Performance of an Alternative Final Cover System at the Little Blue Run Disposal Area

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CONFERENCE: 2017 World of Coal Ash – (www.worldofcoalash.org)

KEYWORDS: final cover, alternative, disposal impoundment

ABSTRACT

The Little Blue Run Disposal Area, at 940 acres (380 hectares) in area, is the largest Coal Combustion Residual (CCR) disposal impoundment in the United States. The facility, which is owned by FirstEnergy Generation, LLC (FirstEnergy), straddles the Pennsylvania and West Virginia state lines. Due to the size of the impoundment and the relatively soft subgrade, FirstEnergy proposed a final cover system that consists of several alternative design components. Each alternative component was required to achieve the performance standard for that component stated in the regulations and needed to perform in a manner equivalent to or superior to the standard. Because of the soft subgrade, the cap system is constructed over the existing vegetative cover which was demonstrated to significantly improve the bearing capacity of the underlying CCR. A geotextile drainage layer was used to replace a geocomposite drainage layer by demonstrating sufficient capacity. Finally, the final cover soil was reduced in thickness from 2 feet (0.6 meter) to 1 foot (0.3 meter) reducing the required soil volume by more than 1.5 million cubic yards. Following 2 years and 40 acres (16 hectares) of construction experience, this paper will evaluate the performance of the alternative final cover. Furthermore, we have developed a protocol to evaluate the vegetation on the final cover using small Unmanned Aerial System (aka, drone) technology providing highly accurate results over large areas.

INTRODUCTION

The Little Blue Run Disposal Area (LBR) is a Coal Combustion Residual (CCR) surface impoundment located in Beaver County, Pennsylvania and Hancock County, West Virginia. LBR is owned and operated by FirstEnergy Generation, LLC (FirstEnergy), and has been used since 1975 for the disposal of CCR from the Bruce Mansfield Generating Station. LBR is formed behind a 400 feet (122 meter) high earth and rock fill dam that was constructed within the Little Blue Run stream valley, a tributary to the Ohio River.

The CCR materials produced at the Bruce Mansfield Station consist of calcium sulfite scrubber material and fly ash. These materials are mixed with a granulated blast
furnace slag (calcilox) and lime and are pumped in a slurry through a 7 mile (11 km) long pipeline for disposal at LBR. The calcilox, lime, and fly ash act as stabilizing agents, providing additional strength to the CCR materials through chemical reactions that occur following placement. The mixing and placement process results in an in-situ material with a very high water content to void ratio.

For the first 30 years of its existence, the facility operated as a surface impoundment in which stabilized CCR was deposited entirely below water (Figure 1). In 2006, FirstEnergy received a demonstration permit from the Pennsylvania Department of Environmental Protection (PADEP) to expand the size of the facility to 970 acres (385 hectares) and employ the use of geotubes, increasing the disposal capacity to approximately 135,000,000 cubic yards (103,000,000 m³). The use of geotubes allowed for the staged construction of disposal areas within the facility, where material could be placed above the pool elevation of the impoundment (Figure 2). The final grades of CCR reach 65 feet above the crest of the dam. The subsequent drying of these areas results in a stabilized CCR surface that is mulched and vegetated.
CLOSURE PLAN

In 2012, FirstEnergy and the PADEP entered a consent decree which required the cessation of disposal operations at LBR by December 31, 2016, and the development of a Closure Plan for LBR. FirstEnergy undertook a feasibility assessment of closure options for the disposal area. During the assessment, it was concluded that the level of the post-closure water table in the CCR will have a significant impact on post-closure settlements, slopes, and surface drainage.

On April 3, 2014, PADEP approved a Major Permit Modification Closure Plan that detailed the closure plan for the facility. The Closure Plan included revisions to the final CCR grades to reduce the permitted 214 acre (86.6 hectares) operating pool to approximately 100 acres (40.5 hectares) by strategically placing CCR during the remaining years of operation to reduce pooled water. The airspace was balanced so there is no increase in permitted CCR volume.

The Closure Plan includes an alternative final cover system consisting of a geomembrane liner, cushion geotextile, and 1 foot (0.3 m) thick final cover soil layer. Closure is planned to occur in phases starting in 2015 and extending until 2028. The extended closure period was required because of the very large size of the disposal area and the difficult construction conditions anticipated with capping the CCR materials.

FINAL COVER SYSTEM DESIGN

FirstEnergy completed an assessment of various cover/capping options for preventing and/or minimizing the infiltration of precipitation into the waste material at LBR.

The tasks performed as part of these investigations included.

2. Evaluation of Capping System Options, which included:
   d. Schedule to Close for Various Capping System Options
3. Development of a Short List Of Capping System Options For Consideration

Development of a Comprehensive List of Capping System Options

A comprehensive list of capping system options was developed to determine the feasibility and effectiveness of various closure measures for preventing and/or minimizing the infiltration of precipitation into the CCR. This comprehensive list included the 25 initial capping system options. The proposed capping options included various configurations including:
- Direct seeding of the in-situ CCR,
- Varying thicknesses of soil placed over the in-situ CCR,
- Varying thicknesses of stabilized CCR placed over the in-situ CCR,
- Geosynthetic materials and cover soil placed over the in-situ CCR, and
- Geosynthetic materials and cover soil placed over intermediate cover soil.

An initial evaluation of the various capping system options including evaluating the infiltration potential, constructability and technical feasibility, and economic feasibility of each option was performed. The initial evaluation resulted in reducing the list of 25 options to a short list of 6 potential capping system options.

Evaluation of Capping System Options


An evaluation of the infiltration potential of each capping system option was performed using the Hydrologic Evaluation of Landfill Performance (HELP) Model. The HELP Model computations were used to compare potential infiltration rates of each proposed capping system option.

The HELP Model outputs are long term average annual infiltration rates in inches per year through the proposed cap system and the underlying upper 1 foot of in-situ CCR material. The reported infiltration rates account for surface runoff, evapotranspiration, lateral drainage (if applicable), soil moisture retention and vertical infiltration through each proposed capping component.

Based on the HELP Model analyses, the following key points are highlighted:

- The average annual precipitation for LBR used in the HELP model analyses is approximately 36.6 in/year (93 cm/year).
- Placing soil cover over the direct-seeded in-situ CCR resulted in a calculated infiltration rate of 5 to 6 in/year (12.7 to 15.2 cm/year) depending on the thickness of the soil cover.
- Placing stabilized CCR had essentially the same infiltration as the soil cover because the permeability of that material is similar to the in-situ CCR and soils.
- Including a geomembrane in the cap system reduces the infiltration to less than 0.2 in/year (0.5 cm/year).

Alternatives to increase the slopes of the final grades of CCR were also evaluated. These include regrading the in-situ CCR material or placing additional stabilized CCR over the in-situ CCR before capping. As discussed in the following section which contains the evaluation of constructability and technical feasibility, regrading the in-situ CCR material is not feasible because of the low bearing capacity of the excavated CCR. To evaluate placing additional stabilized CCR over the in-situ CCR before capping, a
grading plan was developed to model placement of stabilized CCR to increase final slopes to 2.5 percent (the currently permitted final CCR grades are 0.3 percent). This grading plan required a volume of approximately 11 million cubic yards (8.3 million m³) of stabilized CCR, and also would require significant infrastructure and effort to transport and place stabilized CCR from the Bruce Mansfield Plant at LBR.

Additional HELP Model analyses were performed on cap system options with slopes of 2.0 percent to evaluate infiltration rates resulting from variations in the final cover slopes. The 2 percent slope was modeled to account for predicted future settlement of the 2.5 percent grading plan. The Help Model analysis indicated that varying the design slope had minimal effect on the infiltration rates even when a defined lateral drainage layer was considered. Therefore, increasing the slope of the final grades a relatively small amount has an insignificant effect on the calculated infiltration rates into the CCR material.

Evaluation of the Constructability and Technical Feasibility of Each Capping System Option

A small scale field demonstration project was performed to evaluate the constructability and technical feasibility of various capping options for the closure of LBR. The field demonstration was also intended to address limitations in the ability of the CCR surface to support various types of construction equipment. There was limited understanding of the ability of construction equipment to perform large-scale excavation, fill placement and grading activities on the in-situ CCR surface. The most direct concern was the ability of vegetated and unvegetated in-situ CCR surface to support repetitive movements of construction equipment of the scale needed to construct economically and technically feasible closure system alternatives.

The primary objectives intended for the study were:

- Evaluate the constructability and technical feasibility of several different final capping options.
- Evaluate the various types of construction equipment that could be used during final cover closure construction and their ability to operate on the in-situ CCR material.
- Evaluate the ability of vegetated vs. unvegetated in-situ CCR to support repetitive movements of construction equipment.
- Evaluate the feasibility of excavating in-situ CCR and re-placing the material to potentially increase the slopes of the final cover system.

Fourteen demonstration pads were constructed to evaluate the constructability and technical feasibility of construction of various cap system configurations over vegetated and unvegetated in-situ CCR material using different construction equipment. The various cap system configurations included 1-foot (0.3 m) and 2-feet (0.6 m) thick soil layers placed over vegetated CCR, geosynthetic materials and cover soil placed over...
vegetated and unvegetated in-situ CCR, geosynthetic materials and cover soil placed over intermediate cover soil that was placed over vegetated and unvegetated in-situ CCR, stabilized CCR material placed over the unvegetated in-situ CCR, and installation of an exposed reinforced polypropylene product above the unvegetated in-situ CCR. The test pad demonstration also evaluated the ability of standard and low ground pressure (LGP) dozers, smooth drum rollers, and excavators to operate on vegetated and unvegetated in-situ CCR, varying thicknesses of soil and/or stabilized CCR material placed over unvegetated and vegetated in-situ CCR and composite systems containing soil and geosynthetic layers.

This demonstration project also evaluated the operation of repeated trips by construction equipment over a 2-feet thick soil road constructed over the in-situ CCR. During the course of construction of the demonstration pads, loaded and unloaded triaxle dump trucks and various types of heavy equipment made numerous passes and turns over the access road and staging area.

An in-situ CCR excavation and grading demonstration was also performed. The demonstration consisted of excavating an area into the in-situ CCR material, loading a truck with excavated CCR material and driving for an approximately 1-mile (1.6 km) round trip to demonstrate the potential of future hauling of in-situ CCR, stockpiling the excavated CCR material, and then attempting to grade the stockpiled CCR using a LGP dozer.

A brief summary of the findings during construction of the various cap system demonstration pads and excavation and grading of in-situ CCR is provided below:

- An LGP dozer was able to successfully place a 1-foot thick soil lift across both vegetated and unvegetated in-situ CCR, an LGP dozer was also able to successfully operate on vegetated CCR as long as the dozer made minimal turns. An LGP dozer could not successfully operate directly on unvegetated CCR.
- A standard D8 dozer was able to successfully place a soil lift with a minimum thickness of 2 feet. The standard D8 dozer was unable to place soil lifts less than 2-feet thick. The standard D8 dozer was also unable to operate on unvegetated CCR.
- A midsize-excavator and a mini-excavator were able to successfully operate on vegetative cover, unvegetated CCR, and the underlying weathered CCR layer adjacent to the limits of waste under optimum conditions. Under poor conditions and away from the limits of waste, both excavators are susceptible to breaking through the vegetative cover and becoming stuck in the CCR. Both excavators were able to excavate into the CCR.
- A smooth drum roller was able to successfully static roll soil lifts 1-foot thick and greater with no observable problems. The smooth drum roller was unable to operate on vegetative cover, unvegetated CCR, and the underlying weathered CCR layer.
• Loaded tractor trailers and triaxle dump trucks were able to successfully drive over a 2-feet thick access road constructed over the in-situ CCR. Loaded trucks were unable to operate on vegetative cover, unvegetated CCR, and the underlying weathered CCR layer.
• Geomembrane was able to be successfully placed over intermediate soil cover over in-situ CCR, vegetated and unvegetated CCR, and the underlying weathered CCR layer with no observable problems.
• Exposed reinforced polypropylene product geomembrane was able to be successfully placed over intermediate cover and anchored with no observable problems.
• Stabilized CCR material was able to be successfully placed, worked, transported, rolled, and graded in 2-feet thick lifts by all pieces of equipment that were utilized on the demonstration pads.
• Excavated in-situ CCR material remained saturated and could not be successfully re-worked or graded. Even after additional attempts made after allowing the material to dewater in weekly increments over the course of a month, it remained saturated and could not be re-worked or graded.

Evaluation of the Economic Feasibility of Each Capping System Option

Each capping system option was evaluated for economic feasibility based on a theoretical estimated cost of construction for each capping system option. The following components were considered in the cost estimates as applicable for the various options:

• Mobilization/demobilization;
• Geosynthetic material;
• Intermediate cover soil;
• Final cover soil (price varies depending on thickness of soil placement);
• Compacted clay liner; and
• Final seeding and mulching.

The costs were estimated to represent direct costs associated with the capping system installation for the various closure options evaluated and did not include site preparation, borrow area development and reclamation, or other associated indirect closure costs, including owner’s costs. The relative capping system construction costs were used as one of the decision drivers in the development of a short list of capping system options. These costs are used for relative ranking of options, not for representation of total project costs.

Schedule to Close for Various Capping System Options

An important consideration in selecting viable cap system options was the estimated time required to complete the installation over the entire permitted disposal area. The permitted disposal area is approximately 970 acres (actual limits of CCR are approximately 940 acres) so considerable time is required to complete the installation of
all capping system options. CEC developed conceptual sequencing plans and schedules to complete closure construction for the different capping system options to provide a representative sample of the range of construction timelines for the various options.

**DEVELOPMENT OF A SHORT LIST OF CAPPING SYSTEM OPTIONS FOR CONSIDERATION**

*Determining a Short List of Capping System Options*

Based on the evaluations of the initial comprehensive list of capping system options that was developed, a decision matrix was generated to reduce the cap system options to a reasonable and representative sample of options for further study.

In the decision matrix, each cap option was assigned a rank value from 1 through 5 for economic feasibility (cost per acre), constructability, infiltration amount, and schedule (estimated years to completion). A rank of 5 was best and corresponded to lowest cost, easiest construction, lowest infiltration, and shortest schedule. Cost rankings were determined by estimated relative capping cost per acre. Infiltration rankings were determined according to the modeled infiltration for each option. Schedule rankings were determined according to CEC’s estimated schedule of closure for each capping alternative. Constructability ranks did not have a quantitative reference, but were assigned based on understanding the constructability issues associated with each capping option. Each factor – constructability, cost, infiltration, and schedule – was assigned an equal weight to generate the final scores in the decision matrix.

Based on the decision matrix, a short list of six capping options was generated. The short list of capping system options developed for consideration for closure of LBR is as follows:

- Option 1 – Direct seeding
- Option 2 – 1-foot thick cover soil
- Option 3 – 2-feet thick cover soil
- Option 4 – 2-feet thick cover soil over 2-feet thick stabilized CCR
- Option 5 – Geomembrane over existing vegetated CCR, cushion geotextile, 1-foot thick cover soil
- Option 6 – 1-foot thick intermediate cover soil, geomembrane, drainage geocomposite, 2-feet thick cover soil (PADEP Regulatory Requirement)

Options 1 and 2 represented the highest ranking alternatives in the decision matrix. Option 3 was chosen for inclusion in the short list (despite its lower rank) because the additional foot of cover soil may provide a constructability advantage. Option 4 was added to consider an option which includes placement of stabilized CCR material. Option 5 proposes placing the geomembrane directly over the existing vegetated CCR surface, a cushion geotextile, and 1-foot thick cover soil. Option 6 was included for comparison as the PADEP regulatory option.
Conclusions

Option 5 did not rank as high on the decision matrix as similar options, however, it was chosen as the final proposed alternate final cover system design over other options as described below:

- Option 5 includes a geomembrane layer which provides reduced infiltration over options that do not include geosynthetics;
- The constructability demonstration indicated that geomembrane could be placed directly on the vegetated surface without damaging the geomembrane, eliminating the need for an intermediate soil layer over the in-situ CCR;
- Laboratory testing of soils in the proposed site borrow areas indicate that a 1-foot thick soil cover is expected to provide sufficient water retention to support vegetation;
- Option 5 includes a cushion geotextile layer above the geomembrane, which is necessary for protection of the geomembrane during placement of the cover soil;
- Option 5 includes 1-foot of final cover soil (instead of 2-feet thick as required by the PADEP Regulatory option) and does not include a layer of intermediate cover soil above the CCR. This reduces the overall volume of soil needed for other closure options, and also minimizes the need for borrow area sources and the resulting impacts.

The following Table below summarizes the short list of capping options and includes additional costs for site preparation, borrow area development and reclamation associated with each short list alternative, as well as road construction and other required infrastructure. Note that these costs are intended to include a detailed consideration of costs associated with closure, they should not be understood as a comprehensive estimate of all closure costs. The total costs presented in the following table are based on capping to the permitted horizontal limit of CCR.
### Cap System List of Alternatives

<table>
<thead>
<tr>
<th>Cap Alternative</th>
<th>Cost ($/acre)⁴</th>
<th>Cap System Cost² ($)</th>
<th>Other Costs³ ($)</th>
<th>Total Cost ($)</th>
<th>Total Cost ($/acre)</th>
<th>Decision Matrix Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Direct Seed CCR Surface</td>
<td>$14,000</td>
<td>$13,600,000</td>
<td>$12,400,000</td>
<td>$26,000,000</td>
<td>$27,000</td>
<td>4.00</td>
</tr>
<tr>
<td>2. 1' Cover Soil Over Existing Surface</td>
<td>$30,000</td>
<td>$29,100,000</td>
<td>$26,600,000</td>
<td>$55,700,000</td>
<td>$58,000</td>
<td>3.50</td>
</tr>
<tr>
<td>3. 2' Cover Soil Over Existing Surface</td>
<td>$45,000</td>
<td>$43,700,000</td>
<td>$30,200,000</td>
<td>$73,900,000</td>
<td>$77,000</td>
<td>3.25</td>
</tr>
<tr>
<td>4. Place 2' Stabilized CCR Material Over Existing Surface Below 2' Cover Soil</td>
<td>$45,000</td>
<td>$44,000,000</td>
<td>$96,000,000</td>
<td>$140,000,000</td>
<td>$145,000</td>
<td>2.75</td>
</tr>
<tr>
<td>5. Geomembrane Over Existing Surface, Place Cushion Geotextile and Cover w/1' Soil</td>
<td>$88,000</td>
<td>$85,400,000</td>
<td>$26,600,000</td>
<td>$112,000,000</td>
<td>$116,000</td>
<td>3.25</td>
</tr>
<tr>
<td>6. 1' Cover Soil Over Existing Surface, Place Geomembrane and Geocomposite, Cover w/2' Soil (PADEP Regulatory Requirements)</td>
<td>$133,000</td>
<td>$130,000,000</td>
<td>$34,000,000</td>
<td>$164,000,000</td>
<td>$170,000</td>
<td>2.25</td>
</tr>
</tbody>
</table>

**Notes:**
1. All costs presented have been adjusted for inflation to year 2017.
2. Includes entire permitted limit of the LBR Impoundment CCR disposal area (970 acres).
3. Includes disposal area and borrow area development and reclamation costs. Also includes construction, transportation and associated costs to place stabilized CCR for alternative 4.
FINAL COVER SYSTEM EQUIVALENCY DEMONSTRATION

In 25 PA Code, Chapter 289.242, PADEP established unambiguous default capping system profiles for CCR impoundments. From top to bottom, the capping system includes:

1) Soil growing media 2-feet (0.6 m) thick, fitting specific USDA textural classes and maximum rock content criteria,
2) Optional drainage layers unless demonstrated to not be necessary,
3) A protective barrier layer, and, unless demonstrated to not be necessary,
4) A clay or geomembrane barrier layer.

Similarly, in 25 PA Code, Chapter 288.233, PADEP sets forth requirements for interim site stabilization using vegetated intermediate cover soil that is essentially a 1-foot (0.3 m) vegetated thickness of soil with the same properties as the final cover soil.

In 25 PA Code, Chapter 287.231, PADEP provides an opportunity to propose alternatives to the default capping system profile components through an Equivalency Demonstration procedure. FirstEnergy obtained positive equivalency reviews for:

1) Use of CCR as an interim growing medium instead of using soil.
2) Use of final cover soils with USDA textures that have higher clay contents than required by default regulation.
3) Use of a 1-foot instead of a 2-feet thickness of final cover soil over the geomembrane barrier layer.

Outlines of the equivalency demonstrations are presented below.

1) Use Of CCR as an Interim Growing Medium Instead of Using Soil

A waiver from the 1-foot intermediate cover soil requirement was granted because the CCR met equivalency requirements as a growing medium and other requirements stipulated in 25 PA Code, Chapter 289.242(e). The wet, weakly cemented character of the CCRs would have made placement of intermediate soil cover very difficult. Established intermediate cover vegetation on the CCR helped strengthen and dewater the surface of the CCR and made later placement of geomembrane and soil cover much easier.

Above-water filling of silt-sized, gypsum-rich CCRs required that CCRs be covered with mulch and or vegetation to prevent erosion by wind and water. The potential for freeze-drying and dusting was high over winter months. Through a series of demonstration seeding projects, FirstEnergy demonstrated that CCRs could be directly vegetated without soil.
Revegetation challenges included high unweathered CCR pH (often greater than pH 9), low fertility, and very poor trafficability. Trial seedings began with hydroseeding of adapted grass and legume species, fertilizers, beneficial microbial inoculants, and wood fiber hydromulch. Because of trafficability problems with weakly-cemented CCRs, hydroseeding was done from the shoreline using long extension hoses. Full-scale direct seeding was done using broadcast application of fertilizer, seed, and inoculants and heavy (3 ton/acre) application of switchgrass straw using very-low-ground pressure, and buoyant, “swamp buggy” machines.

We found that the pH of the surface naturally decreased to near-neutral levels over time, presumably the result of recarbonation of hydroxides in the CO2-rich root zone, but to provide a more moderate surface pH from the start some ferrous sulfate was added to some of the broadcast applications.

Systematic vegetation counts were made using the PADEP “Milacre Hoop” counting approach to demonstrate compliance with minimum regulatory standards for successful revegetation (per 25 PA Code, Chapter 289.245, at least 70 percent perennial groundcover, no contiguous areas larger than 3,000 square feet (278 m²) with less than 30 percent groundcover, not more than 1 percent of the entire area with less than 30 percent groundcover.) Vegetative cover consistently exceeded regulatory requirements.

2) Use of Final Cover Soils with USDA Textures with Higher Clay Contents than Required by Default Regulations.

25 PA Code, Chapter 289.242(f) sets standards for final cover soils as outlined below:

1) The cover soil shall fall within the United States Department of Agriculture textural classes of sandy loam, loam, sandy clay loam, silty clay loam, loamy sand and silt loam.

2) At least 40 percent by weight of the cover soil shall be capable of passing through a 2 millimeter, No. 10 mesh sieve.

3) The cover may not include rocks that are greater than 6 inches (15 cm) in diameter.

4) The layer of cover soil shall be at least 2 feet (0.6 m) thick

In western Pennsylvania many soils contain more clay than would fit within the specified USDA textural classes stated above. From past project studies on CCR disposal sites we documented cases where vegetation thrived in final cover soils with up to 45 percent clay content, and falling within the sandy clay, clay loam, clay, and silty clay USDA textural classes. On the basis of past empirical evidence of good growth in such clayey
The Equivalency Demonstration process approved inclusion of more clayey soil textures. The approved soil textures are summarized in Figure 3 below.

**Final Cover Soil Equivalency Review Textural Classes**

![Figure 3 – approved USDA soil textural classes.](image)

3) Use of a 1-Foot Instead of a 2-Feet Thickness of Final Cover Soil over the Geomembrane Barrier Layer

We evaluated the properties of specified final cover soil configurations, specifically a 2-feet thickness of approved USDA soil textures and considering the allowable coarse fragment content, to develop a numerical target for the minimum performance of an alternative cover soil. Because the final cover soil would be placed over an impermeable geomembrane, we concluded that the total plant-available water storage capacity (PAW) of final cover soils would be the most critical limitation to plant growth during dry weather. We considered the range of PAW contained in the specified soil textures and coarse fragment (particles larger than 2 millimeters) content and set the equivalency target as the soil that would provide the least when placed to a 2-feet thickness.

We assumed that coarse fragments would provide no PAW and used generalized soil texture water retention and bulk density properties to calculate net PAW over a range of soil texture and coarse fragment content conditions. As illustrated in Figure 2, we
concluded that the “worst” (most drought-prone) of the specified soils would be a USDA Sandy Loam textured soil containing 40 percent coarse fragments, and that soil would provide a total of 1.39 inches (3.53 cm) of PAW in a 2-feet thickness.

Figure 4 - Range of approved soil PAW performance for a 2-feet soil thickness

Laboratory testing of borrow soil sources included sieve and hydrometer analysis to determine percent coarse fragments, percent fine earth (particles finer than 2 mm), and USDA Texture. In addition, we had the laboratory measure the field capacity (FC, water retained at 0.33 bar tension) water content and permanent wilting point (PWP, water retained at 15 bar tension), with calculation of whole-soil PAW as FC-PWP in the fine earth volumetric fraction of the soils.

Most of the borrow soils tested would provide at least 1.39 inches (3.53 cm) of PAW when applied 1-foot thick, and soils not meeting this standard were used for purposes other than final cover soil. On the basis of these analyses and supported by a successful field plot demonstration, the PADEP approved the Equivalency Demonstration to use a 1-foot thickness instead of a 2-feet thickness of final cover soil.

FINAL COVER CONSTRUCTION

To date, FirstEnergy has completed the initial two phases of final cover construction including 11 acres (4.5 hectares) in 2015 and 31 acres (12.5 hectares) in 2016. Both
phases of final cover construction were performed on areas that had a dense vegetative cover established which improved the trafficability during construction. A key aspect to cap construction was preparatory activities conducted in the preceding year to improve the surface of the CCR and increase the bearing capacity. Typical activities include the following:

- Surveying and drainage improvements including installing surface water conveyance trenches construction to remove ponding water;
- Surface preparation/grade improvements including placing general soil fill as needed on the existing CCR surface;
- Tree and stump removal;
- Mowing existing vegetation on the CCR surface; and
- Installing a perimeter bench for access/geosynthetics deployment and future anchor trench installation.

Immediately prior to final cover system construction, additional surface preparation was performed including additional mowing of existing vegetation on CCR surface, and removal of rocks, debris, and other protrusions from the closure area CCR surface. A 16 oz/sy (542 g/m²) nonwoven geotextile cushion layer was installed in areas where the CCR subgrade was soft and areas where the general soil fill was rocky or had minor rutting that could not be removed because of the soft nature of the CCR material.

Following preparatory activities, the final cover system was constructed which consists of the following from bottom to top:

- 40-mil (1 mm) High Density Polyethylene (HDPE) Smooth Geomembrane Liner;
- 6 oz/sy (203 g/m²) Nonwoven Geotextile Cushion Layer; and
- 12-inch (0.3 m) thick (minimum) Final Cover Soil.

As part of final cover system construction, soil borrow areas were developed for the final cover soil. Extensive soil prequalification testing was performed to confirm the soils met the parameters established as part of the equivalency demonstration. Borrow area preparation included tree clearing, installation of erosion and sedimentation controls, and access road construction. Tree clearing needed to be performed from October to March due to potential Indiana bat habitat. Soils were excavated, processed, stockpiled and sampled for laboratory testing prior to use.

In addition to the final cover system components, the cap included the following:

- Cap drainage layer outlet aggregate and piping;
- Air vents within the geomembrane; and
- Surface water control structures for surface water runon and runoff.
Lessons have been learned from the construction of the 2015 and 2016 cap systems that can be applied to the approach and methods used to construct the remaining approximately 900 acres (364 hectares) to be completed in the next 12 years.

- Surface preparatory activities are required and need to be anticipated and incorporated into construction schedule.

- Surface preparatory activities improved constructability and surface recovery times, which helped to significantly shortened the capping schedule.

- Rain caused significant impacts to liner deployment rates, but lesser impacts to fabric deployment and soil deployment. Extended rain events significantly slowed work progress (deployment was not possible in some instances due to surface conditions from rain occurring on preceding days).

- Next day recovery from short term rain events was faster than expected due to preparatory drainage work and pumping to improve surface conditions. More extended rain events significantly slowed work progress.

- Although the liner deployment is seen as a critical factor in achieving the schedule, soil preparation and deployment present significant challenges.

- Soil preparation, prequalification testing and placement is often the critical path item to complete construction and requires significant planning. Processing and laboratory testing of final cover soil earlier in the schedule or as part of preparatory work may be necessary so that soil processing and prequalification does not adversely affect the schedule.

- The use of 16 oz/sy fabric below the geomembrane where needed was effective in reducing the surface preparation effort, and improving surface stability for construction and protection of geomembrane.

- Use of geogrid over the CCR surface in low areas where soil filling was performed provided excellent constructability improvements. Use of processed soil to fill low spots during pre-capping reduces the need for rock picking prior to geomembrane installation.

VEGETATION ASSESSMENT

Conventional and Unmanned Aerial Vehicle (UAV, aka Drone) Groundcover Assessment

The LBR closure permit requires that inspections of vegetation condition and general surface condition (erosion, settlement, etc.) be made on a quarterly basis using walk-overs over a regular grid, with grid spacing 200 feet (61 m) or closer. Because the site
cap system will eventually cover 940 acres, the inspection requirements will become increasingly onerous.

In our experience at the site we have found that most of the site changes take place over the first two years as vegetative cover evolves from a mixture of annual grasses (nurse crop) with perennial grasses and legumes to all perennial grasses and legumes. Invasive plant trends are also tracked in vegetation surveys.

To enable fast identification of trouble areas as the site grows larger, the team has been conducting site reviews on foot, and parallel evaluations using a small unmanned aerial vehicle (sUAV) or “drone”. The sUAV cameras have collected exceptionally high-resolution and georeferenced visible RGB (red green blue) and near-infra-red (NIR) imagery. Imagery has been processed to develop topographic maps, and has been interpreted using GIS algorithms to develop estimates of live vegetative cover during the active growing seasons. A sensitive and standardized metric of vegetative “green-ness” developed from NIR imagery is the normalized difference vegetation index (NDVI), which we have found to be well correlated with ground-truthing of vegetative cover.

UAV NDVI scoring has been a useful tool for identification of thinly vegetated areas that exceed the 3,000 contiguous square feet threshold in the permit. When large contiguous bare spots are identified, follow-up investigations are performed to ground-truth suspected problem areas.

Ground-truthing of vegetative cover has been performed using conventional “milacre hoop” counts of vegetation. The milacre hoop method counts the types of vegetation (or bare ground) at 20 evenly-spaced points around the perimeter of a hoop that inscribes $1/1000^{th}$ of an acre (43.56 square feet). The milacre hoop counts have made systematically on 200 feet centers, plus additional locations of interest, such as follow-up on trouble-spots identified by low NDVI scores in UAV flight data sets.

Example imagery below illustrates the ground assessment and UAV assessment process. To date, we have found a reasonable correlation between UAV and ground based assessments, but we must note that some measures, such as tracking shifts in species composition and emergence of invasive species, will always require ground-based assessments.
UAV Images and Systematic Milacre Survey Points

Figure 3 - Left: visible imagery. Right: NIR imagery enhanced to bring up contrast between adequately vegetated (green) and sparsely vegetated (brown) areas. Note systematic sampling points are identified on the NIR image.
UAV Image Analysis for Problem Area Follow-Up

“Problem areas” >3,000 SF ID’d

Problem area follow-up areas visited

Figure 4 - Left – problem thin/barren areas identified using NIR analysis, highlighted on visible imagery. Right – problem areas shown on NIR interpretive map. Note follow-up milacre hoop ground – truthing locations are shown within larger low vegetation areas.
NDVI error rate acceptable: 2 “false passes”, 1 “false fail”

Figure 5 - Comparison of percent cover by milacre hoop counts with percent cover by sUAV NDVI interpretation. Areas to the left of the 70 percent threshold are considered inadequate. NDVI interpretation generated two “false pass” and one “false fail” when measured against the 70 percent ground-based threshold.

SUMMARY AND CONCLUSIONS

FirstEnergy submitted a Closure Plan for the comprehensive design and monitoring of a closure system for the Little Blue Run Disposal Area. The approved Closure Plan included an alternative final cover system that was designed to demonstrate equivalency with the PADEP regulatory final cover system. The equivalency demonstration included a wider range of soil textures and a reduced soil thickness.

FirstEnergy has constructed the final cover system over the initial 42 acres (17 hectares) of the disposal area. Lessons have been learned from these areas that can be applied to the approach and methods used to construct the remaining approximately 900 acres (364 hectares) to be completed in the next 12 years.
FirstEnergy is conducting evaluations of the vegetation on the alternative final cover areas as required by the approved Closure Plan. Evaluations include both visual milacre hoop surveys and UAV evaluations. Comparisons between ground-based milacre hoop surveys and UAV evaluations of percent cover indicate that use of the UAV is a valuable tool to aid in the assessment of vegetation adequacy of final cover areas. This tool will become increasingly efficient as larger areas are capped. Monitoring of 2015 cap area indicates that the vegetation meets the regulatory standards for percent cover. Monitoring of 2016 cap area indicates there is temporary vegetation on 85 percent of the area. After annual species have been winter-killed, 2017 growing season UAV counts will reflect the percent of perennial vegetation. The initial data indicates that the 1-foot thick cover soil is able to support the vegetation on the final cover.

REFERENCES