"Five Fundamentals for Successful Restoration of Coal Ash Sites"

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ABSTRACT

Successful rehabilitation of massive soil and vegetation disturbances from fossil plants and subsequent coal ash disposal requires a comprehensive and holistic approach. Those overseeing rehabilitation efforts must integrate and stage several considerations into a working relationship that entails proper planning and execution. "Soil poor" sites associated with coal ash storage and disposal offer considerable challenges particularly when topsoil sources are scarce. Such sites will require innovative thinking and implementation to overcome the absence of favorable growing conditions. This publication offers "Five Fundamentals for Successful Restoration of Coal Ash Sites" as a proven model to facilitate successful land rehabilitation.

The first fundamental is employing creative methodologies to develop suitable growing media from less than desirable soils or substrates. This can only be accomplished by first understanding the make-up of the soil or substrate through comprehensive soil testing for agronomic potential and limitations. The second fundamental requires an assessment of suitable plant species for achieving sustainable growth and effective erosion control – while meeting the collective restoration needs or requirements of regulatory agencies, consultants and utility owners.

Once soil, agronomic and species selection considerations have been addressed, it is appropriate to begin analyzing site conditions or characteristics to assess and select necessary erosion and sediment control measures – the third fundamental. Site conditions, such as soils, climate, seasonality, slope lengths, gradients and aspects, ditch and channel flow hydraulics, pond and stream banks, wetlands and more must be examined and proper controls selected.

The fourth fundamental entails proper installation practices critical to the success of the rehabilitation program. Complete guidelines and details must be developed and combined with onsite supervision to assure correct installation. Finally, once the restoration measures have been implemented all active sites should be routinely inspected and maintained after each significant precipitation or other potentially damaging climatic event. This is the fifth and final fundamental.

An overview of a software program developed to facilitate the discovery process, integration and execution of the Five Fundamentals will be provided. Finally, this publication will offer brief case histories where the “Five Fundamentals” have been successfully employed in coal ash restoration projects.

INTRODUCTION

Successful restoration of coal ash sites entails an inclusive approach to assess, address, manage and integrate treatments or techniques to overcome the considerable challenges presented in post-deposition environments such as poor substrates, large unprotected areas with high erosion potential, difficult access, adverse climatic or seasonal weather conditions and much more. Reclamation or rehabilitation managers must then balance these challenges with other operational concerns such as budgetary constraints, cost of materials, availability of labor, the sequencing of earthmoving activities and required timing of completion for closure related activities.

The Five Fundamentals are neither novel nor revolutionary advancements or methodologies for successful coal ash rehabilitation, but rather the assimilation of time proven design considerations combined with proper execution and implementation in the field. A web-based design and selection tool, Profile Soil Solutions Software (PS^3), has been developed to facilitate the integration of erosion and sediment control engineering with agronomic considerations. PS^3 software is a comprehensive resource for designing and selecting techniques to develop holistic, sustainable solutions for cost-effective erosion control, vegetative establishment and subsequent reductions in sediment and other pollutants from leaving coal ash sites and entering water bodies. PS^3 enables users to effectively integrate and stage multiple considerations into a functional working relationship that entails proper planning and execution of the Five Fundamentals.

Fundamental #1 – Understand Your Soils or Substrates

The first fundamental is employing creative methodologies to develop suitable growing media from less than desirable soils or substrates. This can only be accomplished by first understanding the make-up of the soil or substrate through comprehensive soil testing for agronomic potential and limitations. Soil testing, interpretation of the test results, and incorporating prescriptive remedies to improve soils should be a fundamental part of any reclamation or revegetation project. It is difficult to predict potential project success without a proper understanding of soils or substrates considered for use as growing media to establish vegetation.

Prior to conducting and interpreting soil tests, it is important to understand test methods that are relevant for reclamation and/or vegetation establishment projects. There are various ways to extract measurable soil characteristics and analyze samples, but rarely do varying soil testing methods produce identical results. Further, it is important to properly collect and label soil samples prior to sending them to a reputable laboratory. Detailed instructions are in the PS^3 software program with three instructive videos that can be accessed at www.profileevs.com/video/soil-foundation-success-part-1-3.

In addition, there is a laboratory dedicated to properly testing soils, including international specimens, for erosion control projects at no cost to the client. More information can be gained at www.profileps3.com. Whether you are utilizing the PS^3 soil testing laboratory or another facility, please refer to the methodologies listed below to insure you are employing relevant testing protocol for erosion control projects that require vegetative establishment.

Testing Methodology

- Texture - Hydrometer Method
- Soil pH/Soluble Salts - 1:1 Soil/Water Slurry and Saturated Paste Extraction
- Buffer pH - Sikora Method
- Cations (Ca, K, Mg, Na) - Ammonium Acetate Extraction
- Phosphorus - Bray 1 Extraction or Olson Extraction
- Trace Elements (Zn, Mn, Cu, Fe) - DTPA Extraction
- Sulfur - Phosphate Extraction
- Boron - DTPA/Sorbitol
- Nitrate Nitrogen - Cadmium Reduction
- Particle Size Analysis - Hydrometer Measurement
- Salinity Evaluation - Saturated Paste Extraction
- All Soluble Nutrients - Saturated Paste Extraction

Consistency in testing methods allows for simplified and more rapid evaluations of the results. Table 1 on the following page provides optimal ranges for various soil parameters and values where deficiencies or excesses may compromise or limit vegetative establishment – using the test methods identified above[1].

One vexing issue facing successful restoration of coal ash sites is lack of inherent soils used to cover coal ash deposits. Unlike mining, landfilling and many other construction related activities that first entail stripping soils, deposition of coal ash creates exceptionally “soil poor” scenarios where there never was an onsite source of soils to be stockpiled for future use. The standard approach has been to locate nearby soil borrow areas and truck in vast quantities of cover material prior to revegetation or restoration. However, testing of coal ash for agronomic potential has revealed some optimistic scenarios where in some cases successful revegetation can be accomplished even on bare ash alone. Such sites will likely require healthy amounts and supplemental applications of soil amendments, but the cost savings can be substantial versus expensive imported topsoil or subsoil. Recently biotic soil media and amendments have been developed to cost effectively complement or replace topsoil – thus reducing quantity requirements and costs.

Table 1: General Soil Test Interpretations

Soil Characteristic Tested	Unit	Low Value (Deficiency*)	Optimal Range (Sufficiency*)	High Value (Toxicity*)
Texture (Hydrometer Method)	%	N/A	N/A	N/A
OM (Organic Matter)	OM mass / sample mass	< 3%	3%-5%	> 10%
pH	0-14	< 6.3	6.3 - 7.3	> 7.3
$HC0_3$ (Bicarbonate)	ppm	N/A	< 50	> 50
Electrical Conductivity (EC)	mmhos/cm = dS/m	N/A	< 0.75	> 7.0
Total Dissolved Solids (TDS)	ppm	N/A	< 480	> 4480
Sodium Adsorption Ratio (SAR)		N/A	< 2.0	> 7.0
N (Nitrogen)	ppm	< 10	10 – 30	> 30
Bray 1 P (Phosphorus) pH<7.2	ppm	< 20	20 – 40	> 40
Olsen P (Phosphorus) pH>7.2	ppm	< 10	10 – 25	> 25
K (Potassium)	ppm	< 150	150 - 250	> 250
Mg (Magnesium)	ppm	< 60	60 - 300	> 300
Ca (Calcium)	ppm	< 400	≥ 400	N/A
S (Sulfur)	ppm	< 5	5 – 20	> 20
Zn (Zinc)	ppm	< 1.0	1.3 - 3.0	> 5.0
Mn (Manganese)	ppm	< 2.5	4.1 - 12.0	> 50
Cu (Copper)	ppm	< 1.0	1.0 - 2.0	> 2.0
Fe (Iron)	ppm	< 4.5	7.1 - 20.0	> 70
B (Boron)	ppm	< 0.5	1.0 - 1.5	> 2.0
K (Potassium)	CEC %		3.0 - 7.0	
Mg (Magnesium)	CEC %		15 – 20	
Ca (Calcium)	CEC %		65 - 75	
Na (Sodium)	CEC %		0 - 4	> 15
H (Hydrogen)	CEC %		0 - 5	
Cation Exchange Capacity (CEC)		< 5	10 - 30	> 50
Cl (Chloride)	ppm	< 10	10 - 20	> 800

Fundamental #2 – Proper Species Selection

Equally important to addressing soils is an understanding of plant species for sustainable growth and resulting erosion and sediment control (E&SC) performance. The second fundamental requires an assessment of suitable plant species for achieving sustainable growth and effective erosion control – while meeting the collective post-reclamation needs of regulatory agencies and coal ash owners and operators. Soil properties, climate, moisture regimes, slope aspect, maintenance, future land use and a host of other considerations contribute to proper species selection.

Perhaps the best resource for obtaining information and availability of suitable plant species are regional growers, collectors and suppliers of locally adapted seeds and plant materials. Experienced botanic professionals are well versed in seasonal pricing, quantities and availability of native or introduced seed sources as well as containerized or bare root shrubs and tree species.

In the US there is a wealth of botanical information available from universities, specialized consultants and contractors, as well as federal, state and local agencies such as Office of Surface Mining Reclamation and Enforcement (OSMRE), US Natural Resource Conservation Service (NRCS), US Bureau of Land Management (BLM), US Forest Service (USFS), US Army Corps of Engineers (USACE), state mining agencies and departments of transportation (DOTs) and local soil conservation chapters.

Beyond these resources a module has been placed within PS^3 to offer species selection assistance to its users. Essentially, the module is designed as a self-assessment asking the user a series of questions such as:

- Where is the project located?
- What are the soil characteristics?
- Do you want to achieve permanent or temporary vegetation?
- When will the installation occur – seasonality?
- What are the desired plant materials?
    - Native, introduced, drought tolerant, palatable, warm or cool season, legumes, wildflowers, shrubs, trees, etc.
- What is the intended application?
    - Slope, channel, riverine, shoreline, levee, cover system, etc.
- What are the site characteristics – such as elevation, topography, aspect, climatic conditions?
- Will there be maintenance activities – irrigation, mowing, supplemental amendments or grazing?
- Do you want to discourage birds and other wildlife from inhabiting the area?

Once the project information is uploaded, the user can ask to be contacted by an agronomic professional for additional input and potential advice, and then directed to other knowledgeable references and/or suppliers of the desired species or plant materials. Certainly the best resources are individuals intimately aware of the site specific conditions with prior experience with the selected plant materials in that vicinity.

Fundamental #3 – Select the Most Cost-Effective Erosion Control Techniques

Once soil, agronomic and species selection considerations have been addressed, it is appropriate to begin analyzing site conditions or characteristics to assess and select necessary erosion and sediment control measures. Site conditions, such as soils, climate, seasonality, slope lengths, gradients and aspects, ditch and channel flow hydraulics, pond and stream banks, wetlands and more must examined and proper controls selected.

PS^3 uses widely accepted methodologies such as the Revised Universal Soil Loss Equation (RUSLE/RUSLE 2) for predicting annual soil loss on slopes combined with erosion control effectiveness, an international rainfall database, growth establishment rates, functional longevities and factors of safety to facilitate product selection for slopes using the following equation. (Renard, K.G, et. al., 1997)[2]

Revised Universal Soil Loss Equation:

$A = R \times K \times LS \times C \times P$

Where:

A = computed soil loss/unit area/year
R = rainfall factor
K = soil erodibility factor
L = slope length factor
S = steepness factor
C = vegetation or cover factor
P = erosion control practice factor

C-Factor is calculated as the soil loss ratio of a treated surface versus the soil loss of an untreated control surface. For example, if the treated surface produces 5 kg of soil loss while the untreated surface produces 100 kg of soil loss, then the C-Factor would be 5 kg/100 kg = 0.05. The lower the C-Factor value, the more effective the erosion control technique is at preventing erosion.

Conversely, percent erosion control effectiveness (PE) may be calculated from the following equation using the above example C-Factor of 0.05 as follows:

PE = (One minus C-Factor) x 100% or
$PE = (1 - 0.05) \times 100\% = 95\%$

Although comparative low C-Factors or high PE values can at first blush appear to be impressive, the potential soil loss values can be very surprising and perhaps alarmingly high without constructed sediment capture and retention devices or practices. For example, as shown in Table 2, an erosion control technique demonstrating a seemingly impressive 95% effectiveness could potentially lose 18,700 kg/ha/year of soil.

However, the C-Factor and erosion control effectiveness values are in an unvegetated condition and their ability to foster or accelerate vegetation establishment must go into design and selection criteria. If a designer is confident an erosion control technique can rapidly establish vegetation and still provide suitable erosion control effectiveness, then he or she may opt to go with a lower cost, less robust technique. One determination of the ability of a material to improve vegetation establishment is using ASTM D7322 - Standard Test Method for Determination of Rolled Erosion Control Product (RECP) Ability to Encourage Seed Germination and Plant Growth Under Bench-Scale Conditions. This test has been modified to accommodate hydraulically-applied erosion control and other types of products used for revegetation.

Another key product characteristic is functional longevity – which can be determined using ASTM D5338 - Standard Test Method for Determining Aerobic Biodegradation of Plastic Materials Under Controlled Composting Conditions, Incorporating Thermophilic Temperatures. This test determines predicted longevities of various biodegradable erosion control techniques and is often correlated with field observations to offer material functional longevity ranges. Functional longevity will be affected by a material's composition as well as site specific conditions such as temperature, moisture, sunlight, soil composition, biological activity and other environmental factors. Thus, localized observations should prevail.

Erosion control effectiveness, growth establishment and functional longevity are the three pillars of product performance and fundamental to PS^3 selection criteria for erosion control techniques. Assessing these three key properties can assist designers in their risk versus reward selection scenarios – balancing performance versus costs and ease of implementation versus factors of safety.

Table 2: Annual Soil Loss Calculations for C-Factor and % Effectiveness Values (Utah Water Research Laboratory, 2007-2014)[3]

C-Factor	% Effectiveness	Potential Soil Loss (kg/ha/yr)
0.01	99	3,740
0.05	95	18,700
0.1	90	37,400
0.2	80	74,816
0.3	70	112,224
0.5	50	187,040
0.75	25	280,560

As demonstrated in Table 3 below, the erosion control practice factor or P-Factor from the Universal Soil Loss Equation can have a large impact on erosion control effectiveness. Using a default value of 1.0 for a loose disked slope, relative P-Factors can be determined for various grading techniques. It is important to note that roughened slopes demonstrate reduced erosion control potential versus slopes that have been smoothed to accommodate and ensure intimate soil contact for techniques such as rolled erosion control products. For example, a compacted and smooth surface has a 20% greater erosion potential than loose disked soil. Rough graded or tracked sites demonstrate up to 42% less erosion potential versus compacted and smoothed soil. More flexible techniques such as hydraulically-applied erosion control products or blown hay/straw can be applied on rough or cat tracked slopes – providing less costly and in some cases superior erosion control effectiveness.

Table 3: Annual Soil Loss Calculations for C-Factor and % Effectiveness Values (Utah Water Research Laboratory, 2007-2014)[3]

P-Factor Practice	**P-Factor Value**	**Potential Soil Loss Relative to P-Factor = 1.0 (kg/ha)**
Compact and Smooth Surface	1.2	134,400
Loose – Disked Plough Layer	1.0	112,000
Rough Surface with Tracks in all Directions	0.9	100,800
Tracked Up and Down Slope	0.7	78,400

Methodologies from the US Federal Highway Administration's Hydraulic Engineering Circular Number 15 (HEC 15) – Design of Roadside Channels with Flexible Linings (Kilgore and Cotton, 2005)[4] are used for both unvegetated and vegetated channel design and product selection. Primary design formulas are Manning's Equation and the Shear Stress or Tractive Force Equation as follows:

Manning's Equation for Permissible Velocity

$$V = \frac{C}{n} R^{2/3} S_f^{1/2}$$

Where:

V = average velocity (m/s)
C = 1.0 for SI Units
n = Manning's roughness coefficient (dimensionless)
R = hydraulic radius (m)
= cross sectional area divided by wetted perimeter (A/P)
S_f = friction slope of channel (can be approximated as average bed slope for uniform flow conditions) (m/m)

Permissible Shear Stress or Tractive Force Equation

$$\tau = \gamma d S_o$$

Where:

τ = shear stress or tractive force (Pa)
γ = unit weight of water (9.8 kN/m^3)
d = maximum flow depth (m)
S_o = average bed slope (m/m)

Next on PS^3 is a calculator tool that can be used to determine how much mulch, fertilizer, seed, and agronomic amendments should be mixed into each hydroseeder load and how much will be required for a specific site. It allows for imperial or metric conversions between common units found for all product recommendations.

Additionally, unit pricing may be entered for all selected products. This will provide a cost estimate for the products needed on a site based on slope and channel analysis, soil testing, and plant species selection. This enables users to develop comprehensive cost estimates for the project as well as mixing and loading rates for tank loads of hydraulically-applied products – based upon the size of the equipment and anticipated loading rates.

Project Information

Project Size:	2.00 20,000.00	Hectares Square Meters
Working Capacity Hydroseeder Size:	11,356.24	Liters
Mulch Application Rate:	3920	kg/ha
Total Hydroseeder Tanks:	14.41	
Total Project Cost (USD):	$23,722.78	

Mulch

Product Name	Total Amount Required		Total Units Required		Product / Tank Load		Cost Per Unit (USD)	Total Cost (USD)
Flexterra	7,845.96	Kilograms	345.95	Bags	24.00	Bags	$60.00	$20,756.85

Liquid Amendment

Product Name	Total Amount Required		Total Units Required		Product / Tank Load		Cost Per Unit (USD)	Total Cost (USD)
JumpStart (2.5 gal/9.46 L Bottle)	93.54	Liters	9.89	Bottles	6.49	Liters	$180.00	$1,779.82

* DO NOT MIX AQUA-PHIX AND JUMPSTART IN THE SAME HYDROSEEDING MIXTURE. USE A TWO-STEP PROCESS.

Dry Amendments

Product Name	Total Amount Required		Total Units Required		Product / Tank Load		Cost Per Unit (USD)	Total Cost (USD)
BioPrime (40 lb/18.14 kg Bag)	269.00	Kilograms	14.83	Bags	18.66	Kilograms	$80.00	$1,186.11

Fertilizers / Seed / Other

Product Name	Total Amount Required	Product / Tank Load

Figure 1: PS^3 Cost Calculator Screen Shot

Performance data for these erosion control products has been obtained from the most prestigious US universities and private testing laboratories and provides the impetus for proper product selection. Once the appropriate product(s) and techniques have been selected, a detailed project summary report along with a suite of supporting information is available including: product brochures, installation guides, CAD drawings, SDSs, example specifications, certification letters, case studies and other relevant material.

Dust Control and Temporary Stabilization

Aeolian or wind influenced erosion is also a major consideration for coal ash since the fine and very fine particles can present health hazards when entering respiratory tracts of humans and animals while also causing damage to property and equipment. Large surface areas characteristic of wet or dry coal ash impoundments can become persistent sources of fugitive dust. Measures should be taken to minimize and control dust emissions from coal ash storage facilities during transport, placement and the life of the impoundment. Dust control can be viewed through time horizons such as short-term, intermediate and long-term.

Short-term stabilization could be as short as one day (daily cover) when ash is being transported and placed into storage. Water is the most obvious treatment for short-term stabilization although polymeric, naturally-derived and petroleum based products have been developed that can cost-effectively enhance protection while reducing quantities of water required. Intermediate dust control could represent weeks to months when ash is being deposited only to be moved again or earmarked for permanent storage at a later date. These treatments may entail dust control polymers and/or hydraulically-applied erosion control formulations that develop a durable erosion resistant matrix on top of the ash. The addition of temporary seed mixes can extend and improve dust suppression. Longevity of these systems is dependent upon a variety of factors including amount of traffic, environmental conditions, application rates, soil/substrate conditions and more.

Long-term stabilization generally entails strategies to permanently vegetate coal ash sites during final cover or closure activities. Such an approach involves agronomic assessments, proper species selection and then selection of effective erosion control materials such as hydraulically-applied or rolled erosion control products.

Fundamental #4 – Oversee and Insure Proper Installation

Proper installation practices are critical to the success of any rehabilitation program. Comprehensive and detailed construction specifications with clearly delineated plans and drawings as well as complete mixing/application guidelines and details must be developed and combined with onsite supervision to assure proper installation.

PS^3 provides detailed installation guidelines and CAD drawings for several erosion and sediment control techniques, including Hydraulically-applied Erosion Control Products (HECPs), Rolled Erosion Control Products (RECPs), and Sediment Retention Fiber Rolls (SRFRs). In addition, PS^3 houses an installation calculator to facilitate mixing ratios and/or application rates. Examples are shown in Figures 2 and 3.

Loading Chart for Profile's SMM, BFM, HP-FGM and ET-FGM

Tank Size (liters)	# of 22.7-kg bales	(kg)	Displacement (liters)	2,800 kg/ha		3,400 kg/ha		4,000 kg/ha		4,500 kg/ha		5,000 kg/ha	
				m²	ha	m²	ha	m²	ha	m²	ha	m²	ha
946	2	45	1,060	162	0.016	133	0.013	113	0.011	101	0.010	91	0.009
1,893	4	91	2,120	324	0.032	267	0.027	227	0.023	202	0.020	181	0.018
2,839	6	136	3,180	486	0.049	400	0.040	340	0.034	302	0.030	272	0.027
3,785	8	181	4,240	648	0.065	534	0.053	454	0.045	403	0.040	363	0.036
5,678	12	272	6,359	972	0.097	800	0.080	680	0.068	605	0.060	544	0.054
7,571	16	363	8,479	1,296	0.130	1,067	0.107	907	0.091	806	0.081	726	0.073
9,464	20	454	10,599	1,620	0.162	1,334	0.133	1,134	0.113	1,008	0.101	907	0.091
11,356	24	545	12,719	1,944	0.194	1,601	0.160	1,361	0.136	1,210	0.121	1,089	0.109
13,249	28	636	14,839	2,268	0.227	1,868	0.187	1,588	0.159	1,411	0.141	1,270	0.127

Additional Notes:

- For hose applications, 16 kg/378 liters is recommended.
- Rough surfaces (rocky terrain, cat tracks, ripped soils, etc.) may require additional product to achieve 100% coverage.
- Be sure to allow for residual material in tank on subsequent applications.

Application Rates

Slope Condition	SI
≤ 4H to 1V	2,800 kg/hectare
> 4H to 1V and ≤ 3H to 1V	3,400 kg/hectare
> 3H to 1V and ≤ 2H to 1V[1]	3,900 kg/hectare
> 2H to 1V and ≤ 1H to 1V[2]	4,500 kg/hectare
> 1H to 1V[3]	5,100 kg/hectare
Below ECB or TRM	1,700 kg/hectare
As infill for TRM[4]	3,900 kg/hectare

[1]SMM not recommended for slopes greater than 2H:1V.
[2]BFM not recommended for slopes greater than 1H:1V.
[3]HP-FGM or ET-FGM recommended for slopes greater than 1H:1V.
[4]Use only approved and tested TRMs to create the GreenArmor System.

Slope Interruption Limits*

Product Category	Length (m)
SMM	15
BFM	23
HP-FGM	30
ET-FGM	38

*Listed slope interruption limits are for product applications on a 3H:1V slope. For application on steeper slopes, slope interruption lengths may need to be decreased.

Visual Key for Proper Application
(Flexterra HP-FGM shown below)

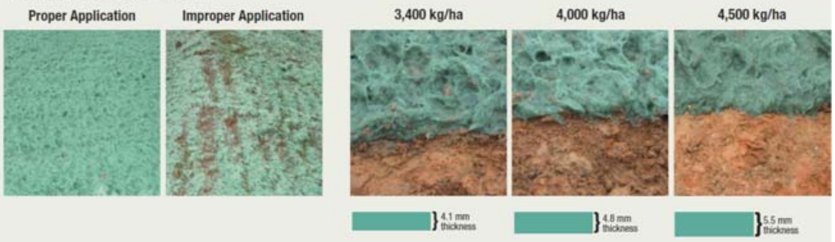

Figure 2: Loading Chart for Hydraulically-Applied Products

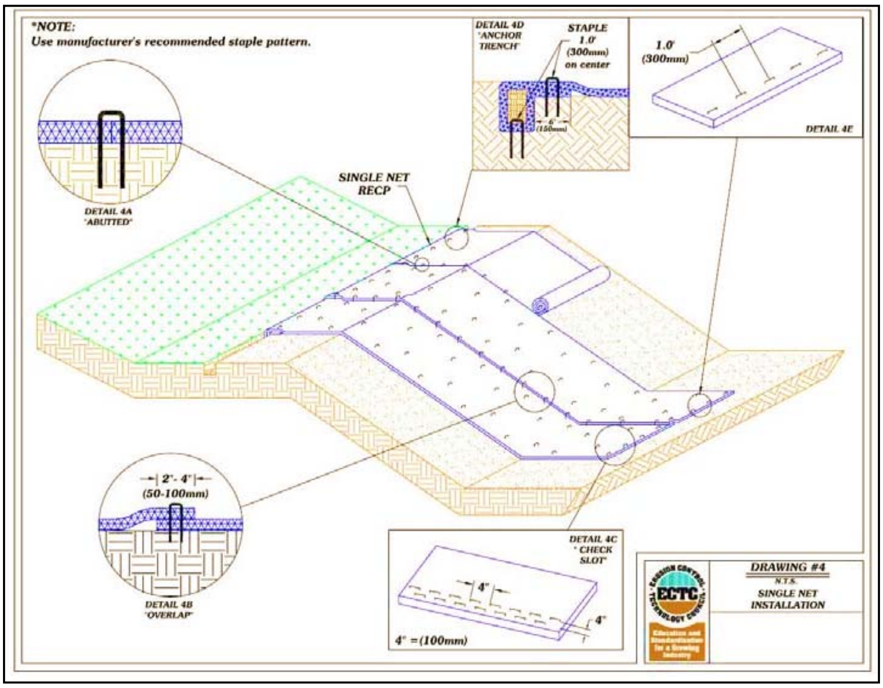

Figure 3: Generic Erosion Control Blanket Installation Guidelines – (Erosion Control Technology Council, 2014)[5]

All installations should be overseen qualified and experienced professionals who are intimately immersed in and familiar with the construction requirements for the project. Experience…preferably site specific experience is always a desired pre-requisite!

Fundamental #5 – Coordinate and Conduct Timely Inspection and Maintenance Activities

Once the erosion and sediment control measures have been installed it is important to visually inspect and maintain them on a regular basis. All active construction sites must be inspected and maintained after each significant precipitation or other potentially damaging event. Inspections should be conducted by qualified professionals whose expectations are consistent with the installer as well as owner and regulatory entity(s).

Initial inspections should insure that all installations are in accordance with plans and specifications with all material quantities and activities fully documented. Subsequent inspections should be executed at pre-determined time intervals and maintenance activities conducted after each significant precipitation or other potentially damaging weather event.

Obvious examples requiring maintenance would be damaged silt fences or sediment control devices, rills appearing on treated slopes, displacement or movement of rock check dams or slope interruption devices, and excessive sediment being deposited at toes of slopes or near/into receiving water bodies. Timely inspections and maintenance can prevent small problems from turning into major complications.

Regrettably this final fundamental is perhaps the most underappreciated and is frequently acted upon with the “one and done” mentality that often is associated with construction bidding and contracting. Savvy coal ash restoration managers should consider incorporating performance requirements and/or maintenance requirements into their construction contracts. Sites with onsite resources should always make inspection and maintenance a standard operating procedure.

Subsequent to the initial “grow in” period inspections should be conducted to assess agronomic aspects of rehabilitation efforts. Beyond monitoring vegetation vigor, cover and species composition, soils or substrates should be tested to determine if supplemental applications of seed, fertilizer, biological inoculants or other soil amendments are warranted. Soil tests may also identify developing problems with soil pH, excessive salts or upward migration of heavy metals or contaminants from underlying substrates.

CASE STUDIES

Following are example projects where some or all of the Five Fundamentals have been successfully applied on coal ash storage sites. The examples discuss intermediate stabilization, final cover systems and research regarding vegetative establishment directly on exposed coal ash.

Intermediate Stabilization of Coal Ash

Figure 1 shows application of an acrylic copolymer formulation on a western US site. When properly diluted and correctly applied at the appropriate rates, these polymers form a durable crust on coal ash that can last for several months – even on trafficked areas. Figure 2 shows a wood based hydraulic matrix providing stabilization and dust control on the sides of an active coal ash storage pile.

Figure 1 – Application of Polymer Agent

Figure 2 – Wood Based Matrix on Slopes

In the second example, coal ash is being stored for an extended time frame prior to either being buried with additional ash and/or moved to another storage area. The owner elected to employ a biodegradable, wood based, hydraulically-applied matrix that forms an intimate bond with the ash to create a porous and absorbent layer providing 3-6 months of stabilization. Seed, fertilizer and biostimulants were included in the hydraulic slurry for additional protection and directly applied on cat tracked coal ash in December of 2009. The seed mix was a blend of annual rye grass – a quick germinating cover species with perennial, turf forming warm season grasses – Bermuda and Bahia grass. The “after’ photo taken 15 weeks later shows uniform growth establishment, resulting in cost effective intermediate stabilization of the ash storage area.

Figure 3 - Post-installation of Matrix

Figure 4 – Growth 15 Weeks Later

Final Cover on Southeastern US Coal Ash Site

Soil tests indicated the coal ash was low in both organic matter and fertility and slightly acidic with a pH range of 6.0-6.3. The slopes were reshaped to create a series of 3H:1V gradients – ranging from 20-30 meters long and divided from the next by horizontal benches 3 meters wide. The owner elected to place 10 cm of topsoil over the ash prior to seeding. The soil cover was rough graded to reduce sheet flow, increase infiltration and provide pockets for water retention and enhanced growth. Lime, synthetic fertilizer, two biostimulants (one fast-acting and the second designed for sustained release) and a prescribed seed mix were hydraulically applied directly on the soil with a small amount of flexible growth medium as a tracer. A biodegradable fugitive green dye in the flexible growth medium assists in visually metering coverage and application rates.

The installation took place in May of 2009 using the following warm season seed mix applied at combined pure live seed rate of 84 kg/ha:

50% *Cynodon dactylon* var. Sahara – Bermuda grass – warm season sod forming grass
25% *Lespedeza cuneata* – Serecia lespedeza – nitrogen fixing legume
10% *Trifolium repens* var. Durana White Clover – nitrogen fixing legume
10% *Urochloa* sp. – Browntop Millet – warm season annual grain used as a cover crop
5% *Eragrostis curvula* – Weeping Lovegrass – warm season bunch grass

Due to anticipated hot and dry summer conditions and the long 3H:1V slopes with significant erosion potential, a flexible growth medium was specified to be applied at the rate of 3,920 kg/ha in a second application above the seed and soil amendments. The flexible growth medium was applied from two directions using a hydroseeder.

Adequate precipitation was received and significant growth was noted in the weeks following the installation such that an abundant stand of vegetation was quickly established as evidenced by the before and after photos shown below. A subsequent site visit in July of 2010 showed essentially the same amount of dense vegetative cover.

Figure 5 – Pre-Installation May 2009

Figure 6 – Luxuriant growth July 2009

Research on Direct Seeding into Coal Ash

One paradigm for developing successful coal ash restoration has been placement of a soil cover over the material, typically at depths of 30-45 cm. This standard of practice is likely a carryover from the landfill and mining industries where regulations may specify or recommend such cover depths to provide sufficient rooting depth and/or prevent “upward migration” of potentially elevated or toxic concentrations of substrate constituents that might discourage, compromise or harm surficial vegetation.

Coal ash storage sites are traditionally “soil poor” in that there was never sufficient onsite top or sub- or top-soil or the foresight to salvage and store such materials for eventual placement on closure or restoration sites. Also consider that many coal ash sites are decades old and were constructed prior to modern regulations or conventional wisdom for constructed cover and closure techniques.

Costs to locate, excavate, haul and place 30-45 cm soil covers over large hectare coal ash storage sites can be exorbitant. Are these costs really necessary or justified? What if we could effectively eliminate or reduce these soil cover depths while still establishing and maintaining vegetation?

Test plots were constructed at a Southeastern US coal ash site on 1H:1V and 4H:1V test slopes subjected to high energy rainfall and weather events. First, soil tests were taken to determine agronomic properties of the coal ash. Surprisingly the samples did not indicate sterility of that specific coal ash. In fact, in was deemed that this material with proper agronomic amendments and species selection could actually support sustainable vegetation. Appropriate seed mixes and agronomic formulations were selected, and then combined with various erosion control techniques and placed in different test plots on September 1 and 2, 2009.

Following are photos showing installation of the test plots and three weeks later from a distance showing significant differences in erosion control effectiveness and establishment of vegetation. Note greater growth and less erosion in the plots to the left.

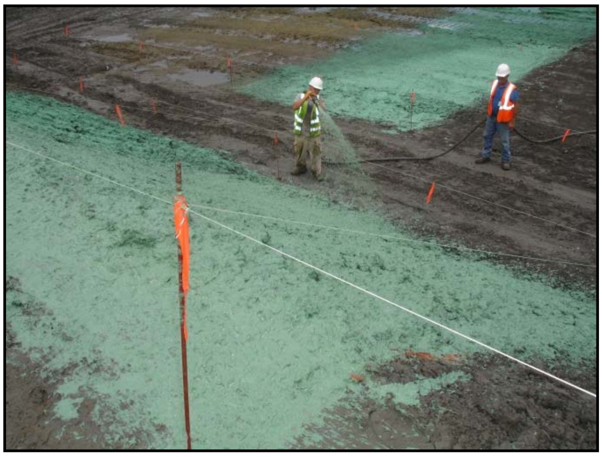

Figure 7 – Installation of Test Plots

Figure 8 – Three Weeks after Installation

Figure 9 – Effects of Erosion on Plots

Figure 10 – Vegetation Growth on Plots

The development of complete formulations that address required soil amendments, proper species selection and suitable erosion control techniques can dramatically affect results. Of course, proper installation and subsequent monitoring and maintenance complete the Five Fundamentals as pre-requisites for success. Clearly luxuriant vegetation can be established directly on coal ash with the right amendments and replacements for topsoil.

CONCLUSION

The Five Fundamentals have been a time proven model for successful disturbed land reclamation on six continents working in many of the planet's biomes, climates, and environments; addressing multiple types of soils and substrates. Employing the discipline to work through the discovery sequence of the first three fundamentals – to analyze soils and substrates, pick the right plant materials for the site and select the most cost effective erosion and sediment control techniques, will undoubtedly head a project in the right direction. These fundamentals must be followed by the development of clear and comprehensive construction plans and specifications to effectively communicate the project requirements to contractors and installers. Once construction commences, onsite oversight of acceptable installations must be conducted by qualified inspectors. Then, the active rehabilitation sites must be regularly inspected and maintained after each significant precipitation or other potentially damaging event. Inspections should be conducted by qualified professionals whose expectations are consistent with the installer as well as the owner, consultant and regulatory entity(s).

The software program introduced in this publication serves as a platform for coordinating the Five Fundamentals into a cohesive and interconnected framework for the designer as well as other project stakeholders. The contributions of this software program will become increasingly enhanced with the continued input of environmental conditions, design rainfall return frequencies and project information supplied by users around the world.

Some case studies with varying environmental conditions were provided to briefly illustrate the discovery (required information gathering) and implementation of the Five Fundamentals – leading to successful coal ash restoration. There are many more projects from mining, energy, transportation and other market segments around the world to substantiate the utility and legacy of the Five Fundamentals.

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