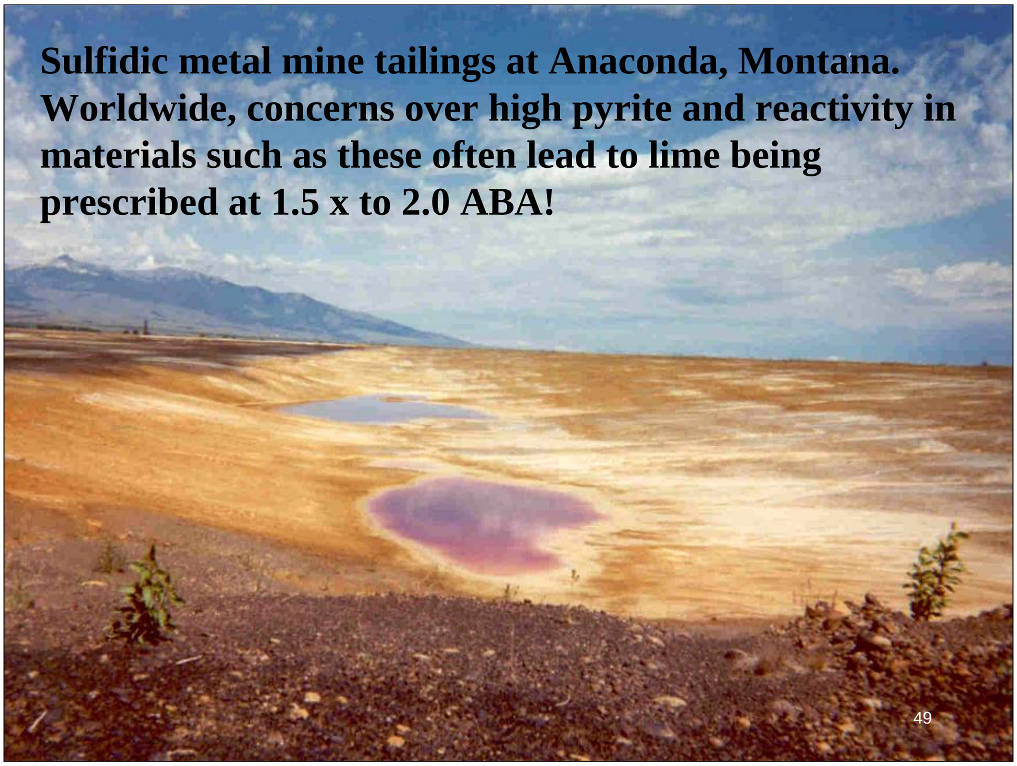
48


Sulfidic metal mine tailings at Anaconda, Montana. Worldwide, concerns over high pyrite and reactivity in materials such as these often lead to lime being prescribed at 1.5 x to 2.0 ABA!
49

Other P.A. Techniques

- Direct bulk oxidation with H_2O_2 and titration of acid load produced (Potential Peroxide Acidity - PPA).
- Humidity cells and incubation techniques (Used in Soil Taxonomy for sulfidic materials definition)
- Leaching columns (See Stewart's ash leaching papers on web site)
- Soxhlet Reactors (Stiller and Renton at WVU)

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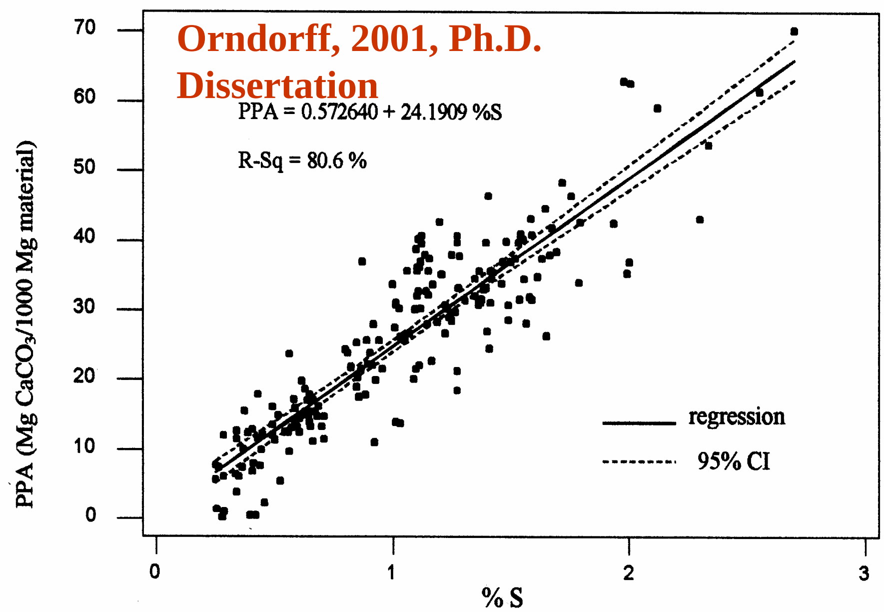

Figure 5.5. Regression analysis for potential peroxide acidity (PPA) and %S for samples with greater than 0.25% S.

51

Summary

- Pyrite oxidation has profound effects on soil and water quality in a variety of geologic setting worldwide.

- Accurate prediction of pyrite oxidation and net water quality effects is complicated by differences in the kinetics of oxidation of varying sulfides and carbonate dissolution, microbial interactions, complex secondary salt precipitation and dissolution, carbonate armoring, and other poorly understood factors.

52

Reconstructing New Soils on Mining and Remediation Sites

Note: This material is covered in two Powell River Project Bulletins for the Appalachian example and by posted papers on the Coastal Plain mineral sands example.

http://www.cses.vt.edu/revegetation/

53

Oxidized, pH 5.5 overburden over reduced carbonate (2%) containing overburden at depth.

54

Table 1. Topsoil substitute selection criteria for Southwest Virginia. Criteria are listed in order of importance.

Potential Acidity	Determined by acid-base accounting by competent lab. Should be net neutral or better (0 to positive values). Materials with values less than -5 tons per thousand $CaCO_3$ requirement must be avoided.
Rock Type	Mixtures of sandstones and siltstones/shales are superior to unmixed spoils. Avoid pure fine siltstone and shales when possible.
Extractable Nutrients	Useful for general comparisons among candidate materials, but cannot be literally interpreted in terms of plant availability or for fertilizer recommendations.
pH	Not reliable as a predictor of the long term soil quality for unweathered mine spoils. Values less than 4 indicate that pyrite oxidation has occurred.
Soluble Salts	Avoid when > 4 mmhos/cm (or 5000 ppm). Many pasture legumes and other salt sensitive crops will be affected at much lower values (< 3000 ppm). Generally not a problem as long as acid forming materials are avoided.
Weathering Extent	Brown oxidized strata will blast to finer spoils with higher water and nutrient holding capacities. However, oxidized strata will be lower in pH and extractable nutrients (P, Ca, Mg, K).
Thickness/ Location	Any designated topsoil substitute strata must be present in sufficient thickness and location within the overburden section to be economically isolated and hauled by the active mining operation.

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Typical unweathered Appalachian rock spoils being graded

Final grading should be minimal to avoid compaction!

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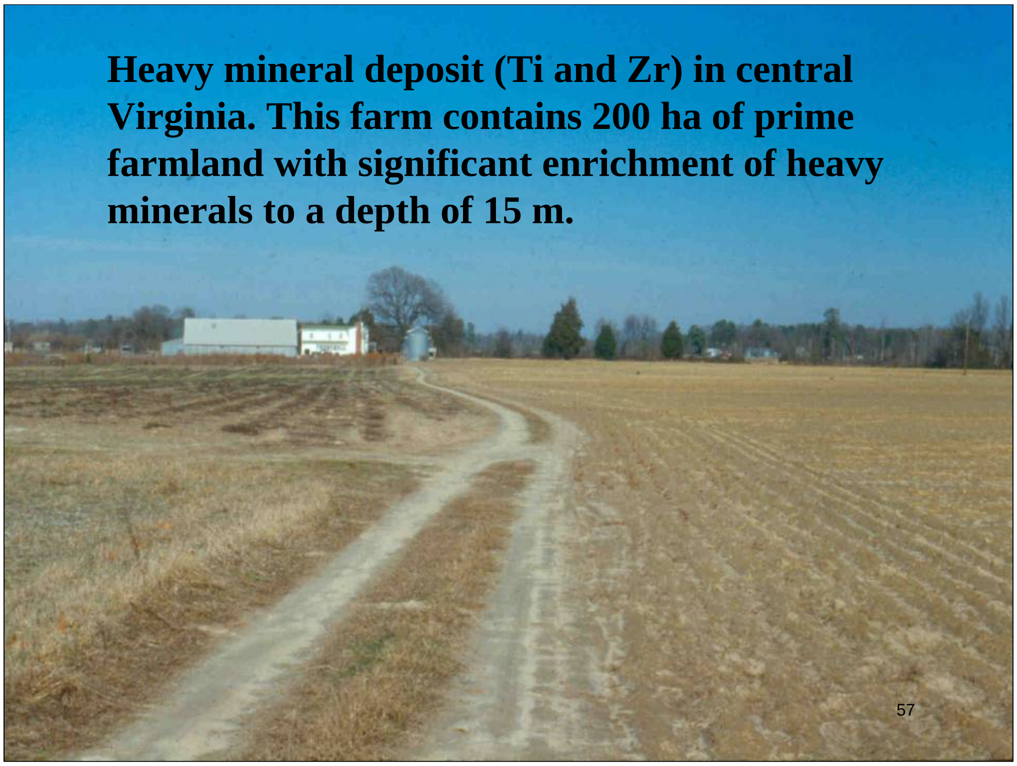
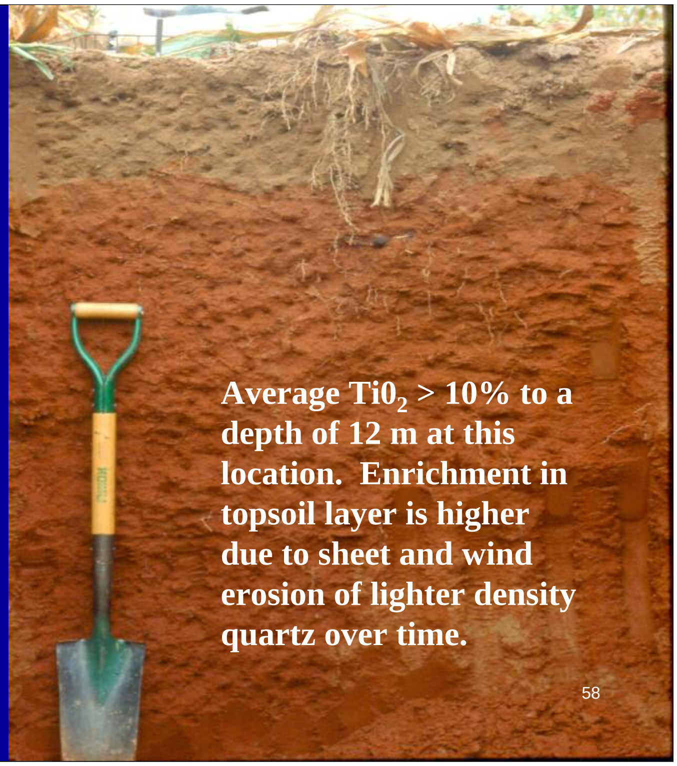
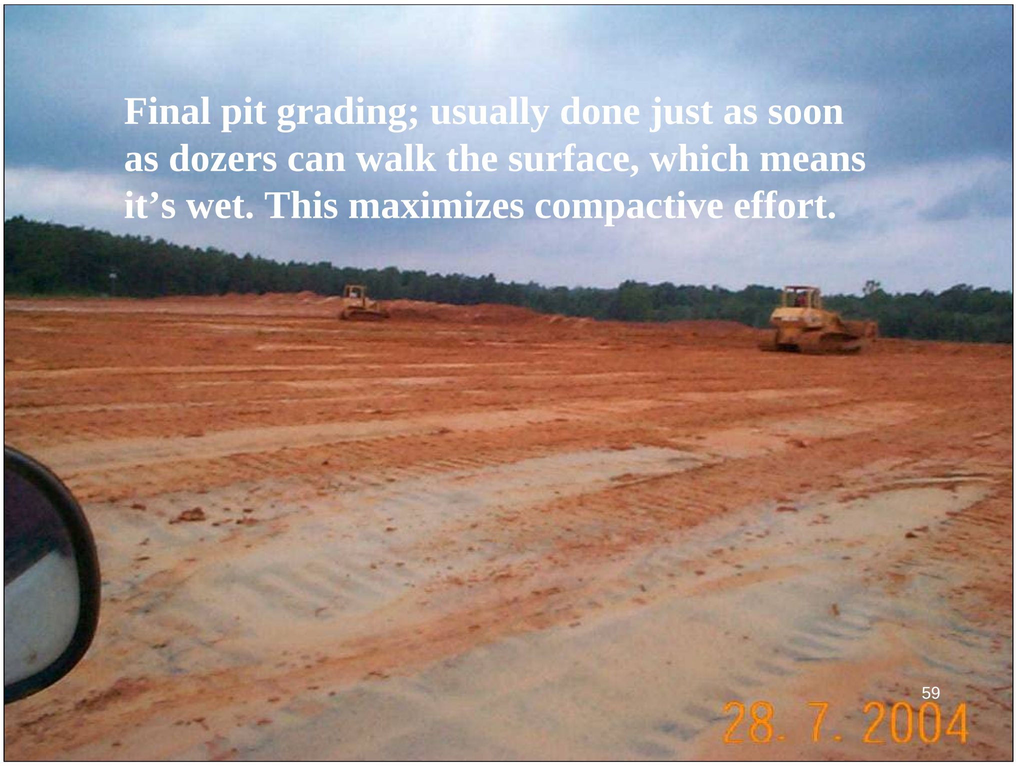

Heavy mineral deposit (Ti and Zr) in central Virginia. This farm contains 200 ha of prime farmland with significant enrichment of heavy minerals to a depth of 15 m.
57

Typical highly productive soil in the Old Hickory area. Rutile-Ilmenite (TiO_2) and Zirconium (Zr) are present between 5 and > 20% w/w from the topsoil down to > 10 m in some locations.




Final pit grading; usually done just as soon as dozers can walk the surface, which means it’s wet. This maximizes compactive effort.
59
28. 7. 2004

Surface of mine soil at Old Hickory. Note dense, massive layered appearance. No structure or roots with depth. Topsoil has been returned here, but also appears at depth due to poor materials management.

60

Directly adjacent area **that received the appropriate ripping treatment. Note lack of standing water and "loose" appearance of surface.** 61

This is the "appropriate ripper" for these kinds of soil problems! The company estimates that they can rip these soils for < $200 per acre, a very reasonable cost; less than seed plus fertilizer! 62

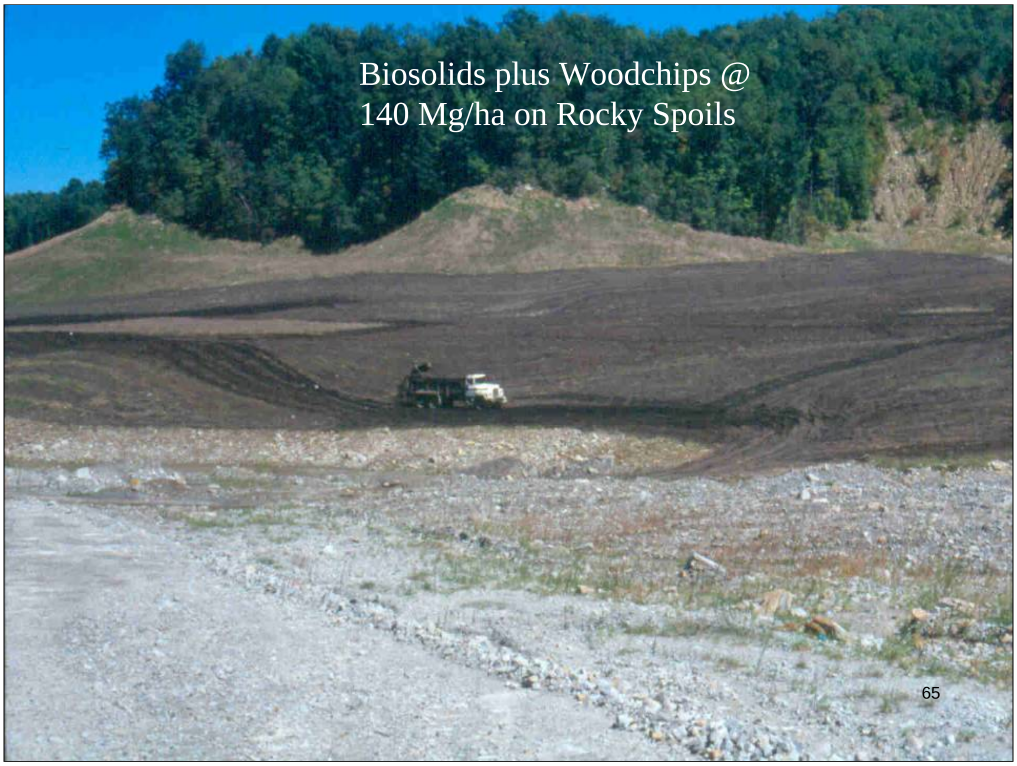
Use of Organics in Land Reclamation and Associated Water Quality Effects

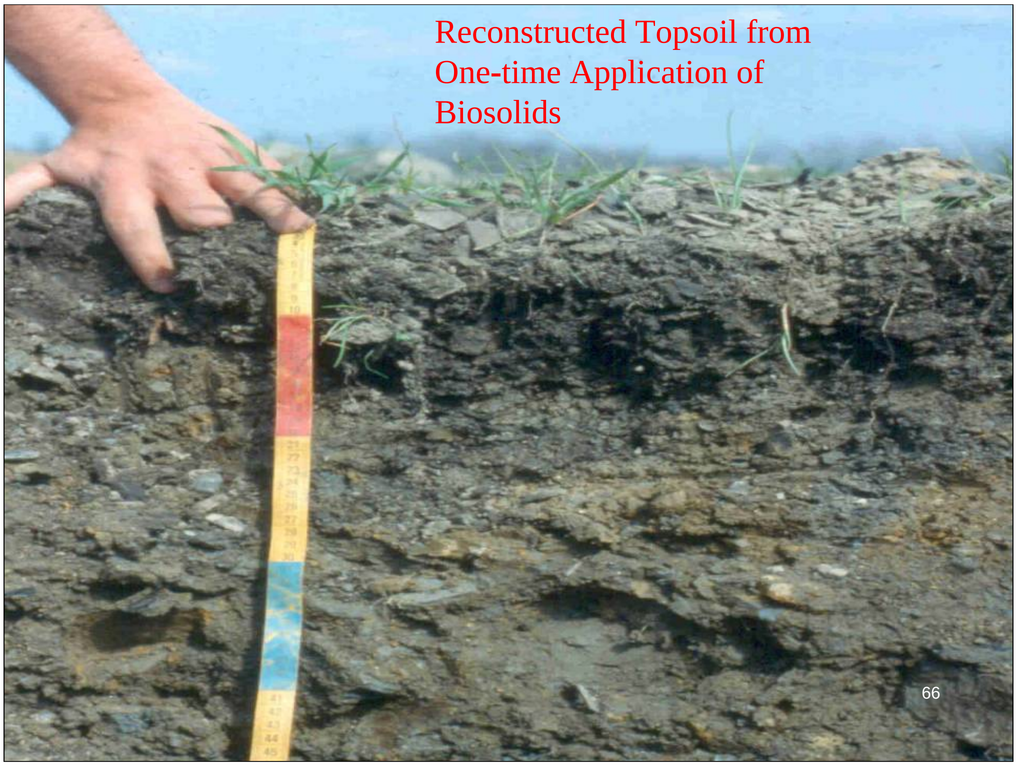
63

History and Background

- Biosolids have been used at higher than agronomic rates on coal surface mined lands in the Appalachians since the 1970’s.
- Research at Penn State and Va Tech has confirmed the benefits of this practice and indicated a general lack of ground- and surface-water impacts.

64


Biosolids plus Woodchips @
140 Mg/ha on Rocky Spoils
65


Reconstructed Topsoil from
One-time Application of
Biosolids
66

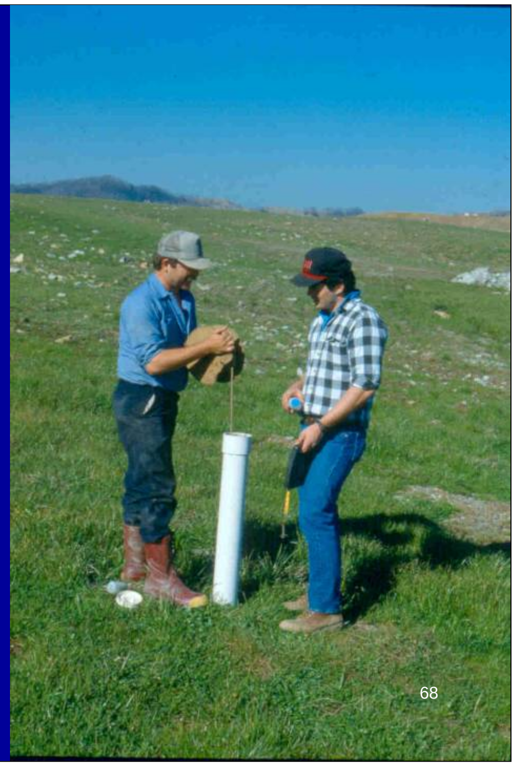
Nutrient and metal loading rates at mine mix application rate of 368 Mg/ha.

Element	kg/ha added
C	121,258
N	4416
P	2551
Ca	6039
Mg	2016
Zn	167
Cu	108
Pb	58
Ni	27
Cd	1

67

Over a five-year period, a 150 ha application of 140 Mg/ha of biosolids + woodchips (C:N = 30) had no effect on ground water NO_3 levels.

In fact, NO_3 levels were highest before application due to the use of NH_4NO_3 explosives!



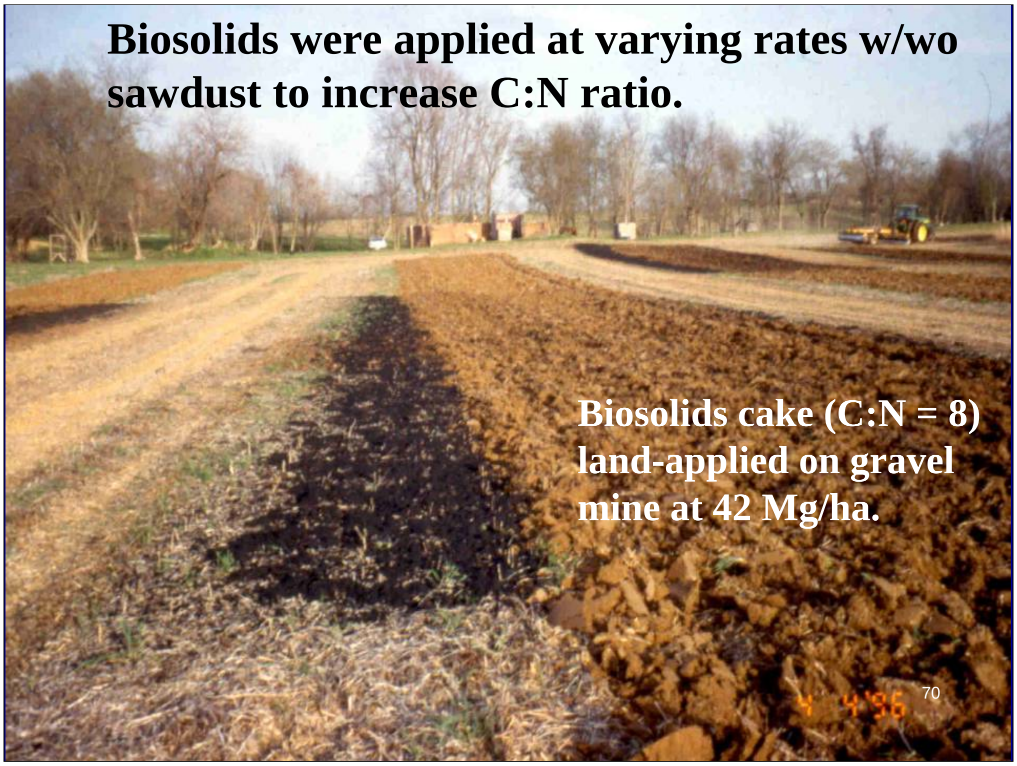
68

History and Background

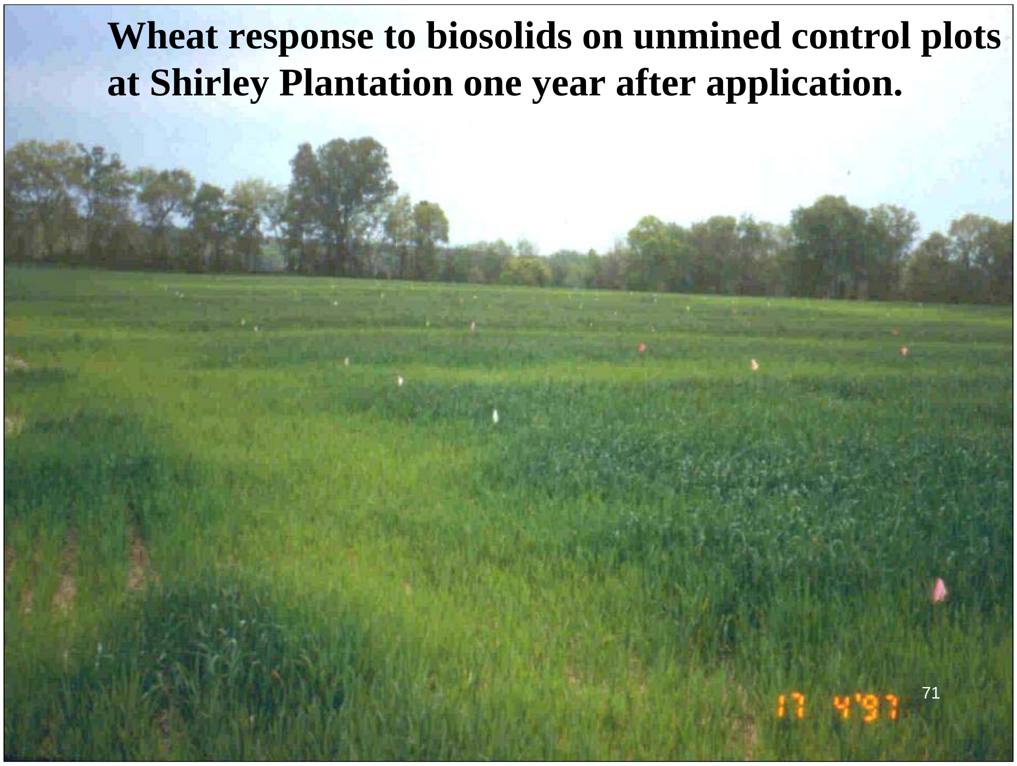
In 1995, the State of Virginia Dept. of Mines, Minerals, and Energy developed guidelines for the application of biosolids to coal mined lands (VDMME, 1995) with Virginia Tech's assistance. Common rates were 35 to 50 T/Ac.

Concerns over application of these rates to sand & gravel mines in the C. Bay watershed led to studies at Shirley Plantation into loading rate X C addition effects on nitrate-N leaching.

69


Biosolids were applied at varying rates w/wo sawdust to increase C:N ratio.
Biosolids cake (C:N = 8) land-applied on gravel mine at 42 Mg/ha.
70

Wheat response to biosolids on unmined control plots at Shirley Plantation one year after application.




Well!
Sampling from zero-tension lysimeter @ 1 m.
2 26 '97
72

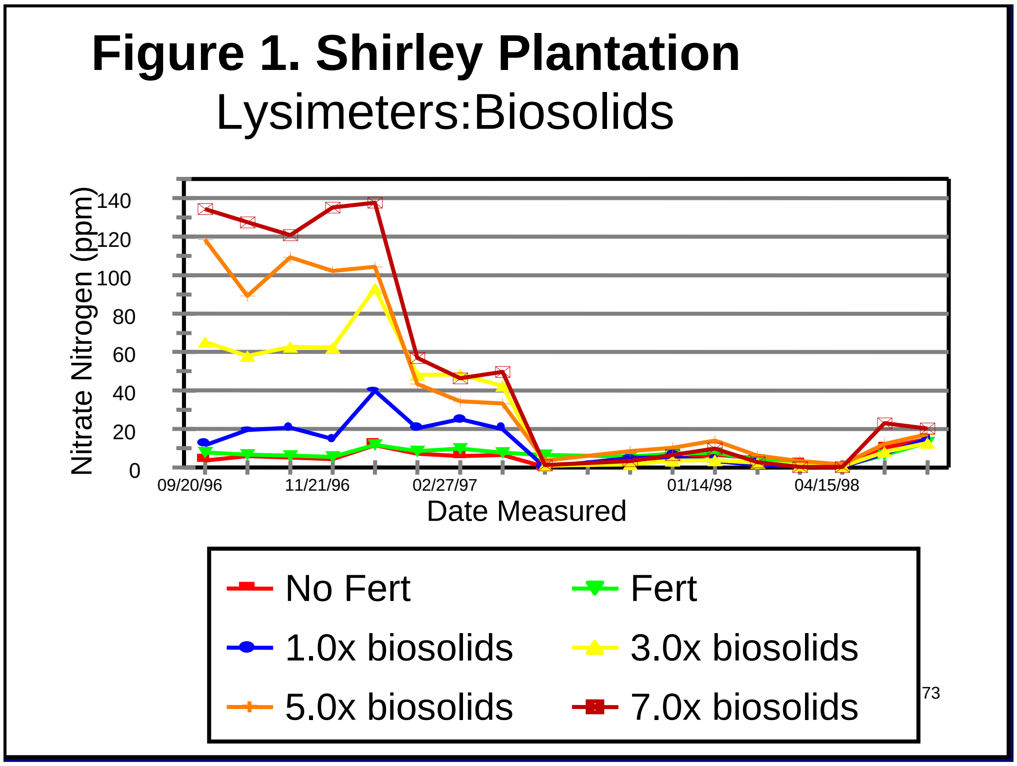
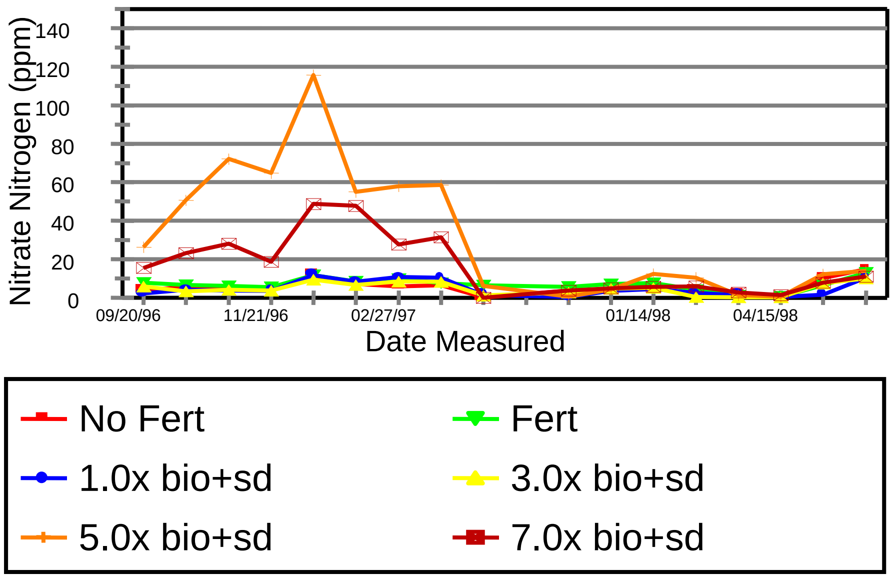


Figure 1. Shirley Plantation
Lysimeters:Biosolids
Nitrate Nitrogen (ppm)
140
120
100
80
60
40
20
0
09/20/96
11/21/96
02/27/97
01/14/98
04/15/98
Date Measured
No Fert
Fert
1.0x biosolids
3.0x biosolids
5.0x biosolids
7.0x biosolids
73

Figure 2. Shirley Plantation

Lysimeters:Biosolids + Sawdust

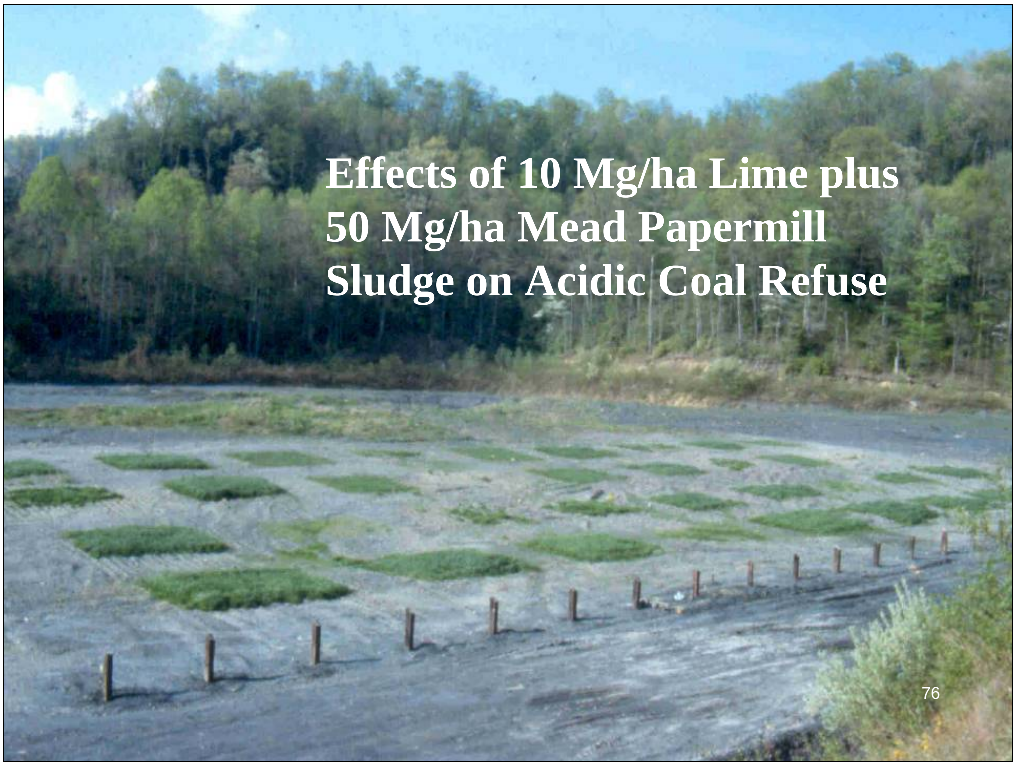


74

Findings at Shirley

- Root zone leachates (@ 75 cm) showed enhanced nitrate-N leaching potentials the first winter after biosolids application that were directly related to loading rate and C:N ratio.
- Treatment effects were only noted the first winter after a spring application.
- Four adjacent shallow ground-water wells showed no effects of the loadings.

75


Effects of 10 Mg/ha Lime plus
50 Mg/ha Mead Papermill
Sludge on Acidic Coal Refuse
76

Mead Paper Results

The mixed residual product was an outstanding soil amendment due to its net positive effects on pH, water holding capacity, and fertility.

Adding fertilizer N beyond 100 lbs per acre had no effect on vegetation, despite a high C:N ratio (> 100 but confounded by carbonates).

77

Mill Sludge Land App. Issues

- Every mill sludge from every plant we've looked at (> 10 counting "paper studies") is different. Mill sludges are ***much*** more variable than biosolids.

- Sodium and EC are land application limiting for certain materials

- Stability and phytotoxicity appear to be problematic for some materials

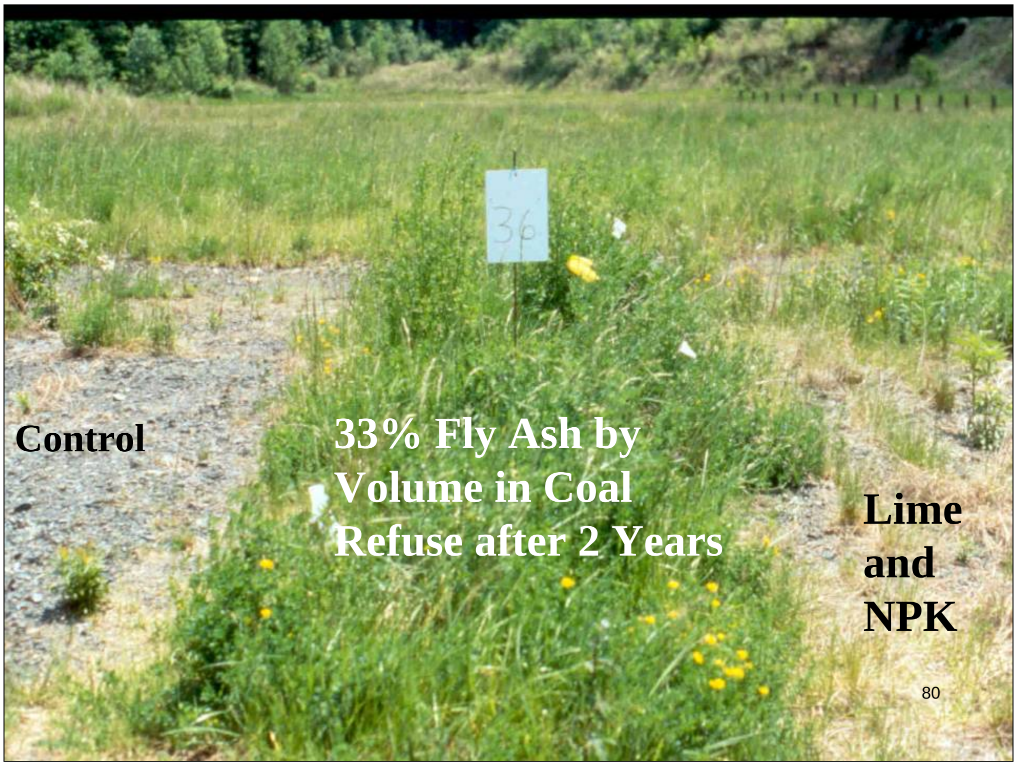
78

Mill Sludge Land App. Issues

- The basic relationships among C:N ratio, immobilization and plant available N over time are obviously different for mill sludges! Labile/palatable C is often very low, so microbes don’t immobilize N.

- Dioxins (and isomers) will continue to be a public issue for many bleached products, along with other trace organics.

79

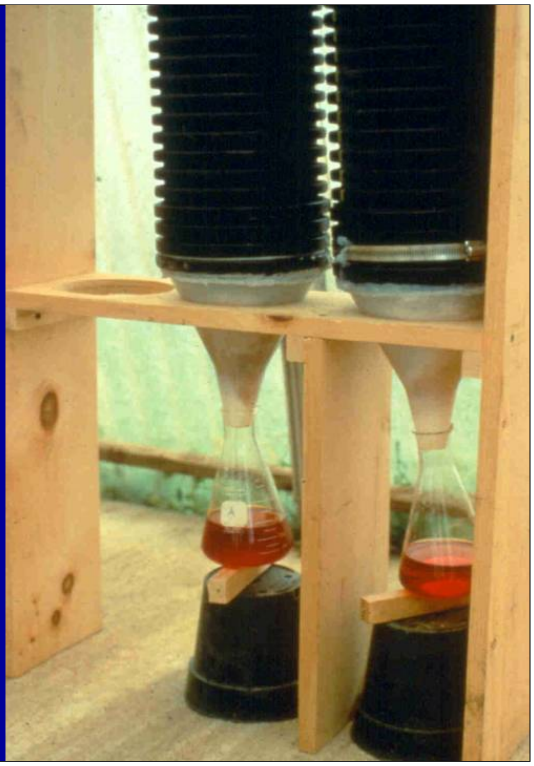

Control
33% Fly Ash by Volume in Coal Refuse after 2 Years
Lime and NPK
80

Soluble salt/B damage on soybean plants grown in sandstone mine spoil amended with 10% coal fly ash.

Most legumes are very sensitive to salt damage, so seeding should be delayed until after salts leach where possible.

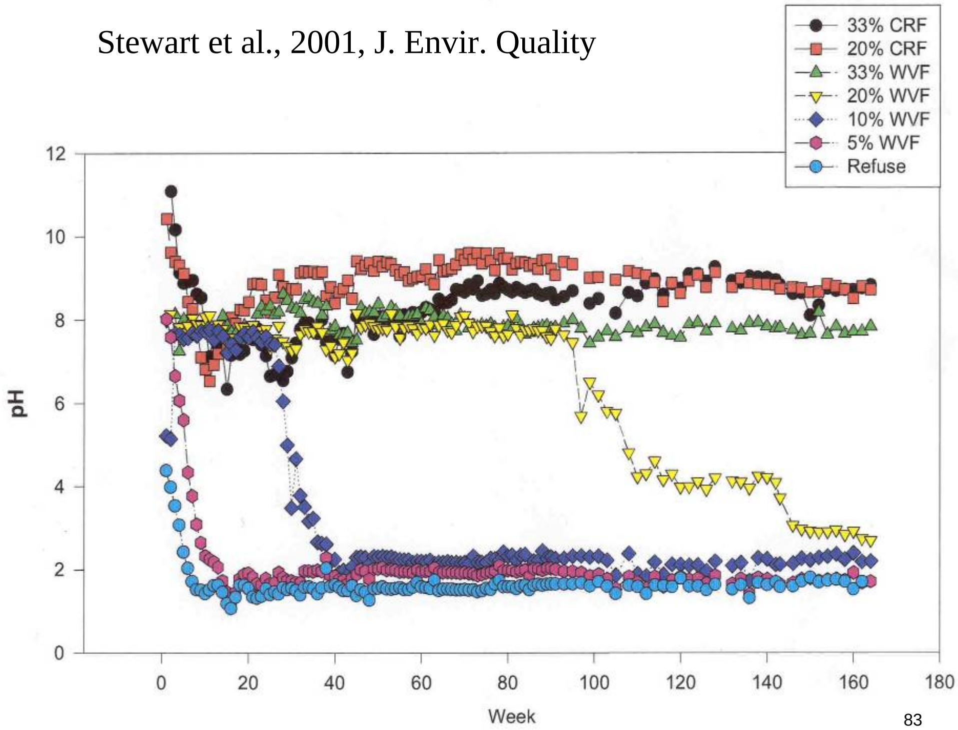
81

Acid mine drainage (pH=2.3; Fe=10,000 ppm) from unsaturated leaching of high S coal refuse (4% pyritic-S).



82

Stewart et al., 2001, J. Envir. Quality



EPA White Paper on Residuals

Ellen Rubin (USEPA) is currently leading an effort of over 10 persons to develop a fully reviewed “white paper” on the use and application of various industrial and municipal residuals on remediation/revitalization sites.

The white paper includes detailed tables of material characteristics and matrices that match site X residual properties.

84

Liming Disturbed Soils

- Lime is always applied on a calcium carbonate equivalent (CCE) basis, but the alkalinity may be added in numerous lime or alkaline waste amendment forms.
- Most conventional lime recommendations assume incorporation and reaction to 15 cm (6”). Obviously, this can be very difficult in many rocky and compacted mine soils.
- Surface application of lime will have some effectiveness, even if not mixed in.

85

Toxic Metals & Oxyanions

Liming and pH control generally immobilize Pb, Cu, Cd, Ni and other "regular heavy metals".

However, As, Se and Mo can be quite soluble in moderate to high pH soils and may leach or be "bioavailable".

Zn, particularly when present in soluble sulfate complexes, will not precipitate out fully until the pH > 7.5!

Low pH spoils will almost always exhibit Al and Mn toxicity that may be more phytotoxic and soluble than the metals listed above!

86

Liming Mine Soils

Woody species have a wide range of optimal pH. However, most natives (*Pinus*, *Quercus*, etc.) are obviously adapted to the lower pH range of our unlimed soils which typically ranges from 4.5 to 6.0 or so in our coal mining areas.

However, many species employed in reclamation such as hybrid poplars actually do better at pH > 6.0.

87

In most eastern USA mining environments, we're dealing with topsoil substitutes or fairly low quality topsoil replacement. We generally assume that the material has very low organic matter and associated N and P reserves.

N in Mine Soils

- Virtually all mine soils will be very low or completely lacking in plant-available N and P.
- N must be added initially as fertilizer, but the establishment of legumes in the vegetation is critical to long-term N supply. Usually no more than 150 kg/ha of N are added at seeding.
- N-fixation by *Rhizobia* is heavily dependent upon soil available P levels.

89


Mixed
Legume/Grass
Stand
90

P in Mine Soils

- Most mine soil-forage plant system respond dramatically to added P.
- P response in woody species is not always so dramatic; more than likely due to effects of mycorrhizae on their roots!
- P is usually added at 100 to 300 kg/ha as P_2O_5 in conventional seedings.

91

Mine Soil Fertility Management

Phosphorus fertilizer additions are subject to “fixation” losses in high Fe or high Ca mine soils, so the accumulation of organic P in the microbial biomass, vegetation, and soil organic matter pools is critical to long term P availability.

92

Goethite (FeOOH) Coating on Spoil Sand Grain from Wise County in Study by Howard et al. 1988.

93

N and P "Co-Dependency"

- It is likely that the development of an organic-P pool over time is important to limit P losses to fixation by Fe, Al, carbonates etc.
- Biomass accumulation and subsequent OM deposition in soils as litter and dead roots are largely driven by N availability.
- Symbiotic N-fixation by Rhizobia is heavily dependent upon adequate soluble P availability for the microbial biomass.

94

Potassium (N-P-K)

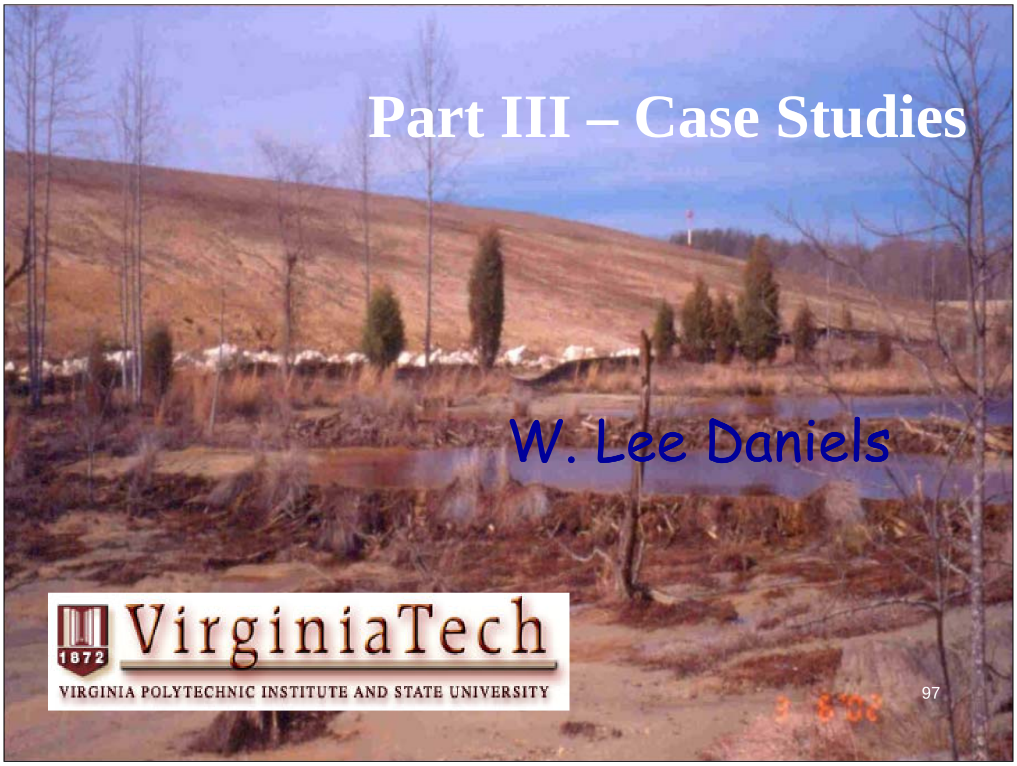
- Usually added at 100 to 200 lbs per acre.
- Grasses can have very high annual K demands, particular if mowed and hay is removed.
- Varies widely by spoil or waste type. Many mine spoils need little if any added K since native amounts are fairly high.

95

Mine Soil Management

- Organic amendments such as sewage sludge biosolids or yardwaste compost are outstanding mine soil amendments when used at “reasonable” loading rates of 50 to 200 Mg per ha (25 to 100 T/Ac).
- Organic amendment benefits overall soil fertility, particularly for N and P, and greatly enhances soil water retention capacity.

96

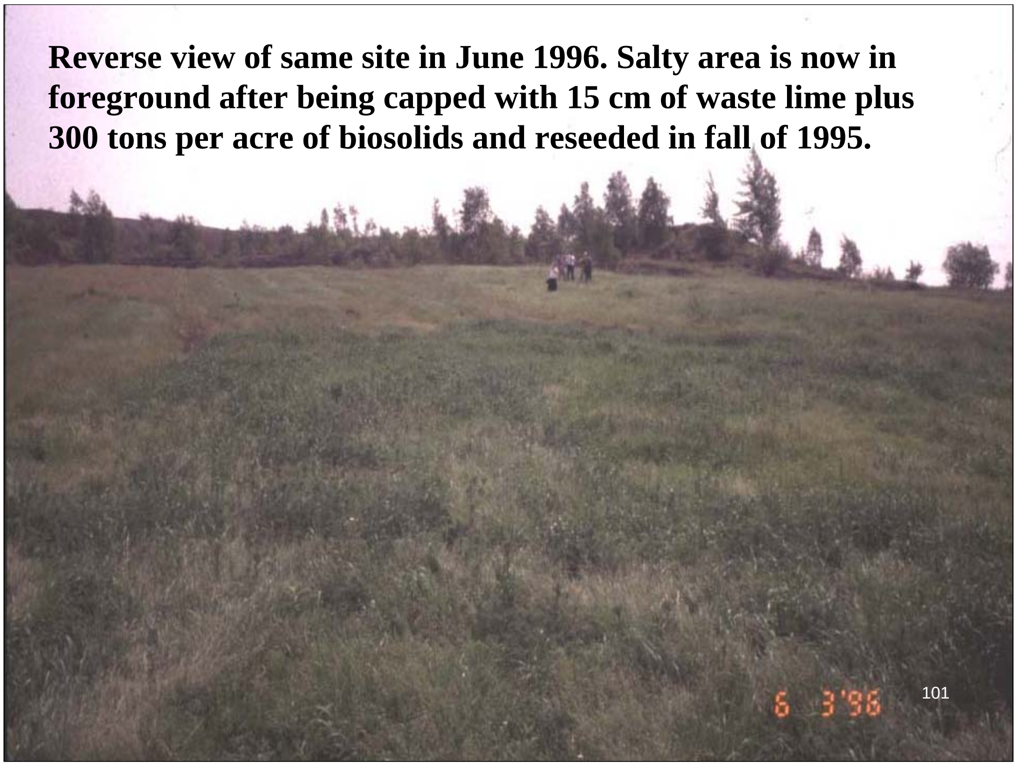

Part III – Case Studies
W. Lee Daniels
VirginiaTech
VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
97


Pb/Zn smelter slag site in Katowice Poland in 1994. Materials were 3 to 10% total-Zn, > 1000 ppm water soluble Zn, and > 90 ppm water soluble Cd.
10 5 '94
98

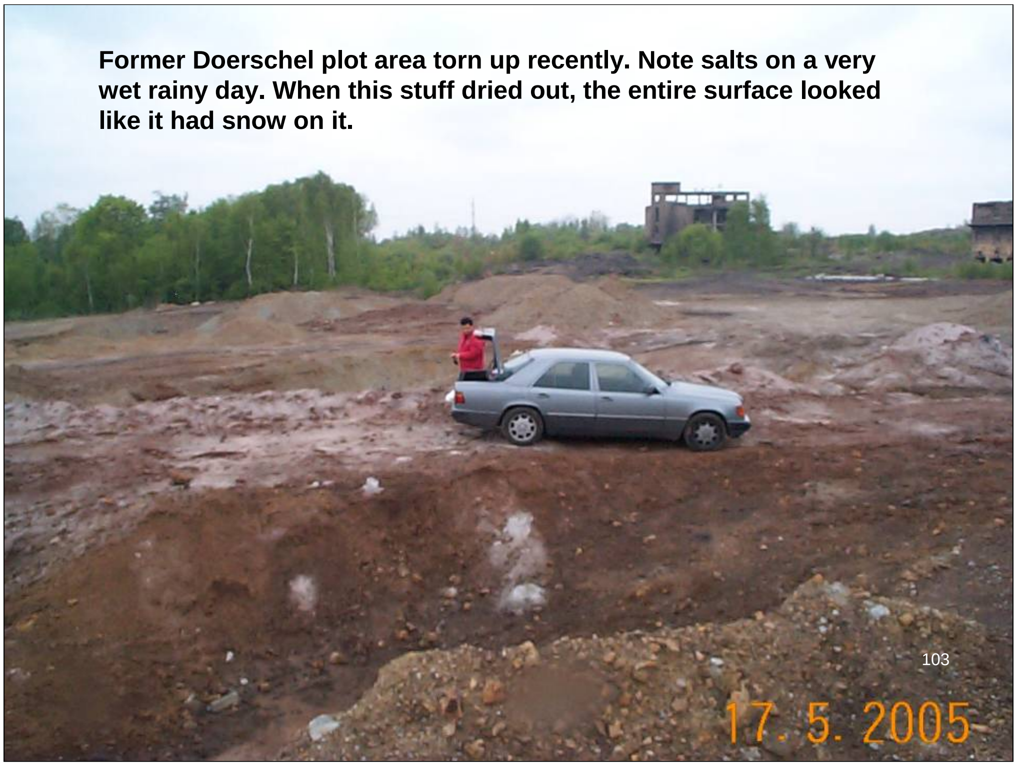
Non-acidic Pb/Zn tailings in Poland with EC > 5 mmhos/cm and water soluble Zn > 1000 mg/L. Both Poland project sites were revegetated via cooperative program with EPA and USDA.

99

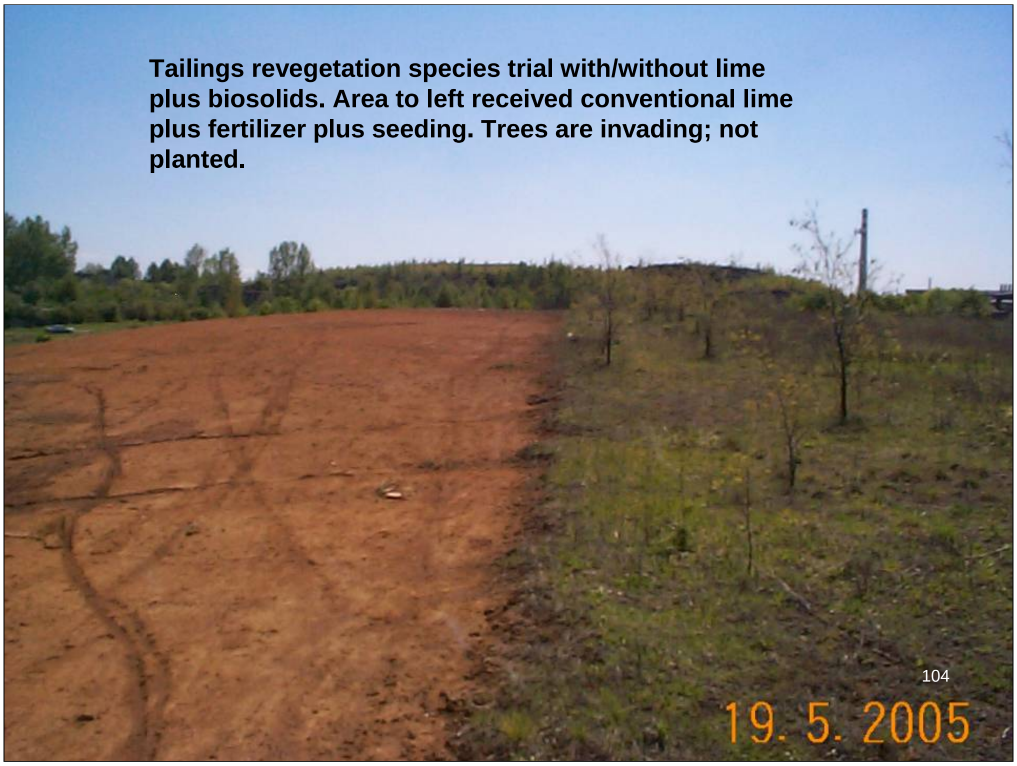
Application of waste lime (partially neutralized CaO from acid water treatment) and biosolids to site at 150 to 300 tons per acre (dry).

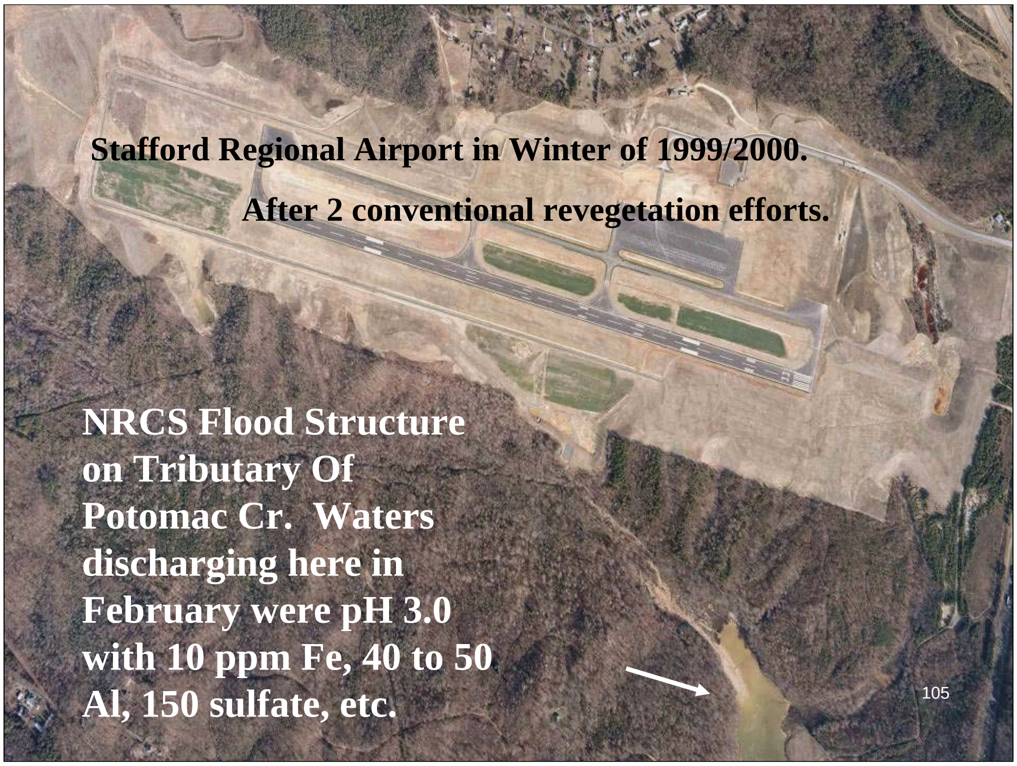

Reverse view of same site in June 1996. Salty area is now in foreground after being capped with 15 cm of waste lime plus 300 tons per acre of biosolids and reseeded in fall of 1995.
6 3 '96
101

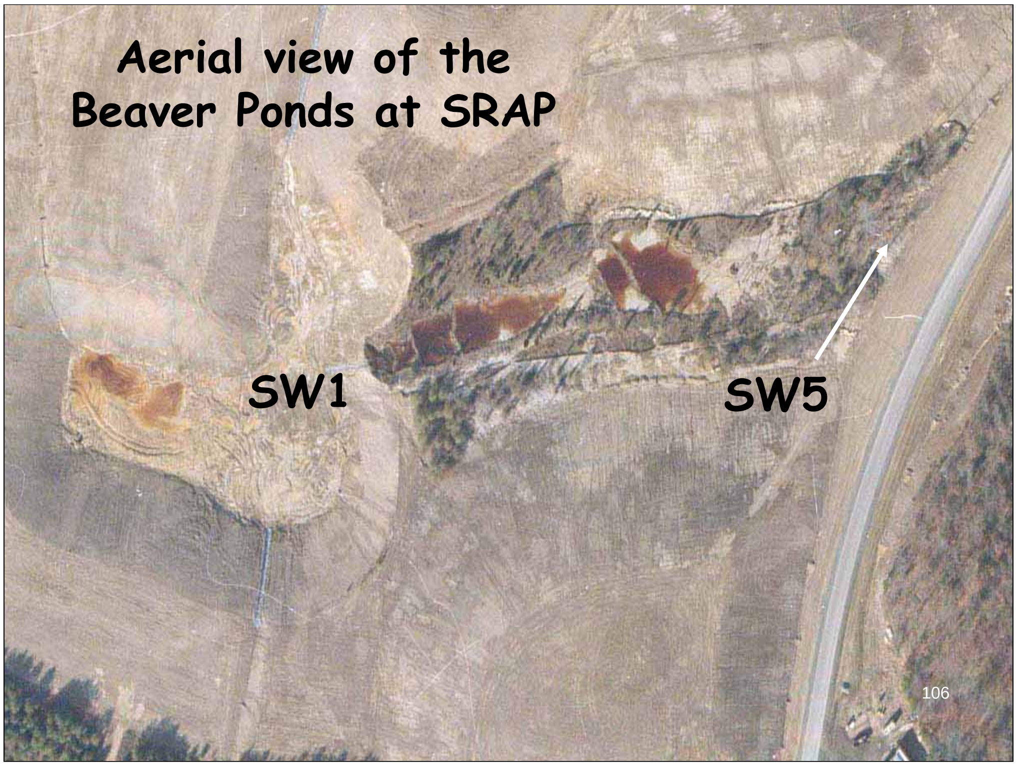

View of treated vs.
untreated Welz;
nothing more to
say?
102
17. 5. 2005



Former Doerschel plot area torn up recently. Note salts on a very wet rainy day. When this stuff dried out, the entire surface looked like it had snow on it.

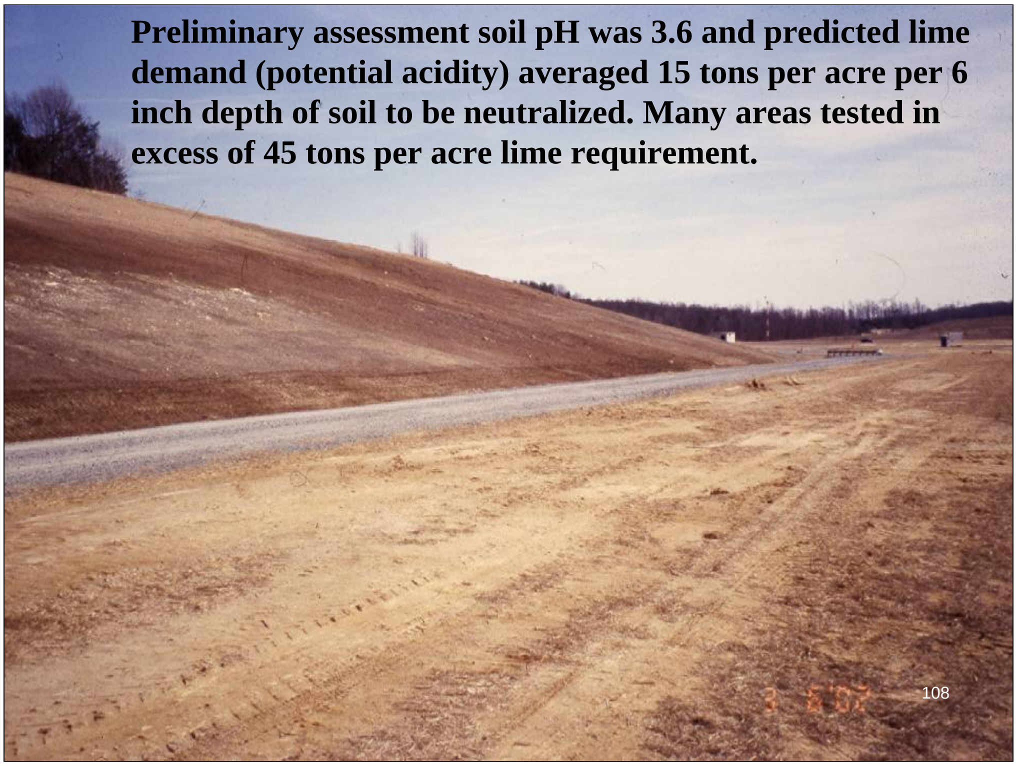

Tailings revegetation species trial with/without lime plus biosolids. Area to left received conventional lime plus fertilizer plus seeding. Trees are invading; not planted.
104
19. 5. 2005


Stafford Regional Airport in Winter of 1999/2000.
After 2 conventional revegetation efforts.
NRCS Flood Structure on Tributary Of Potomac Cr. Waters discharging here in February were pH 3.0 with 10 ppm Fe, 40 to 50 Al, 150 sulfate, etc.
105


Aerial view of the
Beaver Ponds at SRAP
SW1
SW5
106

SRAP - The Problem

- Construction at Stafford Regional Airport (SRAP), beginning around 1998, disturbed over 200 ha of Tertiary marine sediments.
- Traditional revegetation methods failed to produce results (at least three attempts at conventional hydroseeding).
- The site remained barren for over two years before the problem was identified as acid sulfate weathering.


Preliminary assessment soil pH was 3.6 and predicted lime demand (potential acidity) averaged 15 tons per acre per 6 inch depth of soil to be neutralized. Many areas tested in excess of 45 tons per acre lime requirement.
108

Erosion of acid sulfate sediments and acidic leachate from an adjacent spoil fill has severely impaired this wetland.

109

Drainage from SRAP prior to remediation (April 02) 110

Corrosion of metal pipes in drainage basin at SRAP. 111

Prior to remediation, water sampled at the pond drainage had a pH of 3.3.

Potomac Pond - an NRCS stormwater retention basin about 1.5 - 2.0 km downstream from SRAP.

112

Soil Revegetation at SRAP

- A mixture of lime-stabilized biosolids (24 to 52% CCE) was applied in March, April and early May of 2002.

- Loading rates were based on predicted lime requirements of the sulfidic soils and ranged from 50 to 175 Mg/ha of dry biosolids - average loading rate was around 70 Mg/ha.


Spreading biosolids at SRAP
(April, 2002)
114
4 5 02

Soil Revegetation at SRAP

- Following incorporation of biosolids, the soil surface was straw mulched and hydro-seeded to a mix of acid- and salt-tolerant grasses.
- The initial vegetation efforts of April and May, 2002, were largely unsuccessful due to an unusually hot and dry growing season.

115

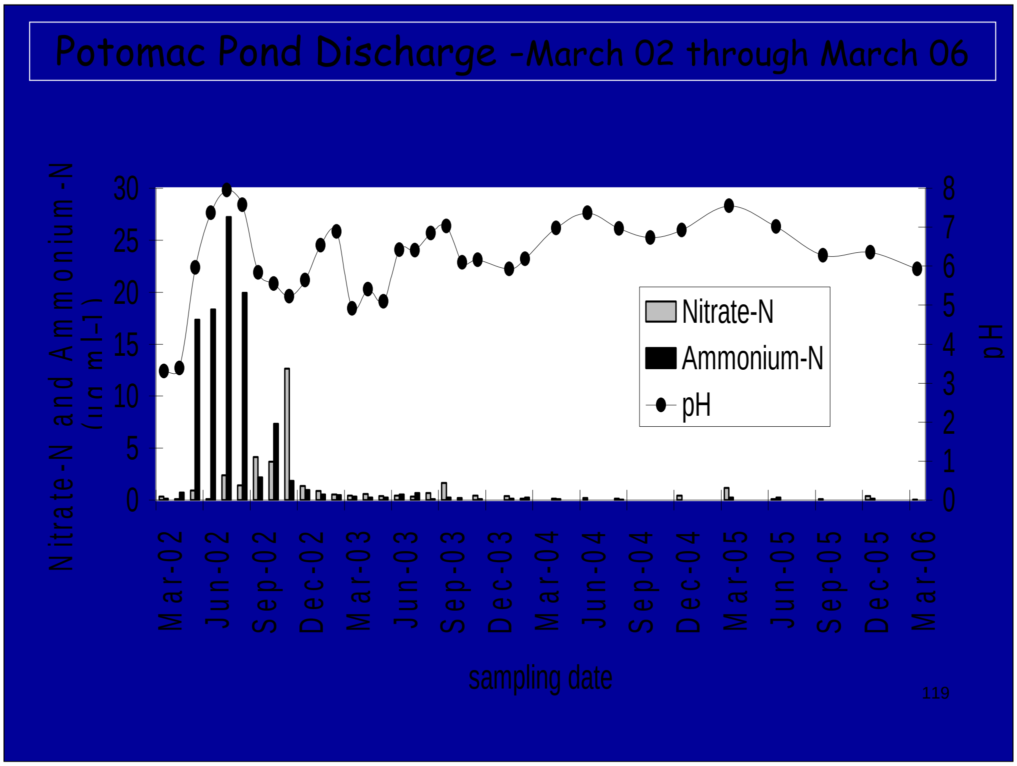

Area revegetated in late May as it appeared in July, 2002. Unfortunately, April through October of 2002 was the hottest/driest period on record.
116


Same view in summer of 2004 after site
had been mowed four times.
117
14. 7. 2004

Soil acidity after reclamation samples collected September 2003

- Surface soil pH: 6.10 - 7.77 average = 7.26.
- Subsurface soil pH: 2.71 - 4.56 average = 3.49.
- A productive topsoil has been established but continued maintenance will be necessary.

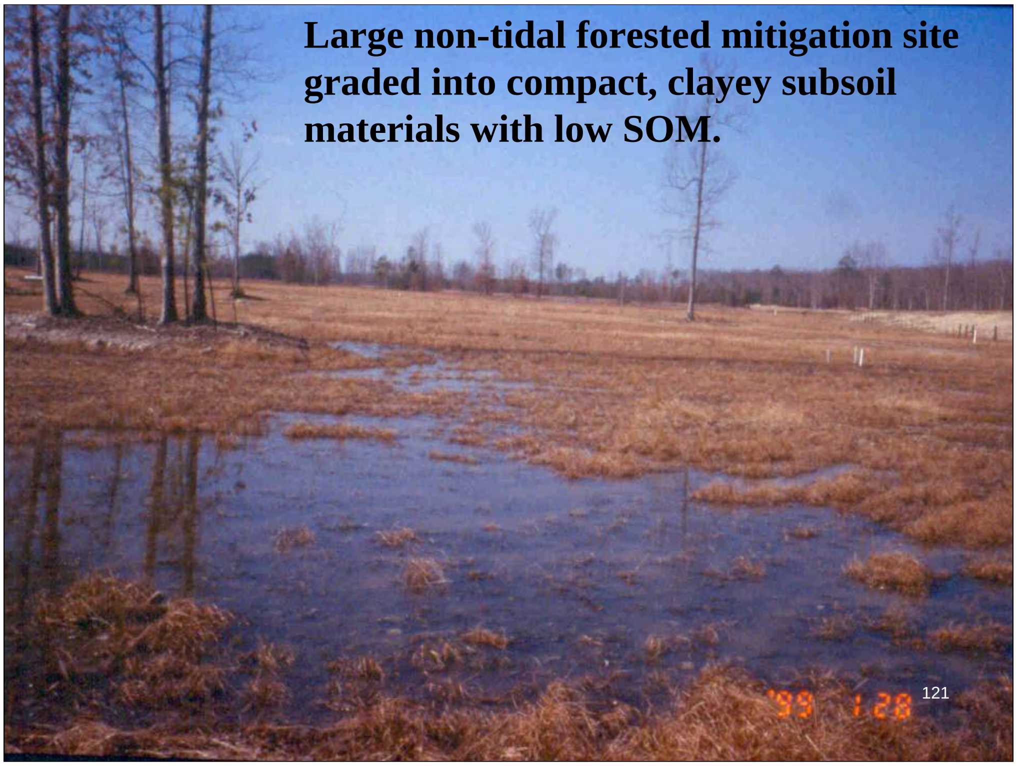
118


Potomac Pond Discharge -March 02 through March 06
Nitrate-N and Ammonium-N (in ml-1)
pH
Nitrate-N
Ammonium-N
pH
0
5
10
15
20
25
30
0
1
2
3
4
5
6
7
8
Mar-02
Jun-02
Sep-02
Dec-02
Mar-03
Jun-03
Sep-03
Dec-03
Mar-04
Jun-04
Sep-04
Dec-04
Mar-05
Jun-05
Sep-05
Dec-05
Mar-06
sampling date
119

Relative Risks?

- Biosolids applied at elevated rates to acidic sloping sites will pose a runoff risk, especially if you don't have active vegetation to take up water soluble N forms. Ammonium loss is also enhanced in very acidic soils.

120

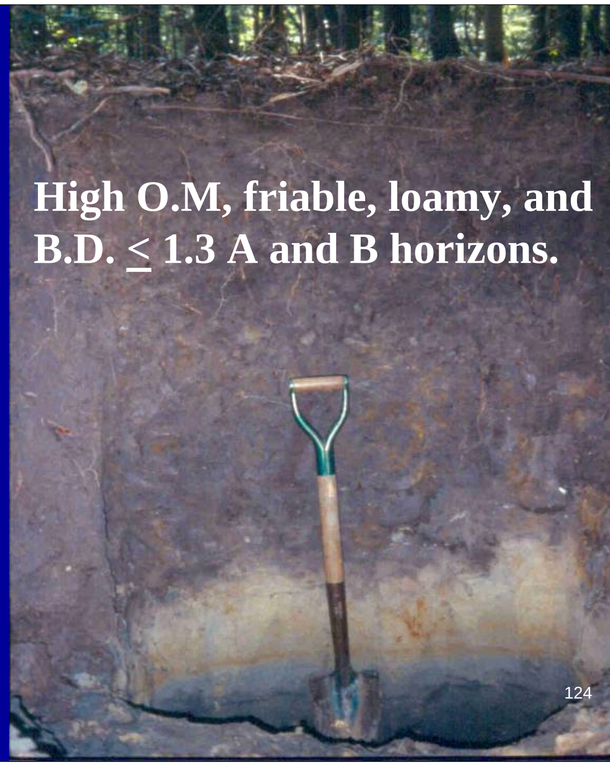


Large non-tidal forested mitigation site graded into compact, clayey subsoil materials with low SOM.
'99 1 28
121


Mitigation Site Established in
Graded/Compacted Subsoil Materials
122
17 5 '94

Same site two years after planting. Most planted woody stems survived, but significant upland herbaceous species were invading.

High OM wetland soil at Sandy Bottom Nature Park in Hampton. The A horizon here is over 30 cm thick. The annual hydroperiod of this soil fluctuates approximately 1.5 m!



Compacted Restored soil in intermediate drainage (poorly d.) class at Fort Lee. Many of these soils supported fac. upland to upland vegetation.


Native wetland soil
adjacent to Fort Lee site.
126

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

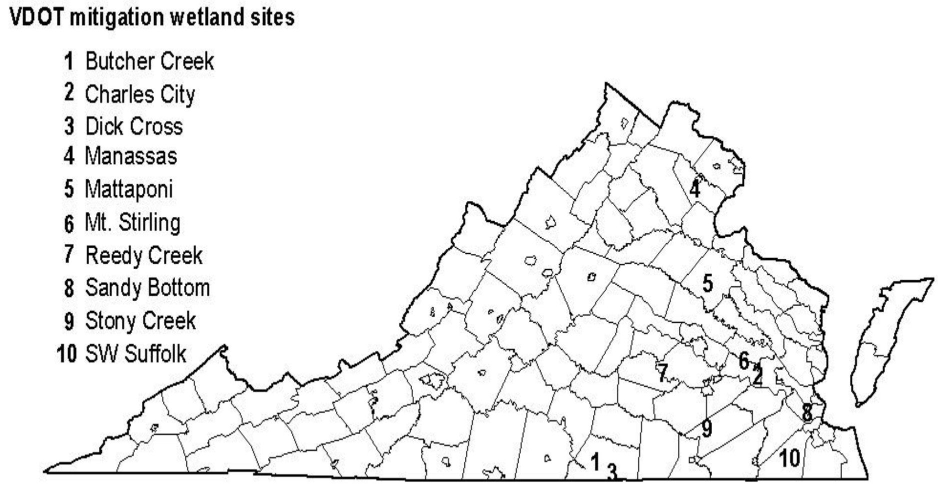
127

Differential Soil Properties at Fort Lee (Cummings, 1999)

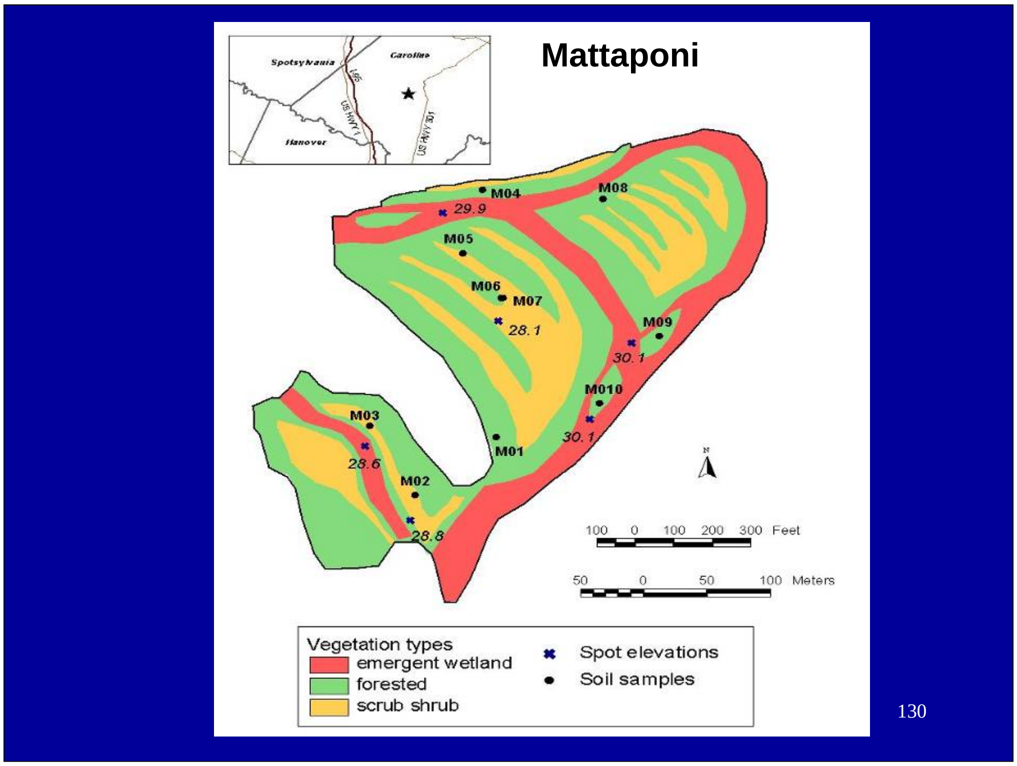
Bulk Density Mg/m^3	Surface (0-15 cm)	Subsurface (70 cm)
Reference	0.71	1.42
Mitigation	1.75	1.71

128

Study Site Locations for VDOT Study #2, 2001-2003



129



Mattaponi
Spotsylvania
Caroline
Hanover
US HWY 1
US HWY 301
M04
M08
29.9
M05
M06
M07
28.1
M09
30.1
M010
M03
M01
30.1
28.6
M02
28.8
100 0 100 200 300 Feet
50 0 50 100 Meters
Vegetation types
emergent wetland
forested
scrub shrub
Spot elevations
Soil samples
130

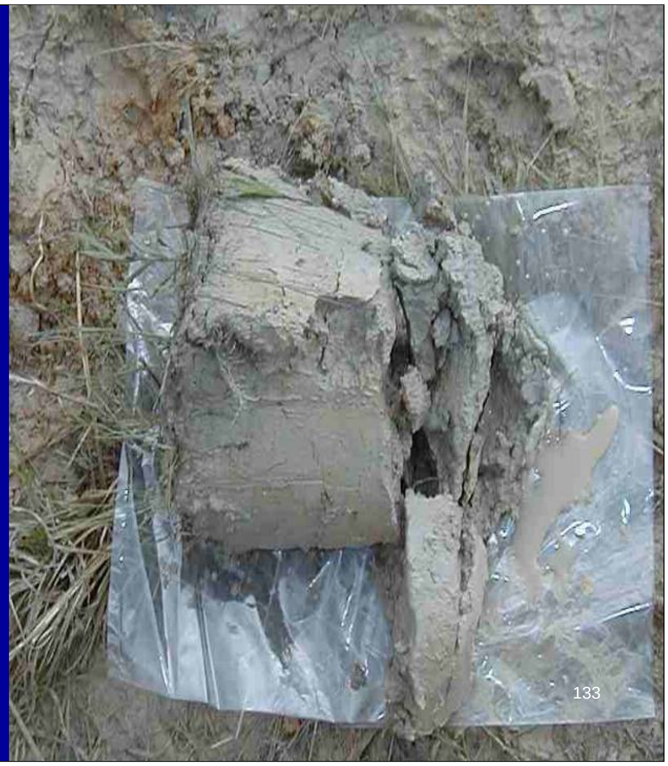

131

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

132

Surface soil from an anonymous 3-year old mitigation wetland.

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



Recommendations for Reconstructing Hydric Soils

- 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).

134

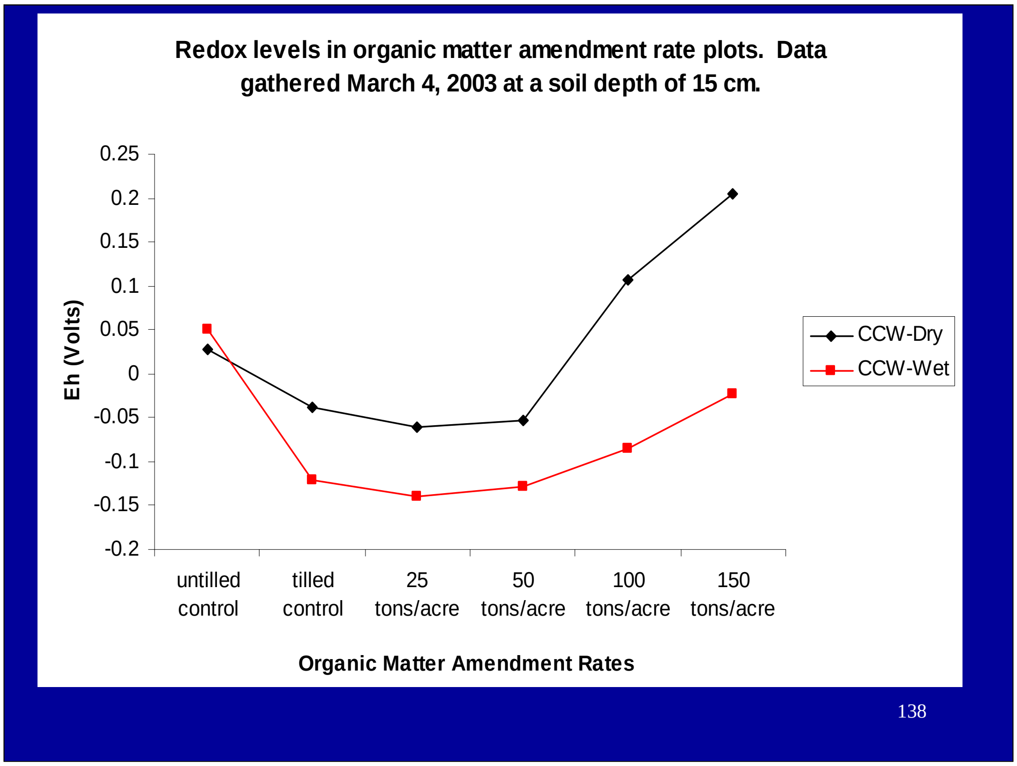

Chisel-plowing and incorporating organics at a very rocky surface mining site. In most wetlands, you need to count on a 100+ hp, 4WD tractor with flotation tires.
135

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 and thoroughly incorporate the materials to 15 cm. How much OM?

136


Dry Experimental Block at Charles City – Rt. 199
Site
137
7 29 '02


Redox levels in organic matter amendment rate plots. Data gathered March 4, 2003 at a soil depth of 15 cm.
Eh (Volts)
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
untilled control
tilled control
25 tons/acre
50 tons/acre
100 tons/acre
150 tons/acre
Organic Matter Amendment Rates
CCW-Dry
CCW-Wet
138

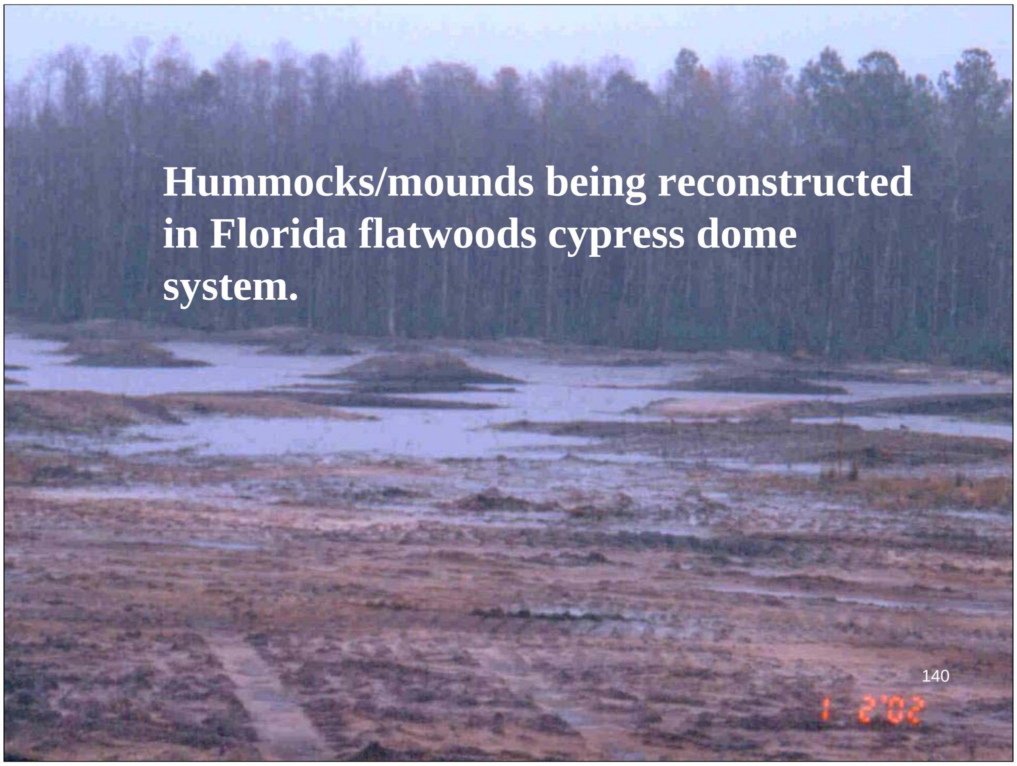
Recommendations for Reconstructing Hydric Soils

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 etc., to recreate micro-topographic variability

Apply any available leaves, wood chips, or other debris as a surface mulch.

139


Hummocks/mounds being reconstructed in Florida flatwoods cypress dome system.
140
1 2'02

Soil bulk density, organic matter content and overall soil reconstruction procedures are now specifically required by:

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

www.nao.usace.army.mil/Regulatory/Annotated_Corps-DEQ_Mit_7 04.pdf.

141

Overall Conclusions

- **You must adequately sample, characterize and understand the substrate you intend to remediate.**

- **Your choice of remedial options will be highly dependent on what your long-term site goals are. For example, full "restoration" will usually require a much more elaborate/ expensive approach than simple revegetation.**

142

Overall Conclusions

- **Avoid pyritic/sulfidic materials whenever possible. Where you can't avoid them, make sure to run appropriate potential acidity procedures and add reactive lime to *at least* 1.0 X predicted acid generation load.**

- **More often than not, compaction will be your major limiting factor.**

143

Overall Conclusions

- **Organic soil amendments, particularly when combined with appropriate liming, have "remarkable effectiveness" when compared to more conventional treatments.**

- **Various waste residuals (e.g. fly ash and mill sludge) can also be quite effective as soil amendments or as part of manufactured soil 144mixes. However, they must be carefully tested and properties will vary widely.**

144

Understanding and Reconstructing Soil Conditions at Remediation Sites

W. Lee Daniels

Crop & Soil Environmental Sciences

VirginiaTech
VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

http://www.cses.vt.edu/revegetation/

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