PREVENTING EROSION ON AREA-WIDE AND LINEAR MINE SITES: WORKING FROM THE TOP DOWN

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INTRODUCTION

Pollutants in the environment are most often just resources that are out of place. Soil erosion turns valuable topsoil into a pollutant: sediment. Protection and/or preservation of topsoil is essential for timely, cost-effective reclamation and restoration of mined areas. Where topsoil cannot be removed and replaced in a progressive manner, it should be stockpiled and protected until such time it can be placed and redistributed on re-graded mined areas. This principle applies not only to area-wide activities—such as strip mining—but also to linear, ancillary areas such as roads and slurry pipeline rights-of-way. Everything that is needed for successful establishment of stabilizing vegetation in final reclamation is contained in the upper most layers of the soil—seeds, viable plant roots, soil bacteria, nutrients. Take care of your topsoil . . . and your topsoil will take care of you.

Once vegetation is removed as part of land disturbance activities—whether they are area-wide or linear in nature—it needs to be replaced with temporary mulch that will last as long as it takes for an area to be reclaimed with permanent, stabilizing vegetation. It is far less expensive to use a mulch to protect disturbed soils from raindrop impact erosion than it is to repair rills and gullies down slope or to remove sediment from stormwater discharges through active treatment systems.

A typical construction slope can be used to illustrate how erosion control and compliance with stormwater regulations can be addressed most effectively—from the top down—through implementation of a system, or "Treatment Train" of complementary erosion, or "source" controls combined with runoff and sediment control practices.

Finally, there are some basic principles that can guide reclamation design and implementation on mining projects. The term "aboriginality" has been coined to describe some of these principles, which are:

- *That one can learn by observing the examples of past reclamation in the mining industry (or the lack thereof);*
- *That we can extract the good examples and eliminate the poor practices from past activities through proper planning and implementation;*
- *That we should look at the physical and biological resources available to determine what rehabilitation nature would achieve in our absence*

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- *That we should "set the table" for that natural succession by designing and implementing practices that enable and do not conflict with ultimate land use; and,*
- *That we should look beyond our own life spans in terms of our reclamation and restoration goals.*

KEYWORDS
area-wide versus linear disturbance; soil erosion; sediment; runoff; storm water regulations; best management practices (BMPs); more benign planning (MBPs); treatment trains; cost-effectiveness; institutional accountability practices (IAPs); planting pallets; succession; aboriginality

AREA-WIDE VERSUS LINEAR PORTIONS OF PROJECTS

Water generally runs downhill. Understanding, planning for, and accommodating this simple fact of nature can determine the success or failure of a mining project in preventing soil erosion and off-site discharge of sediment-laden water. Sediment in runoff water most often originates from uncontrolled run-on or rainfall impact on bare soils upslope from its discharge point. It is generally accepted that the closer one is to the source of sediment (i.e., bare soil at the top of a slope) the more cost-effective the prevention treatments. As one proceeds down the slope, water velocity and volume increase as does the amount of erosion and the costs of remediation.

Beginning at the "top of the hill," it should always be understood that probably the best or at least the most cost-effective form of erosion control is to keep vegetation in-place and limit disturbance of the soil as much as possible. Vegetation is the skin of the Earth and when we remove vegetation, the Earth bleeds—that's called erosion.

Area-Wide: Definition and Examples

There are a few similarities as well as differences in the types of disturbance associated with mining. For area-wide projects, such as strip mining for coal (Figure 1), some notable characteristics are:

- The disturbance occurs within a large, contiguous, polygonal footprint
- Active mining and reclamation may extend for decades
- There are a limited number of permits required, usually just one related to SWPPP
- Activities occur within a defined watershed with fewer outlets or discharge points
- There are similar conditions of soils, topography, hydrology, vegetative types
- Climates, altitude, and slope aspect are relatively similar
- The ability to grade and mimic pre-mining conditions of Approximate Original Contour (AOC) is relatively easier than linear projects
- Wildlife habitat values are generally homogeneous, related, and/or connected
- All mining activities such as overburden removal, extraction, transport, processing, and reclamation are contained within one geographic area

FIGURE 1. An example of an area-wide disturbance: Peabody's Bear Run Mine in southern Indiana.

- Distances between active mining and reclaimed areas is generally less than on linear sites
- Greater freeboard (less restricted) access for equipment
- Number of adjacent private property owners is generally less than with linear sites

In general, there is less potential for off-site impacts on area-wide disturbance when compared to linear sites due to the relatively shorter perimeters of disturbance.

Linear Sites: Definitions and Examples

Linear portions of mining activities are relatively narrow, long, contiguous rights-of-way similar to road construction. On linear sites, construction activities are not confined to one area but spread out over the length of the project, such as delivery of processed slurry, oil, or gas that is delivered from its origin by an above- or below-ground pipe to a refining area some distance from the mine (Figure 2). Linear portions of projects have some of the following characteristics:

- Although their usage will generally last through the life of the active mining process, their active construction is on a relatively shorter time frame of disturbance, e.g., slurry pipeline construction

FIGURE 2. An example of a linear-type disturbance: The Sakhalin II oil and gas pipeline and fiber optic right-of-way. Sakhalin Island, Russia.

- There is the potential for a greater number of SWPPP-related permits required for linear sites than for area-wide sites
- The ability to grade and mimic pre-mining conditions of Approximate Original Contour (AOC) is still required but relatively more difficult that area-wide projects
- Disturbance occurs over a number of watersheds of varying size and catchment
- There are variable conditions of soils, topography, hydrology, and vegetative types
- Climates may be variable due to altitude and slope aspect
- Wildlife habitat values can be heterogeneous (different) and dependent on vegetative types, microclimates, and hydrologic features, e.g., rivers, streams, perennial streams
- Distances between active mining and reclaimed areas are greater than on area-wide sites
- There is generally less freeboard (more restricted) access for equipment
- The number of adjacent private property owners is greater than with area-wide sites

In general, the potential for off-site impacts is greater for linear sites than for area-wide sites due to longer perimeters of disturbance and the variable nature of the environment through which these long corridors are constructed.

However, a 3:1 slope on an area-wide site is generally very similar to a 3:1 slope on a linear site and fundamental principles of erosion, sediment control, and stabilization apply.

FUNDAMENTALS OF EROSION AND SEDIMENT CONTROL

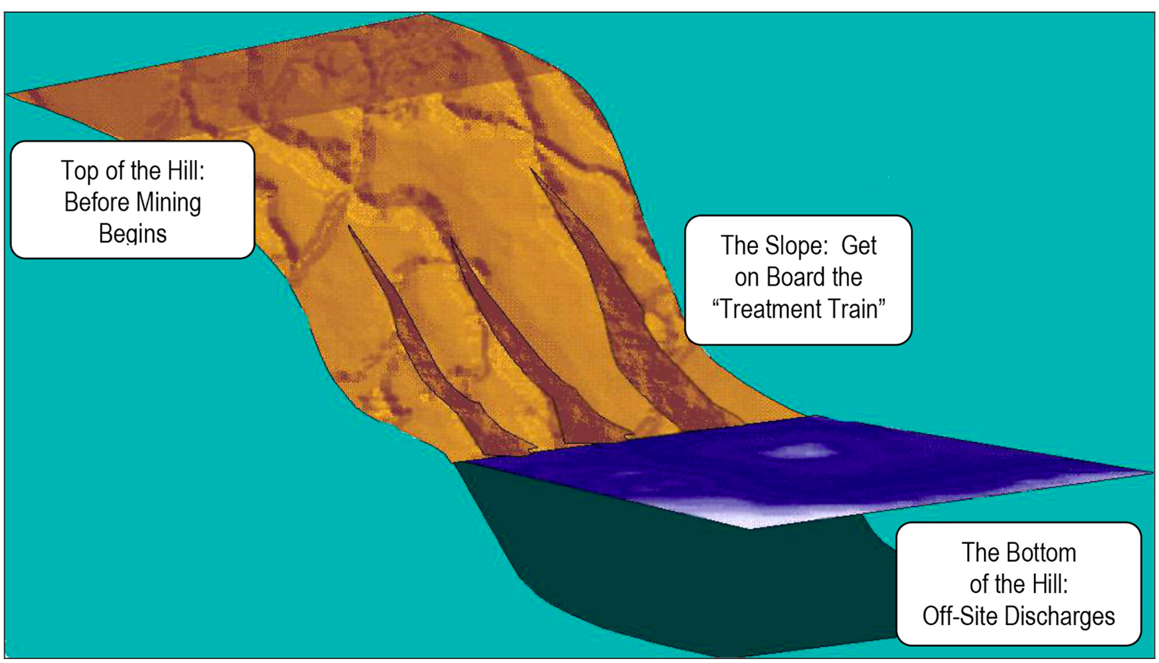
Top of the Hill: Before Mining Begins

Today environmentalists proselytize "sustainable development" and think that they've discovered a new concept. In ancient Hawai'i, an ahupua'a was a narrow wedge of land that ran from the uplands to the sea following the natural boundaries of the watershed. The ahupua'a functioned as a self-sustaining unit for communities or individual families. Each ahupua'a was sized based on natural fertility, the abundance of the land, and contained all the resources that a community needed in the form of water from the mountain-top; koa and other trees in upslope areas; fertile land mid-slope for growing taro or sweet potatoes; and fish and salt from ponds at the toe of the slopes and the sea itself. Stewardship of the land was vital if the human community was to endure. Hawaiians considered soil a resource as much as water.

It shouldn't strain the imagination to apply the principle of ahupua'a to any mainland site, mine, or construction project. In other words, we should begin to address post-mining or construction reclamation at "the top of the hill" (Figure 3), that is, before on-site disturbance begins; before the first shovel point cuts into the earth; before vegetation is removed and topsoil displaced; before the first threatened bird or reptile senses the vibrations of a bulldozer and abandons the field to the strip miner. We must examine our mining activities within the framework of the resources of the area, not the other way around. We need to adapt our erosion, sediment, and drainage control best management practices (BMPs) to the incremental phases of mining, including:

- Control of run-on and runoff of water
- Clearing and grubbing
- Topsoil segregation and preservation
- Removal of overburden

FIGURE 3. Portions of a typical construction slope.



- Mineral extraction
- Replacement and re-grading of overburden
- Replacement and re-vegetation of topsoil

In mining, there is no such thing as serendipitous environmental protection; it has to be planned for well in advance. Before any mineral extraction activities are undertaken we can—through proper design and engineering—eliminate or reduce the off-site impacts of mining activities through MBPs; more benign planning:

"The will to succeed is important: but what's more important is the will to prepare."

—Bobby Knight

It should come as no surprise that all state and federal mining regulations emphasize planning and design that focuses on sources of pollution and for the most part—at least on strip mine sites—that's primarily soil erosion control. Beginning with planning, effective erosion/source control starts upslope and continues downward with the movement of water.

The Slope: Get on Board the "Treatment Train"

There are some important principles to consider in regard to the relationship of the physics of slope erosion and the costs of remediation and repair:

- At the top of a slope, the energy of water is lower and so is its erosive potential and the related costs of erosion prevention, such as temporary mulches or vegetation. Repairing erosion at the top of a slope—usually sheet-type or rill erosion—usually can be accomplished by hand labor using *"shovels and rakes and implements of destruction"* (Arlo Guthrie, *"Alice's Restaurant"* 1967).
- As water proceeds down slope, energy increases, erosion increases, and so too do the costs of repair and remediation. Additional soil might need to be brought in by pans to repair gullies and bulldozers might be needed to re-grade slopes. Start measuring your repairs in terms of the cost of bulldozer time and you'll find that a little mulch and vegetation is a lot less expensive.
- Near the bottom of a slope, if source control has not been particularly successful, the BMPs required to contain liberated sediment—silt fence, sediment ponds, etc.—are relatively more expensive than source controls. It should come as no surprise that these particular BMPs are the most expensive aspect of environmental protection because they require routine inspection and maintenance.
- The discharge point—where runoff meets the receiving water—has the potential to be the most expensive aspect of the stormwater pollution prevention business because of the fines and potential stop work orders associated with off-site discharges of sediment-polluted water.

Figure 4 has been developed from testing conducted at the San Diego State University Soil Erosion Research Laboratory (SDSU/SERL). Figure 4 provides some relative costs and effectiveness of various types of BMPs applicable for source control at the top of a slope and on the slope itself. These practices are also identified by their category: drainage, erosion, and sediment control. Selection of the proper BMP(s) should be based in part on its category of use. The revised California Stormwater Quality Association (CASQA) BMP Manual is a good source for updated information on BMP design, specification (including alternatives)

FIGURE 4. Erosion and drainage control BMPs—installed costs and effectiveness: top and mid-Slope.

BMP	CATEGORY	INSTALLED COST	ESTIMATED EFFECTIVENESS
Top of Slope			
Retain vegetation	Erosion control	0.00	100%
Fertilizer	Erosion control	$450 – 550 per acre	N/A
Seeding	Erosion control	$870-2,170 per acre	100% of pre-existing condition when established
Earthen berm	Drainage control	$1.00-1.50 per lineal foot	100%
Straw wattle	**Drainage control** Erosion control Sediment control	**$1.50-1.75 per lineal foot (top)** $1.75-2.25 per lineal foot (slope) $1.50-1.75 per lineal foot (toe)	94-100%
Compost berm or sock (12-16 inch height)	**Drainage control** Sediment control	**$1.75 - 2.00 per lineal foot (top)** $1.75 - 2.00 per lineal foot	95 - 99%
Mid-Slope			
Track-walking (roughening)	Erosion control	$.50-1.00 per sq ft	52%
Straw wattle	Drainage control **Erosion control** Sediment control	$1.50-1.75 per lineal foot (top) **$1.75-2.25 per lineal foot (slope)** $1.50-1.75 per lineal foot (toe)	94-100%
Hydraulic Mulching	Erosion Control (wood fiber) Erosion control (wood fiber + tak) Erosion control (BFM)	$900 – 1,200 per acre $1,000 – 2,000 per acre $3,000 – 4,000 per acre	50 – 60% 65-99% 90-99%
Straw Mulching	Erosion control (3-step process)	$1,800 – 2,100 per acre	90 – 95%
Compost blanket (1 inch)	Erosion control Erosion control	$900 – 1,200 per acre $7,000 - 10,000 per acre	40 – 50% 95 - 99%

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FIGURE 4. *(continued)*

Compost blanket (2 inch) Compost blanket 3-4 inch	Erosion control	$10,000 - 15,000 per acre	95 - 99%
Jute	Erosion control	$6,000 – 7,000 per acre	65 – 70%
Curled Wood Fiber	Erosion control	$8,000 – 10,500 per acre	90 – 99%
Straw	Erosion control	$8,000 – 10,500 per acre	90 – 99%
Wood Fiber	Erosion control	$8,000 – 10,500 per acre	90 – 99%
Coconut Fiber	Erosion control	$13,000 – 14,000 per acre	90 – 99%
Coconut Fiber Net	Erosion control	$30,000 – 33,000 per acre	90 – 99%
Straw Coconut	Erosion control	$10,000 – 12,000 per acre	90 – 99%
Plastic Netting	Erosion control	$2,000 – 2,200 per acre	< 50%
Plastic Mesh	Erosion control	$3,000 – 3,500 per acre	75 – 80%
Synthetic Fiber w/Netting	Erosion control	$34,000 – 40,000 per acre	90 – 99%
Bonded Synthetic Fibers	Erosion control	$45,000 – 55,000 per acre	90 – 99%
Combination Synthetic and Biodegradable Fibers	Erosion control	$30,000 – 36,000 per acre	85 – 99%

Source: Updated from data from the Erosion Control Pilot Study Report, Caltrans, June 2000, Table 4-1.

application, installation, and operation/maintenance of BMPs. However, an individual BMP is only as good as the complementary BMPs that support it. In the parlance of today's storm water/erosion control industry, that translates into a "treatment train" of drainage, erosion, and sediment control practices on a slope.

Figure 5 presents the mathematical results of candidate BMPs installed as a treatment train. At the top of the table is a bare soil with no controls and a projected soil loss of 100 tons per acre under a specified rain event. BMPs are then applied in order and their individual effectiveness and the system's cumulative effectiveness is presented based on data previously provided in Figure 4. For the purpose of this discussion, our mythical slope will be 2H:1V and around twenty five feet (25) in length—the approximate slope and length of the test bed at the SDSU/SERL on which the effectiveness data presented were determined

One might be tempted to ask the question: from a cost-effective standpoint, why bother with a treatment train at all when one particular practice, in this case, the straw wattle, provides

FIGURE 5. Effectiveness of a treatment train of slope BMPs: one scenario with selected practices.

BMP	EROSION CONTROL EFFECTIVENESS	SOIL LOSS (TONS)	CUMULATIVE SOIL LOSS (TONS)
Bare Soil (No BMPs)	0%	100	100
1) Track-walking (roughening)	52%	48	48
2) Straw wattle as slope interruption device on 10' intervals as required by CGP for 2:1 slopes	95% (avg)	5	2.4 (Track-walking + Straw wattles)
3) Straw mulching	92% (avg)	8	**0.192** (Track-walking + Straw wattles + Straw mulching)
Totals	**98% (approx)**		**0.2 tons (approx)**

Source: Adapted from data from the Erosion Control Pilot Study Report, Caltrans, June 2000. Table 4-1.

a high degree of performance (95%)? Addressing the question with a question, we might ourselves ask: *"What if the straw wattle fails?"* or as legendary UCLA basketball coach John Wooden once said:

"If you don't have time to do it right, when will you have time to do it over?"

Different BMPs provide different functions in a treatment train. A straw wattle's erosion control effectiveness is derived from its impact on reducing slope length and gradient. By contrast, straw mulch is a "cover" BMP that reduces raindrop impact and the dislodgement of soil particles. It helps if one looks at treatment trains as a system of redundant environmental protection; that is, if one BMP's performance is reduced or fails entirely, other BMPs are there to take up the slack. Finally, if slope BMPs are installed as a system which includes final stabilizing vegetation, over time less sediment is delivered to down slope sediment control BMPs—including silt fence, sediment ponds, and inlet structures—reducing the costs of maintenance (i.e., removal of sediment and debris) as well as reducing the potential for fines for exceeding numeric effluent limits for sediment discharges off-site.

The Bottom of the Hill: "Off-Site" Discharges

From the authors' point of view… and from an erosion control/storm water pollution perspective…the bottom of the hill is where *"the rubber meets the road"* or more appropriately, "*where the runoff meets the receiving water"*. Try as one might through proper engineering, design, and implementation of a treatment train of best management practices—after all is said and done—if the runoff water discharging from a mine site is above turbidity or pH limits, additional steps "clearly" have to be taken to stay in compliance.

Traditional structural methods are employed at the bottom of the hill to filter, retain, detain, or otherwise remove sediment from runoff water. As previously noted, they should be designed and implemented as part of a comprehensive treatment train and they function more efficiently when sediment loads are reduced through source controls at the top of the hill or on the slope. However, from an installation, operation, maintenance, and removal perspective, these practices have the potential to be some of the most expensive BMPs in the pantheon of storm water pollution prevention practices and include:

- Silt fence
- Sediment retention/detention basins and ponds
- Sediment barriers
- Sediment removal (i.e., tracking controls, sweeping, etc.)
- Sediment collection (i.e., geotextile bags)
- Passive treatment systems (PTS)
- Active treatment systems (ATS)

In addition to these structural BMPs, there exists an entire constellation of institutional accountability practices (IAPs) that add to "bottom of the hill" costs. Depending on the state or country in which you are conducting your mining activities, the nature and frequency of these IAPs is determined by the site characteristics; i.e., linear versus area-wide portions of projects, proximity to waters receiving mine discharge, soil erodibility, slope gradients, etc. and include:

- Routine site and BMP inspection and reports
- Storm event–related site inspection and reports
- Water quality monitoring and sampling
- Weekly, monthly, or quarterly non-storm water inspections and reports
- Annual Reports

ABORIGINALITY

Anyone reading this article knows that mining in areas that are construction-challenged—i.e., high altitude, extremes in climate, steep topography, locations adjacent to water resources, environmentally sensitive areas, cultural resources, infertile soils, and geotechnical instability—requires a close examination of the resources within the proposed project area of prior to disturbance. Add to this mix of potential problems the fact that no construction is conducted in a vacuum; there will always be an interface with existing development or off-site resources that must be taken into account. It may be as simple as neighbors not appreciating the temporary disturbance caused by construction activities and/or the permanent alteration to their view-shed or adjacent environment by the resulting development of new roads, utility lines, or buildings.

Some sites can be a geographic and/or technologic challenge because they are so remote that current erosion and sediment control equipment or machinery can't reach them cost effectively. Additionally, in many instances of rehabilitation or reclamation of previously disturbed ground—in particular where topsoil resources have been lost—what's left is usually infertile subsoil or even worse, potential toxic materials such as acidic rock, gob, or slurry produced by mineral processing—conditions that are almost impossible to re-vegetate and stabilize cost-effectively without covering them at depth with overburden and suitable growth media.

In many of these cases, instead of relying on the latest development from a menu of best management practices, it's important to apply the basic principles previously mentioned for stabilization and rely on their own experience—or the experience of others—utilizing the resources that are on-site. I call this approach "aboriginality". Some of the principles of aboriginality are:

- That one can learn by observing the examples of past reclamation in the mining industry (or the lack thereof);
- That we can extract the good examples and eliminate the poor practices from past activities through proper planning and implementation;
- That we should look at the physical and biological resources available to determine what rehabilitation nature would achieve in our absence
- That we should "set the table" for that natural succession by designing and implementing practices that enable and do not conflict with ultimate land use; and,
- That we should look beyond our own life spans in terms of our reclamation and restoration goals.

Learning from Past to Guide Restoration for the Future

Slurry is one of the by-products of coal mining. It consists of fine coal and other materials produced by refining or washing coal before it is shipped for use. Typically, slurry is pumped into impoundments near the mine where it is abandoned and considered toxic waste. Past attempts at reclaiming these areas have been to cover the slurry with material from adjacent sites to cut off oxygen to reduce the incidence of acid generation. However, in a lot of cases this "borrow material" is comprised primarily of rock that has stabilized both chemically or vegetatively over time by natural succession or from direct reforestation. Therefore, to reclaim five acres of slurry pond generally requires re-disturbing five acres of stabilized ground and thus creates ten acres of land requiring additional stabilization measures.

At Tecumseh Mine in southern Indiana there were a number of slurry ponds slated for reclamation through the abandoned mined land (AML) program. Observing the natural succession of plants along the edges of these impoundments that had occurred over decades (Figure 6) led to the idea that if one could reproduce and accelerate the physical and chemical changes in the impoundment over time, then it might be possible to eliminate the need to disturb adjacent, vegetated spoil areas and vegetate the slurry directly. Applying the principles of "Aboriginality", the following steps were taken:

1. The slurry was sampled and treated with soil amendments to neutralize its acidity;
2. Plant species were selected that would tolerate extremes in pH, salts, and aridity. These species were primarily native warm season grasses such as switch grass; and,
3. Mulch was applied—in this case erosion control blankets constructed of straw and coconut fiber—to accelerate natural deposition of organic material.

FIGURE 6. Tecumseh slurry pond in southern Indiana. The author applies native seed after conducting soil tests and adding soil amendments. Arrows indicate native switch grass encroaching on thirty-year old site.

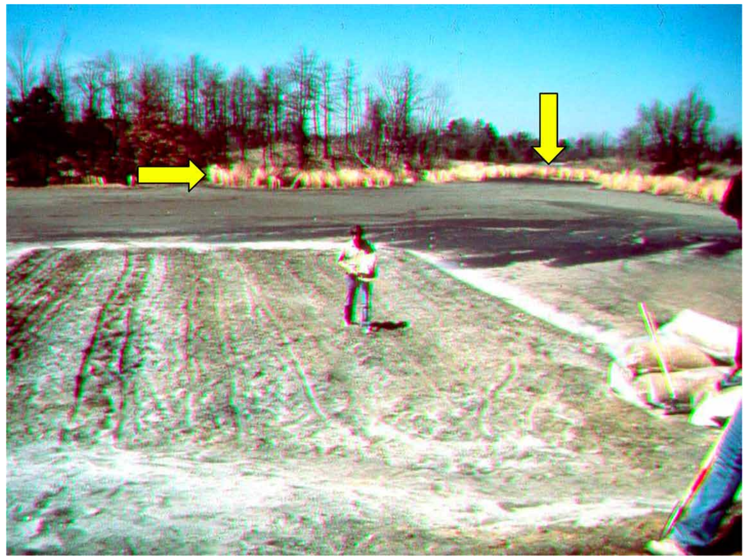

FIGURE 7. Tecumseh slurry pond. Growth of vegetation one month after installation of straw-based erosion control blanket.

The results of such an approach on a small experimental plot are illustrated in Figure 7. However, it is important to note that for the most part, the initial flush of growth was not always what the final vegetative pallet turned out to be. In the case of direct slurry re-vegetation at Peabody's Latta Mine near Jasonville, Indiana, the initial establishment of switch grass (Figure 7) provided a pioneering, organic substrate upon which other plants could root and establish themselves. Eventually the area was capable of supporting the growth of a dense pine forest (Figure 8).

Mine Reclamation Planning Beyond One's Life Span

Some of the many truths that I have learned over the years are:

- You can't legislate personal responsibility—it has to be taught by example;
- You can't regulate environmental quality—you have to change people's attitudes; and,
- There's no such thing as serendipitous mine reclamation—it has to be planned.

FIGURE 8. A stand of mature switch grass on a slurry pond at Peabody's Latta Mine near Jasonville, Indiana in 1983.

FIGURE 9. Growth of pine trees and shrubs on the Latta Mine slurry pond in 2013.

In 1978, while I was reclamation manager at Peabody Coal Company's Sycamore Complex, we started planning for the ultimate reclamation of Dugger Mine near Sullivan, Indiana. Since we were mining through the Busseron Bottoms, it seemed natural to plan for re-establishing wetlands as our primary post-mining land use. To demonstrate our commitment to developing wildlife habitat values through reclamation, Peabody joined the state Department of Natural Resources' "Goose for You, Too" program and accepted delivery of eleven mated pairs of giant Canada Geese in 1979. That winter my reclamation crew established nesting areas on small islands constructed of platforms that floated on the lakes behind the pit. In the engineering department we began to plan grading activities to take advantage of some of the mine characteristics to save money and create wildlife habitat at the same time.

We validated our commitment to reclamation for wildlife habitat by developing concrete plans and designs (no serendipity here) that maximized topsoil replacement in terrestrial areas

FIGURE 10. The author at Peabody's former Dugger Mine near Sullivan, Indiana, which is now part of the state's wildlife habitat program (May 2013).

while minimizing topsoil in areas that were to be inundated by water. We established food plots adjacent to ponds and lakes and implemented a system of mowing to provide continuous lush, grassy vegetation for the geese (who are grazers). We planted over one hundred thousand trees with the species being selected based on their relative position in the landscape and their habitat values.

Most importantly for the company—because of our guarantee to work within the existing reclamation laws to accomplish our objectives—we were able to save a lot of money by not having to grade areas that would be flooded. We left haul roads and inclines as access roads for recreational purposes and retained temporary sediment control ponds as habitat features. It was estimated that in just three months we saved the company $934,000 in rough grading alone.

Today that area is known as the Dugger Unit—part of the Indiana Department of Natural Resources' Greene-Sullivan State Forest (Figure 10). The lakes draw people from all over the Midwest for fishing and other forms of recreation. Additionally, they provide roosting areas for migratory and resident waterfowl.

The last principle of "Aboriginality" is to look beyond you own life span to accomplish your reclamation goals. As I flew over the area in the Spring of 2013 to take photos for a pre-

FIGURE 11. Peabody's Dugger Mine as it appears today as part of the Greene-Sullivan State Forest (May 2013).

sentation I was to give for the Australian Mine Rehabilitation Conference that year (Figure 11) I was struck by the fact that below me—the reclaimed land at Dugger Mine—was what I had envisioned over thirty-five years before.

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