Condition and Modeling Assessment of Geomorphic Landform Design on Coal Refuse Impoundments

Titus C. Smith
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Condition and Modeling Assessment of Geomorphic Landform Design on Coal Refuse Impoundments

Titus C. Smith, E.I.T.

Thesis submitted to the
Benjamin M. Statler College of Engineering and Mineral Resources
at West Virginia University
in partial fulfillment of the requirements for the degree of
Master of Science in
Civil and Environmental Engineering

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Dr. Paul Ziemkiewicz, Ph. D.
Wadsworth Department of Civil and Environmental Engineering

Morgantown, West Virginia
2023

KEYWORDS: Geomorphic landform design (GLD), PLAXIS LE modeling, slope stability, seepage, factor of safety
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ABSTRACT

Condition and Modeling Assessment of Geomorphic Landform Design on Coal Refuse Impoundments

Titus C. Smith

Coal refuse impoundments are the primary storage facility used in the mining industry for the placement and dewatering of fine coal refuse. The West Virginia Department of Environmental Protection (WVDEP) promulgate prescriptive impoundment closure and requirements for the long-term breach and reclamation of the facilities. Typical impoundment reclamation designs consist of backfilling the impoundment with coarse coal refuse and placing soil cap with a minimum 2% slope to the perimeter drainage ditch. Geomorphic landform design (GLD) promotes long term stability of a regraded structure through simulating local topography. By balancing the hydraulic response of the site, runoff and erosion can be mitigated. Of these GLD models, the subsequent factors of safety must be determined and documented with the use of PLAXIS LE. PLAXIS LE is a finite element modeling (FEM) software for geotechnical engineering, such as slope stability, consolidation, groundwater, and dynamic conditions.

The objectives of this research were: 1) coal impoundment site evaluation of active and reclaimed sites, 2) FEM of a reclaimed coal refuse impoundment with design alternatives to the site layout, and 3) incorporating findings from Objective 1 and 2 into a GLD based impoundment closure study of an active coal refuse impoundment to promote long-term stability and reduce reclamation costs for future closure. Through contact with the WVDEP, six reclaimed refuse impoundments, one active freshwater impoundment, and one active impoundment were visited to observe site conditions. The findings of this research determine that GLD applications for impoundment closure and reclamation reduces infiltration and promotes runoff. Complex geometry and limitations to the GLD created profile must be reviewed to ensure slope stability. Based on current reclamation guidelines and standard reclamation practices, GLD is not itself a recommended approach for impoundment closures, but aspects of the design method may be relevant to reduce saturation issues driving soil strength reduction and long slope lengths promoting infiltration.
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1.0 Introduction

1.1 Background

The Surface Mining Control and Reclamation Act of 1977 (SMCRA) was established to address the reclamation process of mines across the United States. Along with the Office of Surface Mining Reclamation and Enforcement (OSMRE) Abandoned Mine Land (AML) Program, funding for such issues was outlined. Over $6 billion has been distributed to states and tribes across the US. In the case of West Virginia, with the second highest potential historic coal production of 20%, only $18 million was awarded in 2022 (FISCAL YEAR 2023). The money awarded for 2022 is enough to reclaim typically one site.

To address long-term environmental sustainability with mine site reclamation, the application of geomorphic landform design (GLD) has been implemented in different cases. GLD focuses on the application of creating a stable design by reducing erosive forces by following the natural topography of a site. While this method can improve long term geotechnical stability and comprehensive hydrologic sustainability, the method has had limited application in the Appalachia region (Santos 2017).

Limitations to GLD application in the Appalachian region include (Michael et al. 2010):

- SMCRA regulations allow for non-GLD options which only benefit the ease of construction
- Increased cost
- Harder to inspect and regulate without legal enforcement
- GLD slopes may be constructed to resemble similar topography but does not ensure the geotechnical stability of the material

1.2 Research Purpose

The reclamation of surface mining can have considerable impact when applied to the coal fields of West Virginia. The purpose of this research is to perform parametric geotechnical and seepage analysis using finite element computer modeling systems to assess the effects of GLD principles applied to closure of a coal refuse impoundment. The application of GLD principles is intended to control a retrofit reclamation generate, access the feasibility of long-term stabilization, and reduced precipitation infiltration and subsequent erosion effects.
1.3 Research Objectives and Scope

The objectives of this research focus on addressing the limitations of the conventional refuse impoundment reclamation approaches that are based on prescriptive permit driven requirements. These current approaches do not factor in refuse pile design configurations to minimize long-term surface erosion, pool area consolidation, development of water impounding hazards, and stream channel designs along the capped impoundment incorporating climate change. The main objectives through this project are proposed as follows:

Objective 1: Perform field visits to identify pertinent environmental conditions at closed, reclaimed, and abandoned fresh water or coal refuse impoundments. This approach is valuable to identifying the long-term site conditions and environmental or hydrologic stressors affecting reclamation sustainability. This work will include evaluating site mine soils and classification.

Objective 2: Develop and analyze a candidate reclaimed coal refuse impoundment for geotechnical stability and seepage effects due to the prescribed promulgated requirements. Perform numerical computer simulations to identify geotechnical stability and seepage effects due to alternative site layouts and design options. Evaluate the geotechnical Finite Element Modeling techniques and solution approaches to consider prior to advancing to modeling the GLD prototype design concepts. Incorporate findings from Objective 1 into retrofit design alternatives for Objective 3.

Objective 3: Develop and analyze a candidate coal refuse impoundment which is currently in an active permit status but may advance to closure. Prepare a computer based finite element analysis of alternative GLD based closure options. Prepare and contrast design alternatives which seek to promote long-term impoundment sustainability and reduced reclamation costs by altering slope profiles and seepage drainage paths.
2.0 Literature Review

2.1 Coal Mining Process

Coal mining is the process of removing a coal seam from either deep below the earth’s surface or surface mining. Each method requires the additional cutting out the seam and collecting some spoil material above and below each seam. This excess material is often controlled through three factors: geology and resulting stability, the seam thickness, and the mining equipment used (D’Appolonia 2009). After the coal has been harvested, it goes through the preparation process to remove incombustible material, also known as refuse. Refuse properties are contingent on the gradation, moisture content, and coal content within the refuse (D’Appolonia 2009). After screening the material to limit the size entering the preparation plant, typically 100 to 150 mm, a heavy media cyclone, vessels, or combination of these process is used reduce the size further to about 1 mm. This process changes the specific gravity of the slurry such that the coal particulate floats with the refuse material sinks. The process uses a large quantity of water, so the process recycles water to the best of its abilities with vibration. The final average moisture content of the coarse refuse is between 8-15%, while the fine refuse had a much higher moisture content which varies based on the facility (D’Appolonia 2009).

Coal refuse is primarily divided into two separate classifications: coarse and fine. These two classifications can be best described as the difference between a solid waste and a sludge, respectively. Coarse coal refuse (CCR) is the larger of the refuse material typically trucked or belted dependent on some considerations such as distance of transportation, gradation, and production. Placement of the material was typical through end dumping of trucks or belting the material to a set location with additional mobilization and shaping with dozers. Fine coal refuse (FCR) is most moved through pumping the slurry to the impoundment. Refuse impoundments are widespread practice for waste handling, used to store and dewater the fine refuse. Most impoundments use the coarse refuse to build an embankment that will retain the fine refuse slurry, while a decant system is used to drain the water out of the fine refuse slurry (Reclaiming 2023).

Coal refuse impoundments are typically constructed in three different methods, either independently or in combination. These methods are upstream, downstream, or centerline. Downstream tends to result in the strongest overall construction method. Materials for the dam are used from a mix of waste material from the mining process, primarily CCR to construct most of the dam. Some additional materials such as FCR or other on-site materials with lower hydraulic conductivity may be used to establish a clay core to lower the phreatic surface within the dam. Drains are often also included in regions to limit seepage within the dam (D’Appolonia 2009).

Coal refuse impoundments are monitored and regulated to a higher level of inspection than other water-based reservoirs. Consideration for the construction, foundation and dam materials, hydrology and hydraulics, seepage analysis, and slope stability (Genes et al. 2000). In addition to monitoring pore water pressure within the structure, visual inspections are performed every
seven days. Additional consideration should be allotted to the construction methods, material gradation with processing plant refinement and improvement.

2.2 Coal Refuse Material

Material properties for FCR and CCR were referenced for an acceptable range of values. Some material testing and classification was done to best evaluate parameters for site specific materials. It is noted that differences in coal preparation and cleaning vary the results of the material properties. Key parameters for modeling input were based on unit weight, cohesion, internal angle of friction, and hydraulic conductivity. Material properties for FCR are cited in Table 1 and CCR are referenced in Table 2.

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Table 2: CCR reference material properties

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2.3 Reclamation Law

After the installment of SMCRA in 1977, additional legislature was passed in Code of Federal Regulation (CFR), 30 § CFR 77.216 and 30 § CFR 780.225. Enforced of such practices is through the West Virginia Department of Environmental Protection (WVDEP). Current reclamation practices involve regrading a mine land to approximate original contours (AOC) with little consideration for the hydraulic response.

These efforts outline that through conventional method, a reclaimed site will through best effort closely resemble the AOC. The result should control drainage, limit erosion, and maintain a stable slope. Often this is accomplished with planar slopes and benches and has been successful in establishing stable designs. Issues such as the loss of stream channels, which with time increase erosion as the site tries to reach equilibrium. To combat this a perimeter drain is implemented to reduce saturation of the material.

Reclamation practices by the West Virginia Department of Environmental Protection (WVDEP) is to cover the coal refuse with materials on site to establish a cap over the top layer of material to limit precipitation infiltration. Through this process, the coal refuse is typically drained of free-standing water and coarse coal refuse is added to increase the stability of the refuse material. After some ground stability has been ensured, topsoil will then be added to cover the refuse with a minimum of 2% final slope grade.

2.4 Geomorphic Landform Design

Geomorphic landform works to reduce the erosion by creating an erosively stable design by mirroring similar topographic features in the area. By implementing a more natural drainage system through pre-established channels, water infiltration is limited, and runoff is promoted in regions which are more hydraulically stable reducing erosion. This method has had success outside the U.S. and within semi-arid regions in the U.S. (Martín-Duque et al. 2010). Some research on GLD has also been applied to West Virginia mining reclamation, though results vary (Russell, 2012; Sears, 2012; DePriest, 2012).

GLD is not perfect and comes with its own limitations. Some cases such as slope topography and stability can be difficult to achieve especially if the footprint of the project area is to be conservative (DePriest et al. 2015). Creating a mature stream can also pose a challenge. Pre-mining watersheds may not be able to be restored with geotechnically sound slopes through GLD. GLD can also limit the capacity of a fill site if the area of impact is not changed to better stabilize the area; regulations may also limit the allowable area of disturbance. In some cases, a stepper slope may reduce the overall soil loss such as that recorded by Kapolka and Dollhopf (2001) as an increase in slope from 40% to 50% decreased the loss of soil. While there was a steady increase in soil loss up to 40%, the reduction indicated that the soil loss is not a linear trend. Infiltration rates also vary with the resultant slope of an impoundment. Traditional valley fills and the flatten crests have an infiltration rate of 55% and 85%, respectively (Ritter and Gardner, 1993; Sharma et al., 1983). With GLD applications the infiltration rate can be reduced to a 55% infiltration rate across the entire structure (DePriest, 2015).
A study outlining some issues on GLD reclamation was conducted by Michael et al. (2010). While the law does allow for the reclamation to allow valley fills and other leveling techniques, it should not come at the expense of the locals. Planar slopes may be easier to construct but will often be rerouted to match the topography of the region to establish equilibrium. Operations such as valley fills do promote development of post-mining land for residential, commercial, or agricultural use. However, valley fills must be designed at a 2H:1V or less and require diversion channels. Diversion channels are used to ensure that fill stability is not compromised during storm events of a 100-year, 6-hour precipitation. GLD design can also disrupt cut and fill balances, reducing the storage capacity and increasing the footprint of a valley fill with spoils; complex slope profiles are also difficult to maintain with a 2H:1V stipulation. As such, more free draining, angular gravels may be required to meet regulatory standards which can increase cost significantly when on the scale of the reclaiming of some post-mining sites. Costs for GLD are estimated to be 10-15% higher than traditional reclamation, inherently, with inexperienced teams. Experienced groups may decrease this to 1-5% with exposure and training (Schor and Gray 2007). Concave slopes are more stable, hydraulically and geotechnically (Schor and Gray 2007).
3.0 Methods and Approach

3.1 Fieldwork Approach

Field visits were conducted to assess how the current reclamation process has left many of these structures years after reclamation. These visits reflected the design criteria used at the time of reclamation and the durability of each impoundment as the years passed. Site characterization was determined based on visual observations made from walking reclaimed impoundments and accessing current conditions. A field inspection sheet (Table 3) was developed to indicate measured results in the field but was limited due to the vast space required to cover with each visit.

After reviewing each site visit, a comprehensive analysis and field writeup was performed to state and address the observations made. Speculation of each observation was done after careful review of photographs and site characteristics before any conclusions were drawn. From the conclusions, some alternative design ideas could be implemented with GLD components.
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<tr>
<th>Impoundment Dimensions:</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Berm Length (ft.):</td>
<td>Impoundment Slope (H:V):</td>
<td>Last Used:</td>
</tr>
<tr>
<td>Berm Width (ft.):</td>
<td>Embankment Slope (H:V):</td>
<td>Reclaimed (Y/N):</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Location</th>
<th>Rating System</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Impoundment</td>
<td>Yes/No/Unknown:</td>
<td>Low:</td>
<td>Moderate:</td>
</tr>
<tr>
<td>10 Tension crack length (ft.):</td>
<td>0.0-5.0'</td>
<td>5.1-10.0'</td>
<td>10.1-20.0'</td>
</tr>
<tr>
<td>11 Settlement distance (in.):</td>
<td>0.5-1.0'</td>
<td>1.1-2.0'</td>
<td>2.1-3.0'</td>
</tr>
<tr>
<td>12 Scabs or slope movement (ft.):</td>
<td>0.5-2.0'</td>
<td>2.1-4.0'</td>
<td>4.1-8.0'</td>
</tr>
<tr>
<td>13 Surface erosion (ft.):</td>
<td>0.5-2.0'</td>
<td>5.1-10.0'</td>
<td>10.1-20.0'</td>
</tr>
<tr>
<td>14 Fish-Gulley depth (in.):</td>
<td>0.5-2.0'</td>
<td>3.1-4.0'</td>
<td>4.1-6.0'</td>
</tr>
<tr>
<td>15 Evidence of piping formation?</td>
<td>0.5-2.0'</td>
<td>3.1-4.0'</td>
<td>4.1-6.0'</td>
</tr>
<tr>
<td>16 Evidence of seeps with soil loss?</td>
<td>Clean water</td>
<td>Grey water</td>
<td>Mucky water</td>
</tr>
<tr>
<td>17 Wet zones?</td>
<td>2</td>
<td>3</td>
<td>4+</td>
</tr>
<tr>
<td>18 Peaking water (ft.):</td>
<td>0.5-5.0'</td>
<td>5.1-10.0'</td>
<td>10.1-25.0'</td>
</tr>
<tr>
<td>19 Animal burrows?</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>20 Trees, tall weeds, or other vegetation?</td>
<td>Grass</td>
<td>Tall Weeds</td>
<td>Brush</td>
</tr>
<tr>
<td>21 Out of place material</td>
<td>Soil Garbage Drainage Refuse</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Embankment</td>
<td>Yes/No:</td>
<td>Low:</td>
<td>Moderate:</td>
</tr>
<tr>
<td>22 Tension crack length (ft.):</td>
<td>0.5-2.0'</td>
<td>2.1-4.0'</td>
<td>4.1-8.0'</td>
</tr>
<tr>
<td>23 Settlement distance (in.):</td>
<td>0.5-2.0'</td>
<td>2.1-4.0'</td>
<td>4.1-8.0'</td>
</tr>
<tr>
<td>24 Scabs or slope movement (ft.):</td>
<td>0.5-2.0'</td>
<td>2.1-4.0'</td>
<td>4.1-8.0'</td>
</tr>
<tr>
<td>25 Surface erosion (ft.):</td>
<td>0.5-2.0'</td>
<td>2.1-4.0'</td>
<td>4.1-8.0'</td>
</tr>
<tr>
<td>26 Fish-Gulley depth (in.):</td>
<td>0.5-2.0'</td>
<td>2.1-4.0'</td>
<td>4.1-6.0'</td>
</tr>
<tr>
<td>27 Evidence of piping formation? (in.):</td>
<td>0.5-2.0'</td>
<td>2.1-4.0'</td>
<td>4.1-6.0'</td>
</tr>
<tr>
<td>28 Evidence of seeps with soil loss?</td>
<td>Clean water</td>
<td>Grey water</td>
<td>Mucky water</td>
</tr>
<tr>
<td>29 Wet zones?</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>30 Animal burrows?</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>31 Trees, tall weeds, or other vegetation?</td>
<td>Grass</td>
<td>Tall Weeds</td>
<td>Brush</td>
</tr>
<tr>
<td>32 Out of place material</td>
<td>Soil Garbage Drainage Refuse</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Emergency spillway drainage system blockage</th>
<th>Yes/No:</th>
<th>Low:</th>
<th>Moderate:</th>
<th>High:</th>
<th>Severe:</th>
</tr>
</thead>
<tbody>
<tr>
<td>33 Tension crack length (ft.):</td>
<td>0.5-2.0'</td>
<td>2.1-4.0'</td>
<td>4.1-6.0'</td>
<td>6.0'</td>
<td></td>
</tr>
<tr>
<td>34 Settlement distance (in.):</td>
<td>0.5-2.0'</td>
<td>2.1-4.0'</td>
<td>4.1-6.0'</td>
<td>6.0'</td>
<td></td>
</tr>
<tr>
<td>35 Scabs or slope movement (ft.):</td>
<td>0.5-2.0'</td>
<td>2.1-4.0'</td>
<td>4.1-6.0'</td>
<td>6.0'</td>
<td></td>
</tr>
<tr>
<td>36 Surface erosion (ft.):</td>
<td>0.5-2.0'</td>
<td>2.1-4.0'</td>
<td>4.1-6.0'</td>
<td>6.0'</td>
<td></td>
</tr>
<tr>
<td>37 Fish-Gulley depth (in.):</td>
<td>0.5-2.0'</td>
<td>2.1-4.0'</td>
<td>4.1-6.0'</td>
<td>6.0'</td>
<td></td>
</tr>
<tr>
<td>38 Evidence of piping formation? (in.):</td>
<td>0.5-2.0'</td>
<td>2.1-4.0'</td>
<td>4.1-6.0'</td>
<td>6.0'</td>
<td></td>
</tr>
<tr>
<td>39 Evidence of seeps with soil loss?</td>
<td>Clean water</td>
<td>Grey water</td>
<td>Mucky water</td>
<td>Observed flow rate</td>
<td></td>
</tr>
<tr>
<td>40 Wet zones?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4+</td>
<td></td>
</tr>
<tr>
<td>41 Animal burrows?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4+</td>
<td></td>
</tr>
<tr>
<td>42 Trees, tall weeds, or other vegetation?</td>
<td>Grass</td>
<td>Tall Weeds</td>
<td>Brush</td>
<td>Trees</td>
<td></td>
</tr>
<tr>
<td>43 Out of place material</td>
<td>Soil Garbage Drainage Refuse</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>44 Impoundment Rim</td>
<td>Yes/No:</td>
<td>Low:</td>
<td>Moderate:</td>
<td>High:</td>
<td>Severe:</td>
</tr>
<tr>
<td>45 Tension crack length (ft.):</td>
<td>0.5-2.0'</td>
<td>2.1-4.0'</td>
<td>4.1-6.0'</td>
<td>6.0'</td>
<td></td>
</tr>
<tr>
<td>46 Settlement distance (in.):</td>
<td>0.5-2.0'</td>
<td>2.1-4.0'</td>
<td>4.1-6.0'</td>
<td>6.0'</td>
<td></td>
</tr>
<tr>
<td>47 Scabs or slope movement (ft.):</td>
<td>0.5-2.0'</td>
<td>2.1-4.0'</td>
<td>4.1-6.0'</td>
<td>6.0'</td>
<td></td>
</tr>
<tr>
<td>48 Surface erosion (ft.):</td>
<td>0.5-2.0'</td>
<td>2.1-4.0'</td>
<td>4.1-6.0'</td>
<td>6.0'</td>
<td></td>
</tr>
<tr>
<td>49 Fish-Gulley depth (in.):</td>
<td>0.5-2.0'</td>
<td>2.1-4.0'</td>
<td>4.1-6.0'</td>
<td>6.0'</td>
<td></td>
</tr>
<tr>
<td>50 Evidence of piping formation? (in.):</td>
<td>0.5-2.0'</td>
<td>2.1-4.0'</td>
<td>4.1-6.0'</td>
<td>6.0'</td>
<td></td>
</tr>
<tr>
<td>51 Evidence of seeps with soil loss?</td>
<td>Clean water</td>
<td>Grey water</td>
<td>Mucky water</td>
<td>Observed flow rate</td>
<td></td>
</tr>
<tr>
<td>52 Wet zones?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4+</td>
<td></td>
</tr>
<tr>
<td>53 Animal burrows?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4+</td>
<td></td>
</tr>
<tr>
<td>54 Trees, tall weeds, or other vegetation?</td>
<td>Grass</td>
<td>Tall Weeds</td>
<td>Brush</td>
<td>Trees</td>
<td></td>
</tr>
<tr>
<td>55 Out of place material</td>
<td>Soil Garbage Drainage Refuse</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Field Check List (Constructed but unused in this research)
3.2 Carlson Natural Regrade

Carlson Natural Regrade is a computer modeling design package extension of Autodesk Civil 3D to create geomorphic landform designs. These models work to establish a balanced site, both hydraulically and geotechnically, with the use of a fluvial geomorphic algorithm (Bugosh, 2004). Common GLD practices look at the specific details of the region, such as climate, rainfall intensity and duration, topography, and materials. These methods help reduce problems such as revegetation, post-land use, maintenance costs, and reclamation compliance. This is primarily done by reducing precipitation runoff to select regions with mature channel geometry. These changes are noted for being minimal as to not significantly increase the cost and reduce long-term compliance and maintenance costs. Input parameters for the software evaluate the use of slope, runoff coefficient, discharge velocity, area, and other parameters. Parameters such as drainage density, channel pattern and sinuosity, longitudinal profile, channel cross-section, ridges, slopes, and volumes.

3.3 Finite Element Modeling using PLAXIS LE

PLAXIS LE is a finite element software for geotechnical engineering problem solving. The program can solve 1D, 2D, and 3D analytical models to provide viable simulations and solutions to remove the ambiguity of geotechnical engineering. Within PLAXIS LE models may be created a conceptual model, review slope stability, estimate consolidation, monitor groundwater, and evaluate dynamic conditions. Across each modeling condition there are options to optimize the solution based on the principals and theories of different codes and practices. Different models can also be linked, or coupled, with one another to produce a more holistic result. Geometry can be shared across platforms such as Civil 3D, ArcGIS, and text files with easy import of complex data.

3.3.1 Material Properties for Modeling

Initial material properties for the site were divided into five distinct components: clay, gravel, shale, FCR and CCR. These materials were based on geotechnical field reports of the site and subsequently properties were determined through literature review or engineering judgement. Input parameters focus on hydraulic conductivity \( k_{\text{sat}} \), volumetric water content at saturation \( VWC_{\text{Sat}} \), cohesion, internal friction angle \( \Phi \), and unit weight. Material properties for FCR and CCR were mixed from the Century Impoundment O-26-84 Technical Specifications and missing values parameters reference. Additional soil parameters for the clay, gravel, and shale layers were devised as per engineering guidance and judgement. Table 4 was used for material properties in early models of the Century impoundment; these parameters were used for the pre-reclamation and WVDEP reclaimed models.
Table 4: Initial material property inputs

<table>
<thead>
<tr>
<th>Name</th>
<th>Strength Type</th>
<th>Unit Weight (lb/ft³)</th>
<th>Cohesion (psf)</th>
<th>Phi (deg)</th>
<th>k_sat (ft/day)</th>
<th>VWC Sat</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCR</td>
<td>Mohr Coulomb</td>
<td>81.12</td>
<td>0</td>
<td>39</td>
<td>5.90X10^-2</td>
<td>0.5</td>
</tr>
<tr>
<td>CCR</td>
<td>Mohr Coulomb</td>
<td>153.504</td>
<td>0</td>
<td>31.5</td>
<td>1.43X10^0</td>
<td>0.5</td>
</tr>
<tr>
<td>Clay</td>
<td>Mohr Coulomb</td>
<td>145</td>
<td>0</td>
<td>30</td>
<td>2.83X10^-3</td>
<td>0.5</td>
</tr>
<tr>
<td>Gravel</td>
<td>Mohr Coulomb</td>
<td>145</td>
<td>0</td>
<td>45</td>
<td>2.83X10^6</td>
<td>0.5</td>
</tr>
<tr>
<td>Shale</td>
<td>Mohr Coulomb</td>
<td>137</td>
<td>0</td>
<td>20</td>
<td>2.83X10^-9</td>
<td>0.5</td>
</tr>
</tbody>
</table>

After the implementation and use of the Century impoundment original permit file, it was determined that some material properties were inaccurate. Values such as hydraulic conductivity, established at 10^-2 cm/sec with laboratory test results from the permit file, for both fine and course coal refuse. Such conditions were not representative of onsite materials. With the two materials being two distinct particle size ranges, different hydraulic conductivity values should be used to prevent instantaneous drainage. Values from D’Appolonia (2009) Table 6.6 were used to determine a hydraulic conductivity range acceptable for FCR. It was also noted that the hydraulic conductivity of FCR varies drastically based on site conditions, and thus lower values were selected for worst case analysis. The Unified Soil Classification System (USCS) does not have a means to classify coal refuse, due to this variability of material. As such, it was assumed that the CCR had properties closest to that of a clayey gravels, poorly graded gravel-sand-clay (GC) and FCR to inorganic clay of high plasticity (CH).

Material parameters were updated in Table 5. These parameters were used for the GLD Century impoundment design and all Federal No. 2 designs. Critical changes were made in the reduction of phi, lower hydraulic conductivity values, and a revised void ratio.

Table 5: Final Material Properties

<table>
<thead>
<tr>
<th>Name</th>
<th>Strength Type</th>
<th>Unit Weight (lb/ft³)</th>
<th>Cohesion (psf)</th>
<th>Phi (deg)</th>
<th>k_sat (ft/day)</th>
<th>VWC Sat</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCR</td>
<td>Mohr Coulomb</td>
<td>80</td>
<td>0</td>
<td>20</td>
<td>2.83X10^-4</td>
<td>0.13</td>
</tr>
<tr>
<td>CCR</td>
<td>Mohr Coulomb</td>
<td>120</td>
<td>0</td>
<td>31.5</td>
<td>2.83 X10^-3</td>
<td>0.33</td>
</tr>
<tr>
<td>Clay</td>
<td>Mohr Coulomb</td>
<td>123</td>
<td>180</td>
<td>30</td>
<td>2.83 X10^-5</td>
<td>0.34</td>
</tr>
<tr>
<td>Shale</td>
<td>Mohr Coulomb</td>
<td>137</td>
<td>0</td>
<td>30</td>
<td>2.83 X10^-5</td>
<td>0.05</td>
</tr>
</tbody>
</table>

One of the parameter inputs required for consolidation involves the stress/void ratio plot. Since this information is not provided in the permit file, a typical e log p curve was selected from the MSHA Engineering and Design Manual. Figure 4 shows the e log p curve used for the fine coal refuse. The method used in the software was the Logarithmic Function Fit (Figure 1).
Figure 1: $e \log p$ curve for Fine Coal Refuse

3.3.2 Time Rate of Consolidation

Fine coal refuse placed by slurry piping has been reviewed to have a varied time rate of consolidation ($C_v$) as performed by work done by Jedari et al. (2022). The assumptions of time rate of consolidation are that the excess pore water pressure is equal to overburden load and ignoring the self-weight of the material; this does not apply directly with fine grained materials which remain in suspension for longer. As such finite strain theory can be used to determine a resultant $C_v$ for a material with a moving boundary such as the variable depth of material in a slurry impoundment. The study concluded that the hydraulically placed material was under consolidated, with an over consolidation ratio anywhere between 0.08 and 0.55. With reporting values like these, the material may not reach full consolidation for years to come. As such, any fieldwork requires careful consideration of site-specific material parameters and the $C_v$ may not accurately represent site conditions.

3.3.3 Federal No. 2 FCR Material Classification

Material testing on FCR from the Federal No. 2 impoundment included particle grain size distribution (ASTM D422), hydrometer (ASTM D7928), specific gravity (ASTM D854) and Atterberg limits (ASTM D4318). Before conducting material classification, the samples had to be dried to be workable. Two drying methods were used: air-dried and oven dried. Air-dried FCR results are in Table 6 and Figure 2. Oven dried FCR results are in Table 7 and Figure 3.

<table>
<thead>
<tr>
<th>Air-dried FCR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture Content (w)</td>
</tr>
<tr>
<td>Specific Gravity ($G_s$)</td>
</tr>
<tr>
<td>Liquid Limit</td>
</tr>
<tr>
<td>Plastic Limit</td>
</tr>
<tr>
<td>Plasticity Index</td>
</tr>
</tbody>
</table>

Table 6: Air-dried FCR summary
Table 7: Oven dried FCR summary

<table>
<thead>
<tr>
<th>Oven-dried FCR</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture Content (w)</td>
<td>0.20%</td>
</tr>
<tr>
<td>Specific Gravity ($G_s$)</td>
<td>1.753</td>
</tr>
<tr>
<td>Liquid Limit</td>
<td>35</td>
</tr>
<tr>
<td>Plastic Limit</td>
<td>26</td>
</tr>
<tr>
<td>Plasticity Index</td>
<td>9</td>
</tr>
</tbody>
</table>

Figure 2: Grain Size Distribution of Air-dried FCR

Figure 2: Grain Size Distribution of Air-dried FCR
3.3.4 Model Geometry

Each model focused on four regions: clay core, dam, foundation, and slurry. Each region was drawn through as-built drawings, pre- and post-reclamation, or through best effort. In early renditions of the model, a drain was also considered but removed to assume worst case scenario. Each model’s geometry was drawn using Civil 3D and was exported into PLAXIS LE, for convenience. The geometry of each model was extended past the extents of the impoundment to allow evaluation of potential failure modes outside of the expected area.

3.3.5 Groundwater Analysis

Groundwater modeling consists of establishing the profile geometry, material properties, a storm event, boundary conditions, and initial conditions, such as groundwater level. After the profile was imported into PLAXIS LE and material properties were assigned to the associated regions, different boundary conditions can be included in the model to develop different conditions and limitations within a dam. These boundaries typically include climate, excess pore pressure, gradient, head, review, flux, and zero flux. Only one boundary condition may be assigned to a region at a time. Groundwater was assigned at the height of the refuse material and exited through the downstream toe of the dam.

Prior to any design storm, a 5-day inundation period was allowed for steady state flow to be achieved within the dam. Steady state allows the seepage through the dam to equate with the defined environment without large variability in the pore pressure, flow rate, and degree of saturation. A climate boundary was placed along the ground surface across all regions. Two
different storm events were considered, a single storm and two storms one day apart. Models were run under transient conditions, allowing changes in the output relative to time.

Precipitation intensity data was determined through the National Oceanic and Atmospheric Administration (NOAA) Precipitation Frequency Data Server (PFDS) and was site specific for each impoundment (US Department of Commerce, 2023). A 100-year storm over a period of 24 hours was chosen as a reasonable storm to design due to its frequency and intensity.

After calculating a seepage model, outputs were reviewed for errors or considerations in the model. Changes in pore pressure, water table, and degree of saturation can be viewed at various stages in the model. Brown colors are indicated of regions without water, while blue indicates water with some pore pressure. Flux lines may be set within specific areas to monitor water as it flows vertically or horizontally through a section. After viewing the results, the output files were coupled to a slope stability model.

### 3.3.6 Slope Stability Analysis

Within each slope stability analysis, multiple slope stability calculation methods can be applied within a single model. Bishop’s method and general limit equilibrium (GLE) methods were selected as the limit equilibrium methods for this research. Slope search methods were selected to be grid and tangent method and automated slope search method.

With the grid and tangent method, failure locations are determined based on user input. The tangential lines are used as the bounds of the failure location, while the grid is set as anywhere the center of rotation may occur. The user specified regions of failure were divided into toe, mid-slope, crest, upstream slope, and deep foundation. An example of each method may be seen below in Figures 4 through 8.

The slope search method applies the slope search to the entire structure but can be reduced to sections of the structure based on the x-axis. Only one resultant slope search was used to determine a slope failure across the impoundment structure. The automated case was the lowest factor of safety that the computer software would generate based on the defined conditions.

![Figure 4: Toe Grid and Tangent](image)
Figure 5: Mid-slope Grid and Tangent

Figure 6: Crest Grid and Tangent

Figure 7: Upstream Grid and Tangent

Figure 8: Deep Foundation Grid and Tangent
3.3.7 Consolidation Analysis

Consolidation models were considered to estimate the deformation when the FCR was loaded with additional material. Self-weight consolidation of FCR from being hydraulically placed, typically occurs within the first few years. Additional loading can cause considerable deformation or localized failures as the bearing capacity is too low. Modeling of these cases was limited due to unforeseen issues within the Bentley Software, in which 2D consolidation was removed after an updated version of the software. An older version of the software was reinstalled, and outputs were produced. Due to the recall of these modeling conditions however, limited research was conducted within this realm.

Input parameters changed between models were the groundwater level, the length a distributed load being applied, and the regions which were evaluated. Deformation of all regions and of only the slurry was analyzed, but deformation of the slurry was found to be the more critical concern. Additionally, groundwater level had negligible effect on the deformation.

Initial modeling concluded that only two parameters had major influence: distribution of load and pressure head along the headwater. The distributed load resembled the additional of soil to the slurry, with an additional trapezoidal mass to resemble mounding. Placement of this load also varied within the models. The pressure head was intended to determine the influence of water from the surrounding terrain during a storm event. Water was only added at the end of the impoundment to allow ensure the longest flow path.
4.0 Field Work Investigation (Objective 1)

A dam inventory list from the WVDEP indicated that there are 143 coal mining related impoundments across the state of WV. Of the 143 impoundments, 95 impoundments fall under the classification of refuse impoundment. Of these, only 23 impoundments fall into the category of capped/non-impounding or complete/abandoned. The distinctions are the relative conditions of their WVDEP permit status. The classification of completed/abandoned refers to the condition when the impoundment is no longer in active permit status and the Dam License has been terminated by the WVDEP Division of Dam Safety. The dam closure process may last for 5 years after reclamation.

Of these sites, 8 were selected for investigation; 6 reclaimed refuse impoundments, 1 freshwater impoundment, and 1 active impoundment were visited. A detailed GLD design was conducted on the Century Impoundment and the Federal No. 2 Impoundment. A summary of all sites is provided in Table 8 and an aerial map of the sites in Figure 9.

Table 8: Visited Impoundments

<table>
<thead>
<tr>
<th>Permit No.</th>
<th>Status</th>
<th>Description</th>
<th>County</th>
<th>Name</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>O002684</td>
<td>Capped/Non-impounding</td>
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<td>Barbour</td>
<td>Energy Marketing North Hollow Impoundment</td>
<td>39.102</td>
<td>-80.183</td>
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<tr>
<td>O101086</td>
<td>Active/Impounding</td>
<td>Refuse Impoundment</td>
<td>Monongalia</td>
<td>BUILDING RUN SLURRY IMPOUNDMENT</td>
<td>39.663</td>
<td>-80.273</td>
</tr>
<tr>
<td>O002184</td>
<td>Capped/Non-impounding</td>
<td>Refuse Impoundment</td>
<td>Nicholas</td>
<td>ROCKCAMP BRANCH #1 COAL REFUSE IMPOUNDMENT</td>
<td>38.271</td>
<td>-80.902</td>
</tr>
<tr>
<td>O301286</td>
<td>Active/Impounding</td>
<td>Freshwater Impoundment</td>
<td>Nicholas</td>
<td>Peerless Eagle Freshwater Impoundment</td>
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<td>-80.900</td>
</tr>
<tr>
<td>R070700</td>
<td>Capped/Non-impounding</td>
<td>Refuse Impoundment</td>
<td>Nicholas</td>
<td>#1 REFUSE AREA/SITE A IMPOUNDMENT</td>
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<td>-80.679</td>
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<tr>
<td>S201988</td>
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<td>Refuse Impoundment</td>
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<td>-80.644</td>
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<tr>
<td>S024076</td>
<td>Capped/Non-impounding</td>
<td>Refuse Impoundment</td>
<td>Webster</td>
<td>North Point Surface Impoundment</td>
<td>38.446</td>
<td>-80.592</td>
</tr>
</tbody>
</table>
Initial site visits were conducted with the aid of a field observation impoundment inspection sheet. With different iterations of the inspection sheet tested, it was ultimately removed from the final report due to immeasurable parameters and inconsistencies with each of the sites. Each dam is like a snowflake, no two are the same. As such, handwritten notes and photos were taken of any observation that would be used in reclamation revisions. It is noted that none of the impoundments visited were in violation of any law.
4.1 Site Visit- Century Impoundment

A site visit was conducted on September 22, 2021, near Century, WV. The site visit consisted of a recently reclaimed FCR impoundment. The Energy Marketing North Hollow fine coal refuse impoundment, permit number O002684, operated from 1984 to 2009. After permit forfeiture to the West Virginia Department of Environmental Protection Office of Special Reclamation, the site was reclaimed, starting in 2013 and completed in 2020. The reclamation of this site was entirely based on available funding at the time of reclamation. Aerial images of the site prior to and after reclamation are illustrated in Figure 10 and 11.

Figure 10: Aerial Image from 2013 showing Century Impoundment prior to reclamation
The impoundment was reclaimed as a cut and fill operation; the dam structure and surrounding terrain were cut and backfilled into the FCR. The remainder of the dam was set at a 2H:1V slope (Figure 13) to maintain geotechnical stability and a minimum 2% slope cap cover (Figure 12) was placed atop the backfilled impoundment. The depth of the cover varied based on the bearing capacity of the material beneath it. A perimeter drain was added to reduce infiltration to the FCR, and precipitation infiltration was limited to that of the cap.

With the limited vegetation on the cap, observations on site were easy and concise. Limited settlement had occurred since reclamation. There were no observed low spots, but the ground was still soft. No migration of sediment or clogging of the perimeter drain was observed. The hillside along the end of the impoundment had experienced slope failure, efforts were being made to reclaim it. The planar slope of the cutback dam had no issues at the time of the visit (Figure 14).
Figure 12: Filled-in slurry pool

Figure 13: Reclaimed downstream embankment
Figure 14: View of downstream embankment
4.2 Site Visit– Federal No. 2

A site visit was conducted on October 4, 2021, near Blacksville, WV. The site visit focused on walking and collecting FCR samples from an active impoundment. The Crown Coal of West Virginia fine coal refuse impoundment, permit number O101086, has been in operation from 1986 to present. This site was selected based on the location convenience and the expectation that it will go for bond forfeiture in the coming years.

Mining operations stopped around 2018. As such, no additional slurry has been added to the impoundment. The current reservoir, around 57 acres, is comprised entirely of rainwater and is in equilibrium with the surrounding environment. The seepage rate through the impoundment is like that of annual rainfall since the pool elevation has not changed; an annual rainfall of 41 inches.

The upstream slope of the impoundment is a mix of compacted fine and course refuse. It is an estimated 50-75’ of water atop 50-75’ of FCR, but this cannot be confirmed without a bathometric survey. AMD for the site was running heavily without treatment and without rain. Terrain was level at top of site and heavy weathering on slope faces. WVDEP officials claimed that the “evidence of a beach of fines indicates that an area is done settling, typically between 6 months and a year”. Construction of the impoundment is speculated to be comprised of both upstream and downstream construction methods but is not known for sure.

The existing reclamation plan would be to backfill the impoundment and grade to a minimum of a 2% slope to the existing groin ditch along the perimeter of the impoundment. The estimate for reclamation may range between $16 to 21 million.

An additional site visit was conducted May 12, 2022. During the site visit, it was observed that much of the surrounding property was being timbered. The water level in the impoundment was around 6” lower than typical pool elevation. Not all of the site was explored due to limited access. There was prevalent vegetation which may have obscured some of the otherwise obvious visual issues along the site, shown in Figure 15 through 18.
Figure 15: Aerial Image from 2022 showing impoundment prior to reclamation

Figure 16: Slurry impoundment reservoir
Figure 17: Beach of fine and course coal refuse pushout on upstream face

Figure 18: Interface between beach and reservoir
4.3 Site Visit- Rockcamp Branch, Peerless Eagle, & #1 Refuse Area

A site visit on July 21, 2022, was conducted near Summersville, WV. The purpose of these site visits was to observe the environmental sustainability of the reclamation regarding surface erosion and general landform stability to gain information to benefit future site reclamation. Aerial imagery from Google Earth Pro was used to review the area of disturbance and potential site conditions prior to walking the impoundments, shown in Figures 19, 20, 22, 24 and 25.

Three impoundments were visited, these are referenced by the WVDEP Impoundment numbers: O002184, O301286, and R070700. Site O002184 (Figure 21) and R070700 (Figure 26) were a reclaimed coal refuse impoundment, closed prematurely due to recession in the coal industry. O301286 (Figure 23) was an active freshwater impoundment. Each reclaimed site had an abundance of vegetation, primarily trees and grasses, growing in all regions of the impoundment pool and previous embankment. Measurable parameters were difficult to observe, with many deemed “not measurable.” Instead, documentation of observations was conducted and documented with field notes and photos.

Erosion was observed across all sites, in various levels of degradation. In O002184, erosion was reduced due to the heavy vegetation to limit soil loss. O301286 had developed erosion channels from the inflow of rainfall and the pumping of water into the reservoir. R070700 had the worst erosion observed across all sites due to the saturation of the impoundment cap and channelization of runoff down the access road.

Figure 19: Aerial Image from 1990 showing impoundment prior to reclamation
Figure 20: Aerial Image from 2022 showing impoundment after reclamation

Figure 21: O002184 Reclaimed impoundment walking along the impoundment rim
Figure 22: Aerial Image from 2022 showing active impoundment

Figure 23: O301286 Active impoundment along reservoir
Figure 24: Aerial Image from 1997 showing impoundment prior to reclamation

Figure 25: Aerial Image from 2022 showing impoundment after reclamation
Observations at R070700 were summarized to be the best indication of measurable parameters and observations available among the sites. Driving along the access road (Figure 27), the road nearing the impoundment had developed various levels of rills and gullies. In one region, the gullies reached a depth too large for the vehicle to cross, estimated over 3 feet deep and over 4 feet wide. Walking the remainder of the road, it was observed that the gullies changed in width and depth relative to the slope. At the time of the visit, water was flowing within these gullies down the length of the road (Figure 28). Upon inspecting the open channel of grouted riprap (Figure 30) beside the access road, it was completely dry and silted up near the crest.

Reaching the crest of the hill, the reclaimed slurry impoundment outline became evident. Along the impoundment, the slurry material had been covered with coarse coal refuse. Some differential settlement and wet zones were observed within the cap (Figure 29). No indication of geotechnical instability within the impoundment was observed. The surrounding impoundment rim was covered with thick vegetation, primarily trees and brush, which made observations difficult. It was noted that only one gully of meaningful size was observed around the rim. Observations indicated that the perimeter ditch had accumulated fine coal particulate and soil covering the entire perimeter.

From the site visit, these conclusions were drawn. Recent rains in the area contributed to the water within the impoundment. However, the vegetation within the impoundment was that of a marsh. This combination of events indicates that the impoundment is often saturated, potentially permanent. Constant saturation limits additional surface water infiltration, promoting surface runoff from the site. This allows the excess water to flow and bypass the contact ditch to the steeper and slightly lower grade roadway. The roadway thus experienced gullies, in which the cross-section area changed with the slope.
Figure 27: R070700 Access Road

Figure 28: R070700 Access Road and vegetated contact ditch
Figure 29: R070700 Differential settlement of impoundment cap

Figure 30: R070700 Grouted riprap
4.4 Site Visit- Knight Ink, Cowen Trench, & North Point

A site visit was conducted near Birch River, WV on July 28\textsuperscript{th}, 2022. Three impoundments were visited, these are referenced by the WVDEP Impoundment numbers: S201988, S003576, and S024076. All three sites were reclaimed coal refuse impoundments owned by ICG Eastern. Almost all backfill material covering the slurry impoundments was coarse coal refuse (CCR). At some locations, the CCR was estimated at 60 feet of cover. In each site there was an abundance of vegetation, primarily grass and brush. Figure 31 is a mine map of all the mining locations and impoundments. Aerial imagery from Google Earth Pro was used to determine the area of disturbance shown in Figures 32, 33, 35, 36, 38, and 39. Site photos of each impoundment are provided in Figures 34, 37, and 40.

![Figure 31: ARCH Resources base map](image)
Figure 32: Aerial Image from 2010 showing impoundment prior to reclamation

Figure 33: Aerial Image from 2022 showing impoundment after reclamation
Figure 34: S201988 reclaimed impoundment

Figure 35: Aerial Image from 1997 showing impoundment prior to reclamation
Figure 36: Aerial Image from 2022 showing impoundment after reclamation

Figure 37: S003576 reclaimed impoundment
Figure 38: Aerial Image from 2016 showing impoundment prior to reclamation

Figure 39: Aerial Image from 2022 showing impoundment after reclamation
In all reclaimed areas, topsoil ground cover was minimal. This observation was based on the presence of CCR exposed on the surface. None of the sites had a clear indication of the reclaimed slurry area experiencing erosion. At the time of visiting there was no straightforward evidence to indicate that there was the migration of CCR or FCR from the reclaimed structure. However, many of the leveled slurry impoundments were observed to have differential ground surface contouring. Within these lower lying regions, standing water was observed (Figure 41); recent rain events contributed to this however the magnitude is unknown. There were no observations of geotechnical related slides or ground movement.
With the compacted CCR material placed over the slurry, precipitation was observed to infiltrate the fine coal refuse slurry. This effect saturates the slurry and results in isolated areas of ponding surface water. Once the ground surface was saturated, surface runoff was observed to be effective in areas of high-grade relief and at other areas of no grade the water was stagnant. Without monitoring the groundwater level, it is difficult to know the discharge rate of the impoundments. However, the differential settlement of these areas did have standing water in many regions without observed soil movement.

These observations tend to indicate that the perimeter drainage culvert systems may not have sufficient slope to promote free drainage. Along the downstream reach of the drainage culvert a washout occurred, and debris blocked the flow (Figure 42). The area had standing water and marsh like vegetation prior to the culvert. The culvert had large granular particles and was absent of fines.

From the site visit, these conclusions were drawn. The cap used at each site was effective in preventing the migration of fine through the structure. With an unlevel surface, water was observed to pond in low lying areas. These observations indicate that the refuse is saturated and re-impounding water.
Figure 42: S024076 Eroded hillside adjoining open channel ditch
4.5 Recommendations from observations

From each site visit, the observed issues were documented and summarized into Table 9. It was observed that historical reclamation designs and practices work at maintaining a steady slope but are hydraulically imbalanced. Sites more recently reclaimed experience fewer issues but are not defect free. In the years after closure, the unchecked wet zones and differential settlement of the cap, lead to more issues. After losing the ability to retain water, erosion is raised due to the reduced infiltration promoting runoff to an under designed drainage system.

Salient Findings:

1. Wet zones and differential settlement were the lead causes in all site erosion issues,
2. Uneven finish grading, and potential localized differential settlement, was observed with ponded water in low spots,
3. All sites exhibited saturated caps and exhibited significant runoff during precipitation events due to complete saturation,
4. Observed runoff channelized at the lowest grade point on the impoundment to the installed drainage ditches or formed erosion ditches,
5. Drainage ditches were often filled with sediment sometime after the 5-year reclamation.
6. Vegetation and ground cover within the impoundment was that of a marsh,
7. The cap used at each site was effective in preventing the migration of fine coal refuse (FCR) particles through the structure,
8. Sediment buildup, erosion, or dense vegetation was observed in all natural contact ditches. Only grouted riprap contact ditches were alleviated of these issues.

Recommendations for these observations would be subsurface drainage consisting of a corrugated pipe with a geosynthetic to prevent the transportation of fines. Mounded material placed along the cap would also reduce the saturation of the refuse by promoting runoff. Any infiltrated water would have a more delayed release than that of a saturated impoundment. Additional drainage and more robust construction of contact ditches around the perimeter are needed to divert and release water, preventing re-saturation of refuse.
<table>
<thead>
<tr>
<th>Permit No.:</th>
<th>O002684</th>
<th>O101086</th>
<th>O002184</th>
<th>O301286</th>
<th>R070700</th>
<th>S20198</th>
<th>S003576</th>
<th>S024076</th>
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<td>Name</td>
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<td>Rockcamp Branch #1 Coal Refuse Impoundment</td>
<td>Peerless Eagle Freshwater Impoundment</td>
<td>#1 Refuse Area/Site A Impoundment</td>
<td>Knight Ink No. 1 Mine Pit</td>
<td>Cowen Trench Area</td>
<td>North Point Surface Impoundment</td>
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<tr>
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<td>Active</td>
<td>Capped</td>
<td>Active</td>
<td>Capped</td>
<td>Capped</td>
<td>Abandoned</td>
<td>Capped</td>
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<td>X</td>
<td>X</td>
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<td>N.O.</td>
<td>X</td>
<td>N.O.</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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Not Observed (N.O.)
5.0 Century Impoundment Modeling Cases (Objective 2)

Input parameters for the model geometry were based on pre-reclamation as-built drawings and reclaimed as-built drawings. Data was referenced from engineering drawings, permits, site visits, inspection reports, and publicly available data. The product of this research was to develop and access the geotechnical stability of the structure relative to design storms in the region.

The focus of these models outlines the results of coupled seepage and slope stability analysis. All models were conducted along the centerline of the impoundment for the highest summation of forces exerted. Two design storm events were considered in the seepage analysis: a 100-year storm and repeating 100-year storms, one day apart. The design precipitation event for the area was 5.24 inches in 24 hours (US Department of Commerce, 2023). Various failure locations were considered, and the resultant factors of safety were condensed into a table.

5.1 Century Pre-reclamation Impoundment

The impoundment geometry was established through the documentation provided from as-built drawings when the dam was first constructed (Figure 43). A cross section of the dam from 1983 was used for the pre-reclamation design. The drawings show an earthen dam with a clay core. Stages of CCR were used to build up and around the clay core, separated with drains at critical points. Overall, the dam is 130 feet tall and has a crest width of 51 feet. Using the original engineering drawings from 1983 (Figure 44 and 45), the geometry of the dam was drawn into AutoCAD and exported to PLAXIS LE (Figure 46).

FCR slurry was used to determine the impoundments slope stability. With a slurry level set to 101 feet above the toe of the dam, this was a more accurate representation of site conditions. This elevation was determined by the maximum allowable slurry content based on construction drawings.
Figure 43: Top view of historical impoundment

Figure 44: Historical impoundment parameters
Figure 45: Additional design specification of historical impoundment

Figure 46: Pre-reclamation impoundment centerline cross section
5.1.1 Century Pre-reclamation Impoundment Results

The results of the pre-reclamation modeling indicate that the impoundment structure would maintain a minimum factor of safety under all cases except for the slope search method, as seen in Table 10. Figure 47 shows the 100-year storm event seepage output and Figure 49 is the repeating 100-year storm event seepage output. Pore water pressures increased with the additional storm event but was able to dissipate some pressure within the dry period assigned. As the driving forces increase with the addition of saturated FCR, the resultant factors of safety are lower but do not fail.

Failures through the foundation layer are an indication that the geometry of the material may not be thick enough or poor assumption of material strength. Due to the unknown top of rock and existing ground, these foundation failures are very unlikely. Likewise, the automated slope search methods produced results that did not match with that of other modeling consideration with the failure plane passing through the foundation. The lowest factor of safety from each design storm were recorded with Figure 48 and 50.

Table 10: Pre-reclamation model results

<table>
<thead>
<tr>
<th>Location:</th>
<th>Toe</th>
<th>Mid-slope</th>
<th>Crest</th>
<th>Upstream Slope</th>
<th>Deep Foundation</th>
<th>Slope Search</th>
</tr>
</thead>
<tbody>
<tr>
<td>100yr storm</td>
<td>1.233</td>
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<td>1.232</td>
<td>1.208</td>
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<tr>
<td>Repeating 100yr storm</td>
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<td>1.237</td>
<td>1.232</td>
<td>1.201</td>
<td>0.931</td>
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</tbody>
</table>

Figure 47: Century pre-reclamation singular 100-year seepage output
Figure 48: Century pre-reclamation auto singular 100-year

Figure 49: Century pre-reclamation repeating 100-year seepage output
Figure 50: Century pre-reclamation auto repeating 100-year
5.2 Century Reclaimed Impoundment

After completing the analysis of the pre-reclaimed site, the reclaimed site was evaluated. The cross-section geometry was outlined as per the available WVDEP as-built drawings and plan sheets (Figure 51 and 52). Some elements for the impoundment were clearly outlined, however some additional engineering judgement was required to infer the final design relative to the 1983 construction. As discussed, the dam crest was cut and pushed back covering the slurry. While the slurry material has an existing topsoil cap placed above it only FCR was used when designing the reclaimed model, as the depth of material is unknown based on the differential settlement of the FCR. Additionally, the drain was omitted from these models and labeled as additional CCR to assume a clogged drain. Figure 53 shows the final cross section of the WVDEP reclaimed impoundment.

Figure 51: WVDEP reclaimed impoundment layout
Figure 52: Cut and fill design cross section for reclaimed site

Figure 53: Reclaimed impoundment centerline cross section
5.2.1 Century Reclaimed Impoundment Results

The reclaimed model indicated that the overall structure has an improved factor of safety. The slope search method still produced lower factors of safety in which the failure was in the toe of the impoundment and into the foundation layer. The 100-year and repeating 100-year storm seepage outputs are outlined in Figure 54 and 56, respectively. The lowest factor of safety from each design storm were recorded with Figure 55 and 57.

Table 11: WVDEP Reclaimed model results

<table>
<thead>
<tr>
<th>Location:</th>
<th>Toe</th>
<th>Mid-slope</th>
<th>Crest</th>
<th>Upstream Slope</th>
<th>Deep Foundation</th>
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</thead>
<tbody>
<tr>
<td>100yr storm</td>
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<td>1.854</td>
<td>N/A</td>
<td>1.368</td>
<td>0.476</td>
</tr>
<tr>
<td>Repeating 100yr storm</td>
<td>1.859</td>
<td>1.843</td>
<td>1.854</td>
<td>N/A</td>
<td>1.368</td>
<td>0.462</td>
</tr>
</tbody>
</table>

Figure 54: WVDEP reclaimed singular 100-year seepage output

Figure 55: WVDEP reclaimed auto singular 100-year
After the slope stability analysis, deformation of the FCR was evaluated. FCR has been observed to have a low bearing capacity when backfilling the impoundment and can be difficult to work with. In each model the lower boundaries were fixed point, not allowing deformation past them, like the existing ground or bedrock. The exposed top surface was allowed to displace horizontally and vertically as a free boundary. Groundwater conditions in the model was set at 60 feet. Water was also allowed to dissipate through the upstream face.

Loads were applied to the model to simulate the addition of mounded material atop the FCR. Two loads were applied to the refuse, a distributed 10-feet-thick layer of CCR and a mounded 5-feet-thick layer of CCR (Figure 58). These loads were the 1,200 lbf/ft$^2$ and the trapezoidal load of 600 lbf/ft$^2$, respectively. Additional models changed the load with the addition of mounded CCR, to a height of 15 and 30 feet. Models were allowed to consolidate and deform over a period of 2,000 days, or about 5.5 years.
Figure 58: 5-ft mound load on top of fine coal refuse

Figure 59, 60, and 61, show the deformation in the y direction after the application of a 5, 15, and 30 feet of mounded CCR. The results for all models indicate that the load causes some consolidation around 400 feet and heave around 1,000 feet. However, the difference in load has minimal to no effect on the displacement of material as it is a nearly identical output from 15 to 30 feet.

Figure 59: y-displacement results for 5-ft mound after 2,000 days

Figure 60: y-displacement results for 15-ft mound after 2,000 days
Additional models were conducted with a pressure head applied to the top right of the model, a length of 15 feet. The pressure head was modeled to imitate that of water runoff from the surrounding hillside and not contained by the perimeter drainage ditch. The pressure heads applied were 5, 15, and 30 feet. The resultant vertical deformation can be seen in Figure 62, 63, and 64, respectively. These models also included a mounded 10-feet-thick layer of CCR.

Results from these loading cases produced nearly identical results across all models. Again, consolidation around 400 feet and heaving around 1,000 feet.
Figure 64: y-displacement with 30-ft pressure head
5.3 GLD Reclaimed Impoundment

After evaluating the pre-reclamation and WVDEP reclamation, a GLD reclamation of the Century impoundment was conducted. These efforts seek to answer what conditions could be changed or prevented with GLD. Models for GLD were produced using Carlson Natural Regrade and were performed by Amanda Rodrigues (Rodrigues, 2022). Of the different modeling outputs generated, the primary difference was the number of subbasins considered when creating a GLD model. After defining the number of subbasins, design criteria for the drainage density were either modeled based on default parameters for the western US or based on the work done by DePriest et al. (2015) for the Central Appalachia region.

Models that used only one subbasin (Figure 65) removed most of the dam structure to establish the desired drainage channel down the centerline of the impoundment. Models of 1 basin were also scaled improperly, resulting in meaningless results when trying to create cross section profiles as the stationing and scale could not be determined. The outputs for the 2 and 3 subbasin designs were drafted into a profile view, Figure 66 and 67, respectively. Upon further comparison of the contours generate and the subsequent profiles, there was minor difference between any of the models. A mounded zone in the center of 8 to 9 feet was added, but the profile was less than a foot different between all models (Figure 68). Due to this limited difference across the models, only the DePriest et al. (2015) cases were models.

![Figure 65: GLD 1 subbasin design](image-url)
Figure 66: GLD 2 subbasin design

Figure 67: GLD 3 subbasin design
Figure 68: GLD 2 and 3 subbasin design profiles
### 5.3.1 GLD Reclaimed Impoundment

The results of the GLD reclamation are with the addition of the revised material parameters from the earlier cases; this involved changes in the seepage models and the slope stability modeling. Both GLD reclaimed models, 2 subbasin DePriest and 3 subbasin DePriest, were evaluated and summarized with Table 12 and 13, respectively. The seepage outputs for the 100-year and repeating 100-year storm are shown in Figure 69 and 71 for the 2 subbasin DePriest design. The 3 subbasin DePriest seepage model outputs are illustrated in Figure 73 and 75. With an increase in pore pressure from the repeating 100-year storm, the resultant factor of safety was lowered. The lowest factor of safety from each design storm were recorded with Figure 70, 72, 74, and 76. It is noted that in this case the lowest factor of safety was produced by the deep foundation failure plane set with the grid and tangent method.

<table>
<thead>
<tr>
<th>Location:</th>
<th>Toe</th>
<th>Mid-slope</th>
<th>Crest</th>
<th>Upstream Slope</th>
<th>Deep Foundation</th>
<th>Slope Search</th>
</tr>
</thead>
<tbody>
<tr>
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<td>1.343 (B)</td>
<td>N/A</td>
<td>0.886 (B)</td>
<td>1.216 (B)</td>
</tr>
</tbody>
</table>

Bishops Method (B)

*Figure 69: 2 subbasin DePriest singular 100-year seepage output*
Figure 70: 2 subbasin DePriest deep foundation singular 100-year

Figure 71: 2 subbasin DePriest repeating 100-year seepage output

Figure 72: 2 subbasin DePriest deep foundation repeating 100-year
Table 13: GLD reclamation model results (3 subbasin DePriest)

<table>
<thead>
<tr>
<th>Location:</th>
<th>Toe</th>
<th>Mid-slope</th>
<th>Crest</th>
<th>Upstream Slope</th>
<th>Deep Foundation</th>
<th>Slope Search</th>
</tr>
</thead>
<tbody>
<tr>
<td>100yr storm</td>
<td>0.995 (B)</td>
<td>1.071</td>
<td>1.614 (B)</td>
<td>N/A</td>
<td>0.937 (B)</td>
<td>1.187 (B)</td>
</tr>
<tr>
<td>Repeating 100yr storm</td>
<td>0.919 (B)</td>
<td>0.924</td>
<td>1.341 (B)</td>
<td>N/A</td>
<td>0.900 (B)</td>
<td>1.165 (B)</td>
</tr>
</tbody>
</table>

Bishops Method (B)
Figure 75: 3 subbasin DePriest repeating 100-year seepage output

Figure 76: 3 subbasin DePriest deep foundation repeating 100-year
5.4 Century Impoundment Modeling Results Evaluation and Advancements

From the modeling of the 3 different cases, some salient findings could be determined and used to improve the modeling and reclamation process:

1. Material properties were determined based on literature: The CCR internal angle of friction ranged 31.5° to 34°. The 31.5° value was used for worst-case scenario conditions,
2. The material hydraulic conductivity, both FCR and CCR, from the permit file were too high and caused rapid pool drawdown; refined values based on literature were used,
3. The General Limit Equilibrium (GLE) calculation method was used because it produced higher resultant factors of safety with convergence between force and moment equilibrium than Bishop’s method,
4. The grid and tangent method had edge effects and limited the analysis,
5. The automated slope method analyzed the overall stability of the structure to locate the failure surfaces,
6. An analysis using the automated slope search method to identify weak regions and a more detailed analysis using grid and tangent method may improve modeling considerations,
7. The worst-case loading condition is a saturated zone located at the reclaimed dam crest elevation. Analysis of recurring storm events for Pre-reclamation, WVDEP reclaimed, and GLD options showed most ranges of FS < 1.5,
8. All WVDEP and GLD reclaimed models experienced toe failures under saturated conditions from the 100-year and recurring 100-year storm events.

Advancements made in the modeling criteria shall be as follows:

- The internal angle of friction for CCR shall be increased to 34°.
- The hydraulic conductivity values of the FCR and CCR shall be changed to better reflect site conditions, cited from the literature used in Hegazy et al (2004).
- General limit equilibrium (GLE) method will be used in conjunction with the automated slope search method to evaluate failure locations across the structure.
6.0 Federal No. 2 Modeling Cases (Objective 3)

The focus of these models outlines the results of coupled seepage and slope stability analysis. All models were conducted along the centerline of the impoundment for the highest summation of forces exerted. Two design storm events were considered in the seepage analysis: a 100-year storm and consecutive 100-year storms, one day apart. The design precipitation event for the area was 5.24 inches in 24 hours (US Department of Commerce, 2023). Various failure locations were considered, and the resultant factors of safety were condensed into a table.

6.1 Federal No. 2 Active Impoundment

All data used for the Federal No. 2 impoundment was compiled from publicly available data and some documentation from the WVDEP. Data included state boundaries, watershed elements, and contour data. The boundary of the impoundment was added to reduce unnecessary data. Civil 3D was used to compile all data and georeferenced to the datum of Code LL83, EPSG Code 4269 for USGS data. Figure 77 illustrates construction of the correct georeferencing combined into a base map with the reference being set to Code WV83-NF, EPSG Code 26853. Data was color coordinated for ease of interpretation and manipulation of information: grey is the state boundary, green is the watershed district, light and dark blue are secondary and primary water ways, yellow was used for the contour, and pink was set as the impoundment boundary. A profile view of the existing impoundment was drawn to be imported into PLAXIS LE.
Figure 78 is a view of the existing Federal No 2 impoundment and Figure 79 illustrates the site contours and base map. Figure 80 is the center-line elevation drawing of the impoundment imported into Plaxis LE.

Figure 78: Zoomed in base map
Figure 79: Base map with contour data

Figure 80: Federal No. 2 centerline existing ground profile and model
6.1.1 Federal No. 2 Active Impoundment Results

The active impoundment was evaluated using the slope search method across the entire impoundment. The resultant factors of safety can are listed in Table 14. For the first 100-year storm event the seepage output is illustrated in Figure 81 and the stability analysis using the slope search method identified the lowest Factor of Safety of 1.484 at the downstream toe (Figure 82). As expected, pore water pressure increased (Figure 83) with the additional storm and the overall factor of safety lowered. Shallow failure planes (Figure 85) were generated in the toe of the impoundment, due to the buildup of pore water pressure internal to the downstream slope face.

Table 14: Active impoundment modeling results

<table>
<thead>
<tr>
<th>Location:</th>
<th>Slope Search</th>
</tr>
</thead>
<tbody>
<tr>
<td>100yr storm</td>
<td>1.484 - 2.868</td>
</tr>
<tr>
<td>Repeating 100yr storm</td>
<td>0.977 - 2.735</td>
</tr>
</tbody>
</table>

Figure 81: Active Federal No. 2 singular 100-year seepage output

Figure 82: Active Federal No. 2 auto singular 100-year
After conducting the slope stability analysis, consolidation of the refuse material was evaluated to determine the deformation of the FCR under load. Only FCR geometry was evaluated due to the issues experienced in the field with the material. In each model the lower boundaries were fixed point, not allowing deformation past them, mirroring that of the site conditions. The exposed top surface was allowed to displace horizontally and vertically as a free boundary. Groundwater conditions in the model was set at 100 feet. Water was also allowed to drain the model through the bottom upstream face of the refuse shell.

Loads were applied to the model to simulate the addition of mounded material atop the FCR. Two loads were applied to the refuse, a distributed 10-feet-thick layer of CCR and a mounded 5-feet-thick layer of CCR (Figure 85). These loads were the 1,200 lbf/ft$^2$ and the trapezoidal load of 600 lbf/ft$^2$, respectively. Additional models changed the load with the addition of mounded CCR, to a height of 15 and 30 feet. Models were allowed to consolidate and deform over a period of 2,000 days, or about 5.5 years.

Figure 86, 87, and 88, show the deformation in the y direction after the application of a 5, 15, and 30 feet of mounded CCR. Results of these models indicate consolidation near the center of
the impoundment (3,000 ft upstream) and heave occurring at approximately 4,000 ft. This deformation is $1 \times 10^{-15}$ ft consolidation and $2 \times 10^{-16}$ ft heave, respectively. These results are nearly identical across all three load cases.

Additional models were conducted with a pressure head applied to the top right of the model, a length of 15 feet. The pressure head was modeled to imitate that of water runoff from the surrounding hillside and not contained by the perimeter drainage ditch. The pressure heads applied were 5, 15, and 30 feet. The resultant vertical deformation can be seen in Figure 89, 90, and 91, respectively. These models also included a mounded 10-feet-thick layer of CCR.

Results from these loading cases produced nearly identical results across all models. No consolidation was observed across the refuse, however some heaving along the upstream 4,000 ft right side moved up $4 \times 10^{-4}$ ft.
This concludes with the impounded refuse (FCR and CCR) did not indicate significant vertical movement, either as consolidation or heave. This observation is relevant because after the reservoir volume is filled with CCR, the site should exhibit long-term stability based on a fixed boundary analysis.
6.2 Federal No. 2 GLD Reclaimed Impoundment

After completing the active impoundment and analysis of foundation stability, GLD iterations could be performed on a basis of comparison. Outputs from Carlson were based on a 2-basin design with different allowable areas of disturbance. The difference in the allowable area of disturbance was between the valley ridge (Figure 92), the entire extend of the impoundment’s watershed, and the active impoundment (Figure 93), from the headwaters to the crest of the dam. From these models, an elevation ridge of 1500 feet was established to dictate a desired grading scheme. Centerline profiles were drawn to model in PLAXIS LE.

Three additional cases were based on modified versions of the Carlson models. These models worked to lower the height of the mounded material to 50 feet and maintain the ideology of GLD. Case 3 modeled the Carlson output used in Case 1, lowered to 50 feet. Case 4 and 5 are the application of mounded CCR with a side slope of a 2H:1V (26.6°) and 3H:1V (18.4°), respectively. The profile of all models is illustrated in Figure 94 and 95. The slope search method was then conducted along the dam and along the mounded refuse to determine the resultant factor of safety.

*Figure 92: GLD 2 subbasin ridge design (Case 1)*
Figure 93: GLD 2 subbasin impoundment design (Case 2)

Figure 94: GLD Profile Cases (Part 1)
Figure 95: GLD Profile Cases (Part 2)
6.2.1 Federal No. 2 GLD Reclaimed Impoundment Results

The singular 100-year storm seepage outputs for the five cases are illustrated in Figure 96, 100, 104, 108, and 116. The repeating 100-year storm seepage outputs for the five cases are outlined in Figure 98, 102, 106, 112, and 120. The resultant factors of safety for the singular 100-year storm are shown in Figure 97, 101, 105, 109, 110, 111, 117, 118, and 119. The resultant factors of safety for the repeating 100-year storm are shown in Figure 99, 103, 107, 113, 114, 115, 121, 122, and 123. Tables 15 through 19 provide the summarized data of each modeling case.

The results of the GLD modeling of the Federal No. 2 impoundment set to reduce infiltration along the mounded material added to backfill the slurry. As seen in Case 1 through 3, the complex geometry of the CCR cap reduces infiltration and saturation of the impoundment cap. However, the complex geometry also generated unstable slopes based on the failure observed on the left end of the mounded CCR. Cases 4 and 5 were simplified profiles, which became completely saturated after each storm event. However, slope stability within the mound was maintained. Small failure planes were still experienced along the dam as pore water pressure built up.
Table 15: Case 1 modeling results

<table>
<thead>
<tr>
<th>Location</th>
<th>Slope Search</th>
</tr>
</thead>
<tbody>
<tr>
<td>100yr storm</td>
<td>0.635 - 0.956</td>
</tr>
<tr>
<td>Repeating 100yr storm</td>
<td>0.635 - 0.956</td>
</tr>
</tbody>
</table>

Figure 96: Case 1 singular 100-year seepage output

Figure 97: Case 1 auto singular 100-year

Figure 98: Case 1 repeating 100-year seepage output

Figure 99: Case 1 auto repeating 100-year
Table 16: Case 2 modeling results

<table>
<thead>
<tr>
<th>Location</th>
<th>Slope Search</th>
</tr>
</thead>
<tbody>
<tr>
<td>100yr storm</td>
<td>0.435 - 0.839</td>
</tr>
<tr>
<td>Repeating 100yr storm</td>
<td>0.435 - 0.839</td>
</tr>
</tbody>
</table>

Figure 100: Case 2 singular 100-year seepage output

Figure 101: Case 2 auto singular 100-year

Figure 102: Case 2 repeating 100-year seepage output

Figure 103: Case 2 auto repeating 100-year
Table 17: Case 3 (Case 1 lowered to 50 ft) modeling results

<table>
<thead>
<tr>
<th>Location</th>
<th>Slope Search</th>
</tr>
</thead>
<tbody>
<tr>
<td>100yr storm</td>
<td>0.472 - 1.322</td>
</tr>
<tr>
<td>Repeating 100yr storm</td>
<td>0.404 - 1.322</td>
</tr>
</tbody>
</table>

Figure 104: Case 3 singular 100-year seepage output

Figure 105: Case 3 auto singular 100-year

Figure 106: Case 3 repeating 100-year seepage output

Figure 107: Case 3 auto repeating 100-year
Table 18: Case 4 (2 mounds, 2H:1V) modeling results

<table>
<thead>
<tr>
<th>Location:</th>
<th>Slope Search</th>
<th>Slope Search along mound</th>
<th>Slope Search along dam</th>
</tr>
</thead>
<tbody>
<tr>
<td>100yr storm</td>
<td>0.895 - 1.330</td>
<td>1.128</td>
<td>0.895</td>
</tr>
<tr>
<td>Repeating 100yr storm</td>
<td>0.881 - 1.405</td>
<td>0.874</td>
<td>0.881</td>
</tr>
</tbody>
</table>

Figure 108: Case 4 singular 100-year seepage output

Figure 109: Case 4 auto singular 100-year

Figure 110: Case 4 auto singular 100-year along mound
Figure 111: Case 4 auto singular 100-year along dam

Figure 112: Case 4 repeating 100-year seepage output

Figure 113: Case 4 auto repeating 100-year
Figure 114: Case 4 auto repeating 100-year along mound

Figure 115: Case 4 auto repeating 100-year along dam
Table 19: Case 5 (2 mounds, 3H:1V) modeling results

<table>
<thead>
<tr>
<th>Location</th>
<th>Slope Search</th>
<th>Slope Search along mound</th>
<th>Slope Search along dam</th>
</tr>
</thead>
<tbody>
<tr>
<td>100yr storm</td>
<td>0.895 - 1.416</td>
<td>1.498</td>
<td>0.895</td>
</tr>
<tr>
<td>Repeating 100yr storm</td>
<td>0.876 - 1.394</td>
<td>1.239</td>
<td>0.876</td>
</tr>
</tbody>
</table>

Figure 116: Case 5 singular 100-year seepage output

Figure 117: Case 5 auto singular 100-year

Figure 118: Case 5 auto singular 100-year along mound

Figure 119: Case 5 auto singular 100-year along dam
Figure 120: Case 5 repeating 100-year seepage output

Figure 121: Case 5 auto repeating 100-year

Figure 122: Case 5 auto repeating 100-year along mound

Figure 123: Case 5 auto repeating 100-year along dam
6.3 Conclusions of Models/Advancements

From the modeling of the six different cases, findings and conclusions can be drawn as well as advancements to be made:

1. With the FCR refuse being saturated, any precipitation results in shallow slope failures along the downstream slope toe. With a low factor of safety (0.977) resulting from the existing conditions, no excavation from the dam, especially due to the unknown FCR depth,
2. GLD mounding the CCR fill practice reduces water infiltration as indicated by the seepage outputs in Cases 1 through 3. However, the complex geometry also generates instability based on the slope angle relative to the angle of repose of the material,
3. Level slope profiles, such as the ones used on Cases 4 and 5, become saturated with precipitation. The mounded structure is not geotechnically stable (Static FS < 1.5) under these conditions,
4. The GLD design with 3:1 profile produces higher CCR fill FS values, however the existing dam toe FS<1,
5. The worst-case slope stability condition for all modeled cases is at the downstream impoundment slope toe location,
6. The toe slope instability is driven by saturation at critical crest height elevation conditions for all GLD modeling analysis,
7. GLD slope modifications are required on the full extent of the impoundment downstream face and toe.

The results of these findings indicate that the overall slope stability of the impoundment does not meet WVDEP minimum factor of safety criteria. Conditions such as the omission of drains and a raised phreatic surface produce a lower-than-expected factor of safety for the active impoundment. These assumptions still indicate that the impoundment should not be excavated in the event of these issues, especially after reclamation is complete. The application of a GLD mound may be effective in reducing infiltration but slope criteria is outside of compliance with the WVDEP.
7.0 Salient Findings and Conclusion

From the observations and conclusions drawn from the different objectives, the compiled findings have been stated here.

Salient Findings of Objective 1: Field Work Investigation

1. Wet zones and differential settlement were the lead causes in all site erosion issues,
2. Uneven finish grading, and potential localized differential settlement, was observed with ponded water in low spots,
3. All sites exhibited saturated caps and exhibited significant runoff during precipitation events due to complete saturation,
4. Observed runoff channelized at the lowest grade point on the impoundment to the installed drainage ditches or formed erosion ditches,
5. Drainage ditches were often filled with sediment sometime after the 5-year reclamation.
6. Vegetation and ground cover within the impoundment was that of a marsh,
7. The cap used at each site was effective in preventing the migration of fine coal refuse (FCR) particles through the structure,
8. Sediment buildup, erosion, or dense vegetation was observed in all natural contact ditches. Only grouted riprap contact ditches were alleviated of these issues.

Salient Findings of Objective 2: Century Impoundment Modeling Cases

1. Material properties were determined based on literature: The CCR internal angle of friction ranged 31.5° to 34°. The 31.5° value was used for worst-case scenario conditions,
2. The material hydraulic conductivity, both FCR and CCR, from the permit file were too high and caused rapid pool drawdown; refined values based on literature were used,
3. The General Limit Equilibrium (GLE) calculation method was used because it produced higher resultant factors of safety with convergence between force and moment equilibrium than Bishop’s method,
4. The grid and tangent method had edge effects and limited the analysis,
5. The automated slope method analyzed the overall stability of the structure to locate the failure surfaces,
6. An analysis using the automated slope search method to identify weak regions and a more detailed analysis using grid and tangent method may improve modeling considerations,
7. The worst-case loading condition is a saturated zone located at the reclaimed dam crest elevation. Analysis of recurring storm events for Pre-reclamation, WVDEP reclaimed, and GLD options showed most ranges of FS < 1.5,
8. All WVDEP and GLD reclaimed models experienced toe failures under saturated conditions from the 100-year and recurring 100-year storm events.
Salient Findings of Objective 3: Federal No. 2 Modeling Cases

1. With the FCR refuse being saturated, any precipitation results in shallow slope failures along the downstream slope toe. With a low factor of safety (0.977) resulting from the existing conditions, no excavation from the dam, especially due to the unknown FCR depth,
2. GLD mounding the CCR fill practice reduces water infiltration as indicated by the seepage outputs in Cases 1 through 3. However, the complex geometry also generates instability based on the slope angle relative to the angle of repose of the material,
3. Level slope profiles, such as the ones used on Cases 4 and 5, become saturated with precipitation. The mounded structure is not geotechnically stable (Static FS < 1.5) under these conditions,
4. The GLD design with 3:1 profile produces higher CCR fill FS values, however the existing dam toe FS<1,
5. The worst-case slope stability condition for all modeled cases is at the downstream impoundment slope toe location,
6. The toe slope instability is driven by saturation at critical crest height elevation conditions for all GLD modeling analysis,
7. GLD slope modifications are required on the full extent of the impoundment downstream face and toe.

Conclusions from this work indicate that saturation of the impoundment is the key element in starting and developing issues on site. The change from effective to total stress in the refuse is enough to cause this instability. The application of GLD helps reduce infiltration within the impoundment cap but should be evaluated to ensure the slope does not exceed the angle of response of the material. Carlson Natural Regrade will generate models based on the user inputs and will not maintain slope stability of the material as such. A 3H:1V slope has been proven to maintain the best slope stability across all modeling parameters in this study and would be recommended as the maximum slope grade allowed. Cutting into the existing dam structure should also be prevented due to the low factor of safety experienced along the downstream toe of the dam. While the failure is shallow, any failure plane will lead to a larger one or the loss of material. Overall, GLD may not be a viable option as compared to the traditional impoundment closure process. With the addition of more fill being required, a cost-benefit analysis would be required to determine a break-even point based on runoff treatment costs.

Future work on the subject matter may evaluate the application of 3D models when analyzing GLD reclamation consideration, as the overall geometry cannot be simulated with a singular profile down the centerline. However, subsurface profile data may be required to generate meaningful results. 3D models also tend to generate a higher factor of safety. The addition of a compacted layer with a reduced hydraulic conductivity may better represent saturation cycles and profiles of the cap during storm events. Additional consolidation models should be considered in 1D, due to the omission of 2D from PLAXIS LE. Models may be misleading of field conditions based on the process used in coal preparation.
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