An Introduction to Reclamation of Drastically Disturbed Lands

W. Lee Daniels
Virginia Tech
wdaniels@vt.edu

The Four “R Words”

Reclamation 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 agricultural production.

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

Another “R Word”

- Regulators and consultants applying similar technologies to Superfund and Brownfields sites have now decided to call this “**Revitalization**” to clearly separate it from restoration or reclamation.
Virginia’s “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

Surface Mining for Coal
Modern Contour Coal Mine
Coal Processing Waste Pile

Acid Mine Drainage
Dredge Spoil Disposal

Good Silt Loam Topsoil or Black Toxic Goo?
Off-Road Effects of Acid Drainage and Sediment Losses

Revegetation Demands of Road Corridors
Suburbanization Disturbance is Major and Highly Variable!

Smelter slag deposit near Katowice, Poland; before treatment.
Laying out replicated plots on smelter slag at Katowice.

Application of biosolids; byproduct limestone applied before.
Katowice plots at end of first growing season.

Katowice revegetated smelter slag in year 3.
Palmerton, PA, 1980; Dead Ecosystem on Blue Mountain.

Palmerton, PA, 1980; because lawn grasses died from Zn, many residents covered their lawns with stones or mulch.
Four Things That Control 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.
Four Things That Control 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.

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

Figure 10.1 Diagram illustrating sulfidization.

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

Massive pyrite crystals in coal
“Simple” Pyrite Oxidation
(Singer & Stumm 1970; Nordstrom, 1982)

\[
\text{FeS}_2 + \frac{7}{2}\text{O}_2 + \text{H}_2\text{O} \rightarrow \text{Fe}^{\text{II}} + 2\text{SO}_4^{2-} + 2\text{H}^+ \quad (1)
\]

\[
\text{Fe}^{\text{II}} + \frac{1}{4}\text{O}_2 + \text{H}^+ \rightarrow \text{Fe}^{\text{III}} + \frac{1}{2}\text{H}_2\text{O} \quad (2)
\]

(Direct oxidation; relatively slow)

\[
\text{Fe}^{\text{III}} + \text{H}_2\text{O} \rightarrow \text{Fe(OH)}_3 + 3\text{H}^+ \quad (3)
\]

\[
\text{FeS}_2 + 14\text{Fe}^{\text{III}} + 8\text{H}_2\text{O} \rightarrow 15\text{Fe}^{\text{II}} + 2\text{SO}_4^{2-} + 16\text{H}^+ \quad (4)
\]

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

Acid-forming materials on 1970’s “pre-SMCRA” surface mine in Virginia
Deep mine adit drainage in West Virginia

Photo courtesy of Jeff Skousen

AMD impact in northern WV

Photo courtesy of Jeff Skousen
Coal Processing Wastes

- Up to 50% of run-of-mine coal from Appalachian deep mines reports to coal waste disposal piles
- In Virginia alone, we have over 5000 ha of active and abandoned coal refuse piles
- The vast majority of Appalachian coal refuse is potentially acidic with an average lime requirement of > 10 Mg per 1,000 Mg or 10 tons of agricultural lime per acre six inches deep.
Berkeley pit at Butte. This is one of three pictures necessary to see entire pit from this vantage point. Acidic, metalliferous mine waters are accumulating and rising due to pumps being turned off.
Metal mine tailings at Anaconda, Montana

Old smelter tower at Anaconda
View from Anaconda smelter. The entire valley (significantly beyond photo right and left) has been affected by smelter emissions and over 2,000 ha in center is covered with acidic tailings. Area in foreground has been revegetated with prescriptions developed by D. Dollhopf at MSU.

Lands denuded by effects of open-air smelting, Copper Basin, Ducktown, TN, in 1973

Photo courtesy of Jack Muncy/TV A
Outcrop of tertiary aged marine sediments near Richmond, VA, with soil pH’s in the 1.8 to 3.0 range.

Acid-S soil bank at Mechanicsville

Compiling a state-wide sulfide hazard map for Virginia: Tertiary marine sediments.

Chesterfield County: Proctor’s Creek was redirected to this excavated channel during road construction.
Compiling a state-wide sulfide hazard map for Virginia: Tertiary marine sediments.

Within 5 years, erosion has removed over 30 cm of sediment...

...and the guardrail is severely corroded.

Compiling a state-wide sulfide hazard map for Virginia: the Quantico Formation.

Iron-staining along curbs and sidewalks through the Hampton Oaks subdivision. Homeowners in this neighborhood apply the equivalent of 2 Mg agricultural lime per ha per month to maintain soil pH above 5.5.
Compiling a state-wide sulfide hazard map forVirginia: Devonian black shales.

Culvert beneath I-64 in Clifton Forge

Compiling a state-wide sulfide hazard map forVirginia: Devonian black shales.

Inside the culvert at Clifton Forge.
Extent of acid-sulfate forming materials in Virginia Coastal Plain of Virginia that are within excavation depths (5 to 20 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 Fredricksburg and Stafford is actually much more problematic!

Acid sedimentation and drainage from airport construction in Virginia.
Coastal mangrove swamp in Senegal. Photo from Fanning & Fanning.

Acid sulfate soil in Senegal due to land drainage.
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.
However, many mining spoils and mine soils are actually quite low in sulfides, and suffer from other limitations.

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.
Three Important Principles

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

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

Mine 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..
Biosolids plus Woodchips @ 140 Mg/ha on Rocky Spoils

Reconstructed Topsoil from One-time Application of Biosolids
60 % Quartz Tailings
40% Fe-Coated Kaolinite

100 Mg/ha Yardwaste Compost + Deep Ripping, + 400 kg/ha P, + 8 Mg/ha Lime applied to Tailings/Slimes

30 cm of Topsoil over Ripped/Limed Tailings/Slimes
Row-crops averaged 78% of unmined ground over four successive growing seasons for wheat/soybeans/corn/cotton. (Schroeder et al., 2000, ASSMR Proc.)

Regardless of their overall acidity and fertility status, the number one limitation to plant growth in mine 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.

Mixed Topsoil + Weathered Overburden (A+B+C+R)

Rocky (15% fines), High pH (7.5), Sandstone Spoil
Incorporation of 45 Mg/ha lime on sulfidic coal waste materials.

Effects of 10 Mg/ha Lime plus 50 Mg/ha Papermill Sludge on Acidic Coal Refuse
33% volumetric addition of alkaline fly ash to acidic coal refuse.

Biosolids cake (C:N = 8) land-applied on gravel mine at 90 Mg/ha.
Corn Response to Nitrogen!

Sampling from zero-tension lysimeter @ 1 m.
Waste Utilization Issues
– Fly Ash

- Many coal fly ash materials are non-alkaline in reaction chemistry and don’t provide any liming benefit.
- Many coal fly ash materials are high in water soluble SO$_4$ and B which can strongly inhibit or kill vegetation until leached.
- If coal fly ash is exposed to acid mine drainage, heavy metals may be preferentially stripped and leached.
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.

Acid mine drainage (pH=2.3; Fe=10,000 ppm) from unsaturated leaching of high S coal refuse (4% pyritic-S).
Stewart et al., 2001, J. Envir. Quality

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

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.
Summary

• The net water quality effects, particularly to ground water, of the utilization of waste products such as biosolids and fly ash must be carefully assessed for each mine utilization scenario. When properly applied and managed, however, their net long-term benefits far outweigh their potential costs.