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Jeffrey T. Lorimer

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Geomorphic Landform Design Principles Applied to an Abandoned Coarse Coal Refuse Pile on
Steep Terrain in Central Appalachia

Jeffrey T. Lorimer

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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2016

Keywords: Surface Mining, Geomorphic Landform Design, Reclamation,
Coal Refuse, Mine Waste, Earthwork Design

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ABSTRACT

Geomorphic Landform Design Principles Applied to an Abandoned Coarse Coal Refuse Pile on Steep Terrain in Central Appalachia

Jeffrey T. Lorimer

Geomorphic reclamation designs applied in western United States, Australia and Spain have reported success quantified by the economic, ecological, and hydrological benefits. Recent research suggests the feasibility of geomorphic principles in a steep humid environment (e.g. West Virginia). The primary objective of this work is to develop a reclamation alternative with geomorphic landform design principles for the coarse coal refuse pile at Royal Scot in Greenbrier County, WV. The reclamation design is based upon currently accepted engineering methods and promotes stormwater runoff, minimizes infiltration through the refuse pile, and is erosively stable. Design features include the following: (1) stormwater time of concentration was minimized using a radial hydraulic network; (2) significant infiltration reduction is expected resulting from the hydraulic barrier; (3) channel sediment transport is resisted by properly sized lining material; (4) prompt flow channelization minimizes overland flow reducing mass wasting effects; and, (5) growth media consisting of soil amendments mixed directly with the coal refuse. Significant reductions in water treatment costs are expected after construction is completed. Extended documentation of water treatment costs, site hydraulics, and noticeable erosion will prove useful to the scientific community providing a case study for future reclamation activities. If the application is proven successful, geomorphic landforming techniques may be considered for other large earthen applications such as other mining operations, landfills, dams, linear transportation projects, and commercial development.

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1.0 Introduction

Coal mining in Appalachia is common due to the abundance of feasibly accessed coal deposits and West Virginia's principally valued natural resource is coal (SME 1973). The targeted reserve is extracted by either underground or surface mining techniques. Inherent to the mineral extraction is a rejected solid waste generated during processing the mineral. Mine waste characteristics are dependent upon the processes required to achieve the desired product properties for sale and the waste is broadly classified in two categories, coarse and fine refuse. Waste is handled with wheeled vehicles when the material gradation is greater than 28-mesh, and is considered "coarse waste" as compared to the smaller sized particles commonly transported in suspension of a slurry (SME 1973).

Royal Scot is an abandoned coarse coal refuse disposal facility in Greenbrier County, West Virginia and was chosen as the site to demonstrate geomorphic landforming in Central Appalachia. The Royal Scot Refuse Disposal Facility is intended to serve as the small scale pilot program following research suggesting successful application of geomorphic valley fill retrofit designs in the region.

Royal Scot is an ideal site to begin large scale testing of geomorphic landform reclamation design in Central Appalachia due to the upland area available. DePriest et al. (2015) highlighted the challenges inherent with avoiding increased stream burial in a retrofit geomorphic design on a valley fill. Royal Scot is more analogous with a surface mine waste pile than that of a valley fill, and stream burial restraints are not present due to the differences in the landform. Site activity ceased prior to achieving maximum storage capacity indicating promise for shallow slope angles consistent with geotechnically stable landform conceptual designs studied in Central Appalachia (DePriest et al. 2015, Hopkinson et al. 2015, Russell et al. 2014, Sears et al. 2014).

1.1 Background

The Royal Scot Refuse Facility is currently under the control responsibility of West Virginia Department of Environmental Protection Office of Special Reclamation (WV-OSR) resulting from the coal mine operators consistently conducting business in non-compliance with governing regulations. Mining activity ended at Royal Scot in 2001, when a cease and desist order was issued by the West Virginia Department of Environmental Protection (N. Parks, personal communication, 2015). Little to no reclamation efforts have been conducted at the

Royal Scot site, and negligible vegetation exists. The uncapped condition of the refuse pile promotes infiltration throughout the refuse media. Many seeps are present below the pile. The water quality characteristics combined with physical pumping experiments have positively linked the seeps to the refuse pile. Currently the seep flows are contained, pumped back onsite to a universal aggregation point at Pond 1 (Figure 3) and costly water treatment processes are used to comply with the current National Pollution and Discharge Elimination System (NPDES) permit (N. Parks, personal communication, 2015).

1.2 Objectives

The primary objective of the research is to develop a reclamation design for the Royal Scot Refuse Facility incorporating geomorphic landforming principles. Royal Scot is currently the financial responsibility of the State of West Virginia, and minimization of perpetual maintenance costs is a major focal point while assessing the use of regionally untested sustainable reclamation practices. The work described in this thesis includes the design of the topography, design of hydraulic structures, a hydrologic analysis and the placement pre-designed cap structures throughout the geomorphic design. The following features are desired in the final design:

1. Apply geomorphic landforming principles;
2. Reduce stormwater infiltration;
3. Segregate stormwater and groundwater flows;
4. Establish sustainable vegetative cover reducing mass wasting;
5. Minimize earthmoving quantities; and,
6. Minimize import material.

2.0 Literature review

2.1 Geomorphic landform design

Geomorphology is a branch of geology relating to the study of the governing chemical and mechanistic forces shaping landmass features. The delicate balances established over a geologic time scale presented by Toy and Chuse (2005) and watershed systems are dependent upon water, sediment type, slope degree and slope aspect. They describe that when the state of dynamic equilibrium is disturbed, the landmass will begin to exhibit ‘youthful’ tendencies through accelerated erosive forces working to regain balanced forces. Mature landforms exhibit slope profiles combining a convex upper region leading to a region lower in elevation and concave in profile promoting biodiversity (Schor and Gray 2007, Eckels and Bugosh 2010, Toy and Chuse 2005).

Geomorphic landforming is the intentional design and construction of an earthen structure minimizing the degree of imbalance between erosive and resistive forces on a watershed scale (Schor and Gray 2007, Eckels and Bugosh 2010, Toy and Chuse 2004, Hancock et al. 2003). Geomorphic landform design is slowly gaining acceptance by implementing the principles on mine sites, documenting the watershed performance, effectively communicating it throughout respective industries, and the promotion by governing agencies (Schor and Gray 2007). The implementation of geomorphic principles has been studied both domestically and internationally consistently reporting benefits associated with initial reclamation project expenditures, ongoing maintenance, constructability and government acceptance (Martín-Duque et al. 2010, Eckels and Bugosh 2010, Robsen et al. 2009, Measles and Bugosh 2007).

Geomorphic designs have yet to be successfully implemented in the eastern coal producing regions of the United States, i.e. Central Appalachia. Challenges limiting the geomorphic landforming in the eastern coal producing regions include: 1) current reclamation enforcement is not explicitly focused on geomorphic methods; 2) regulatory emphasis on minimizing stream burial; 3) cost; and, 4) geologically ‘young’ natural landforms (Michael et al. 2010). Research has been conducted focusing on establishing geomorphic watersheds without increasing the length stream burial (DePriest et al. 2015, Hopkinson et al. 2015) and stream restoration directly on the mine site (Sears et al. 2014, and Hopkinson et al. 2015) to further understand the challenges present in Central Appalachia.

2.2 Drainage

Steep slopes make the application of geomorphic reaches difficult because steep channel design is challenging. Methods for steep channel designs are reviewed in the following sections.

2.2.1 Hydraulic Engineering Circular, Drainage Manual No. 15 (HEC)

Design of Roadside Channels with Flexible Linings titles a publically available design manual, The Hydraulic Engineering Circular Number 15, Third Edition (HEC 2005). This piece of literature is a design manual outlining the methods used in designing flexible channel linings. The manual describes both permissible shear stress and permissible velocity methods for both steep and mild channels. Mild channel methods apply to bed slopes less than 10 percent for vegetated and riprap lining materials. The authors further describe the permissible shear stress method as technically sound and suggest an industry wide shift away from permissible velocity designs (HEC 2005).

The HEC method is well defined for slopes under 10 percent. Hydraulically and topographically steep slopes are defined with a different set of equations outlined within the manual. The force balance conducted on channel lining particle level requires that a large stone size to resist the shear force in the direction of flow. Fluid shear force is the force exerted in the direction of flow by the fluid movement, and fluid shear stress is the magnitude of the shear force applied across a unit area (Gray 2000). As the bed slope increases, the influence of gravity decreases the stability of a single rock particle. On steep slopes, the shear force and the gravitational forces both act downward, and to overcome the forces inducing movement, the weight of the stone is increased by increasing the stone size. The angle of repose is influential within this solution method, and the sensitivity is compensated with an increase in safety factor. Freeboard design is suggested as 0.5 ft in mild channels and twice the flow depth in steep channels (HEC 2005). Shear stress is easily field estimated with simple measurements, depending only on the bed slope, flow depth and fluid density as shown in equation 2.2.1.

$$\tau = \gamma * d * S_0 \quad \text{Eq. 2.2.1}$$

where

τ = shear stress in the channel (lb/ft²)

γ = specific weight of fluid (lb/ft³)

d = depth of flow in the channel, measured normal to the bed slope (ft)

S_0 = Slope of channel (ft/ft)

2.2.2 PADER Drainage Manual

The Commonwealth of Pennsylvania, Department of Environmental Resources (PADER), Erosion and Sediment Pollution Control Manual was published in 1990 and details hydrologic and hydraulic methods considered both current and acceptable for practice. Flows are characterized by the channel slope and the expected development of flow undulations within the channel. Channel waves are expected near the channel critical slope. A limiting flow velocity is promulgated for the material density and size. Shear stress is governed on the channel lining by limiting the flow velocity (PADER 1990).

This publication advocates the use of the Soil Conservation Service's rational method for the hydrologic analysis. The use of WinTR-55 is promoted for the hydrologic analysis when appropriate conditions exist (NRCS 2009). Design storm information is provided within PADER (1990) on a county basis. The hydrologic analysis whether in WinTR-55, or by other method, will result with the design flowrates for the channels. (PADER 1990).

Hydraulic parameters are governed by Manning's Equation and the design is built upon a maximum permissible velocity for a given channel lining type. Some variability to the velocity limit is given if the channel reports to a sediment basin prior to discharging from the site. The PADER method prompts the designer to compute the critical channel slope as follows in Eq. 2.2.2. The unsteady region is considered as a range from the critical slope and is calculated as shown in Eq. 2.2.3. Freeboard is determined on the result of the following equations and further details can be found in the PADER (1990) manual.

$$S_c = \frac{14.56 * n^2 * D_m}{R^{\frac{4}{3}}} \quad \text{Eq. 2.2.2}$$

where

S_c = critical slope (ft/ft)

n = Manning's "n"

D_m = mean depth of flow = $\frac{\text{area of flow}}{\text{top width of channel}}$ (ft)

R = hydraulic radius = $\frac{\text{area of flow}}{\text{wetted perimeter}}$ (ft)

$$0.7*S_c < S_0 < 1.3*S_c \quad \text{Eq. 2.2.3.}$$

where

S_0 = slope of channel being investigated (ft/ft)

The channel velocity resulting from the Manning equation leads the designer to a table of liner and permissible flows. R-7 rock riprap can handle the highest velocity, 14.5 ft/s, of all unconstrained flexible channel liners. Flow velocities are limited at 22.0 ft/s with the use of gabion baskets. The thickness of the rock lining material is specified as 1.25 times the largest particle diameter. Channel filter layers are required as presented within PADER (1990) manual.

2.2.3 Surface Mining Water Diversion Design Manual (OSMRE)

The Surface Mining Water Diversion Design Manual (Simons 1982) was established for the United States Department of Interior, Office of Surface Mining Reclamation and Enforcement (OSMRE) specifically for the use within the eastern United States coal producing region. The coal producing region collectively referred to as Appalachia presents unique hydraulic challenges on disturbed sites. Steep channels and hydraulically steep flow conditions are typical of natural landmasses in the region.

The OSMRE manual was developed through an extensive empirical study of hydraulic structures, and poor performance was prevalent at the study sites. The lack of success was strongly attributed to improper construction methods and lack of adequate material gradation. The operators have historically used spoil material resulting from the mining operation as the channel liner (Simons 1982). The proper use of material segregation by gravity for the development of valley fills with a durable rock underdrain is summarized within Michael et al. (2010) and is common in Central Appalachia. This industry practice is not suggested because dumping material from the top of a slope will promote poor lining gradations. Suggested

placement methods are detailed within the OSMRE manual (Simons 1982). Detailed articulation is required for placement of riprap and small segment completion with smaller equipment, grapple type bucket (clamshell), or hand placement methods are suggested to ensure channel success (Simons 1982).

According to Simons (1982) improper channel lining gradation is the primary cause of riprap failure on steep slopes. The required gradation includes large particles through fine material. Minimal void space is essential to lock the larger particles together, distribute shear forces, and most importantly prevent local jets of water reaching the channel bed. A range of indices based upon the mean particle size of the lining material are provided to guide the designer into accepted gradation envelopes, and generally includes a filter layer. A reduction in the driving shear force is achieved by limiting the amount of protrusions into the water flow and minimizing the area force can physically act upon.

Bathurst et al. (1979) examined mountain streams both in field settings and within a flume. The studies show that the water actually flows around the large particles than overtop of the material. The OSMRE manual directly advocates following Bathurst's methodology for steep channel design based upon compatible shear forces. The shear stress calculation does not differ from that presented in Eq. 2.2.1. The manual provides a simplified set of design curves dependent upon channel slope, discharge and bottom width. SEDCAD 4 directly utilizes the OSMRE manual methods within the program algorithms and is endorsed by the United States Department of Interior Office of Surface Mining, Reclamation and Enforcement. The SEDCAD 4 user is prompted to input the channel slope, channel flow, shape, bottom width, side slope ratio and the freeboard. SEDCAD 4 automatically checks the Froude Number, and if it is greater than 0.8, steep slope channel design algorithms are employed. The user results with a required mean stone size and channel characteristics unique to that flow condition (Schwab 2010).

3.0 Methods

Methods used to design a geomorphic reclamation plan for the Royal Scot Refuse Facility are described in the following sections.

3.1 Existing Field Site

The field site for this work is a coal refuse pile in Greenbrier County, WV, USA (38° 00' 41" N, 80° 36' 08" W) (Figure 1). The field site encompasses 47.0 acre within a larger operation and is situated between 3500 and 3766 ft above mean sea level. An active permit exists along the north and west boundaries, and forestland exists along the south and east boundaries. The site exists in the Central Appalachia ecoregion (EPA 2013). Climate data The Beckley Raleigh County Airport was analyzed over the previous 15 years reporting precipitation averaging 42.1 in and ranging between 33.9 in to 51.4 in. Temperature for the same location averages 52.2°F and extremes range between -9 and 96°F (NOAA 2016).

Legend

- ◆ WV Cities
- WV HWY
- US HWY
- Interstate
- WV Counties

Figure 1. Project location: Greenbrier County, West Virginia, USA

The Royal Scot Minerals Inc. mining permit was revoked on April 21, 1999, and the refuse facility has remained inactive through the present day (N. Parks, personal communication, 2015). Some surface slopes of the landmass are in excess of 26.56° above horizontal, and little to no vegetative cover is present (Figure 2). The combination of steep slopes and barren topography led to advanced gully type erosion features throughout the site. Royal Scot coarse coal refuse material is characterized with the United Soil Classification Scale (USCS) as a 'poorly graded sand with gravel', USCS Symbol SP (Lindeburg 2014). The material exhibits a hydraulic conductivity of 10^{-6} cm/s (0.0864 cm/d) (Stevens 2016). Groundwater seeps are evident downslope of the refuse pile and exhibit a chemical composition consistent with infiltration through coarse coal refuse.

Figure 2. Photo taken from the south embankment looking north across the Interception Pond to the Royal Scot refuse pile

Groundwater and stormwater runoff are collected and directed to Pond #1 (Figure 3). The water is routed through a series of three water treatment ponds prior to discharging from the site. Storm events frequently result in an overtopping condition at Treatment Pond 1, 2, and 3 (N. Parks, personal communication, 2015). The treatment ponds are routinely dredged of sediment to maintain effective treatment capability. The waste material is disposed of in the Sludge Pit (Figure 3). As-built survey information from the former operator is not available prior to use, and future investigation of this area is required to determine the sludge material properties and the extent of the material.

Stormwater was historically routed through the Interception Pond but is not currently used due to acidic seepage (Figure 3). An underdrain exists but is obstructed from flow. The existing pond structure is 1.67 acres in top area. Approximately 35,000 yd³ of material were removed from the pond in 2012, lowering the invert elevation from 3919 ft to 3598 ft. Excavation procedures encountered competent rock strata at 3598 ft, and the joint system within that rock mass is believed to be the source of the seepage.

Figure 3. Aerial image of Royal Scot refuse disposal (38°,00',41" N; 80°,36',08" W) facility showing the main pile, Sludge Pit, Interception Pond, Pond #1, Treatment Pond 1, Treatment Pond 2, Treatment Pond 3 and the NPDES Discharge Point (Google Earth, 2016)

Existing topography (2 ft contour interval) were provided by WVDEP as shown in Figure 4. Figure 4 is an excerpt from Appendix: A Design Package, Sheet P-2. The labeled lines represent the location of the cross sections taken throughout the site. This is further described in Section 4.0 Results.

Figure 4. Existing topography at the Royal Scot Refuse Facility shown with 10 ft index contours. (Excerpt from Appendix: A; Sheet P-2)

3.2 Design area

The Limit of Disturbance (LOD) was iteratively defined with the careful consideration of existing permits, road locations, existing landmasses, and future drainage requirements. The existing Interception Pond was designated as the general location of a future Sediment Pond that would collect the runoff from the 100 yr, 24 hr design event. Existing topography led to a governing design elevation datum of 3,630 ft. The design of all future structures were placed

above the datum, allowing it to shed water freely towards the Sediment Pond. A network of open channels was required around the perimeter to route the stormwater quickly towards the Sediment Pond. Preliminary hydrologic and hydraulic calculations established that a 30 ft wide corridor would be sufficient to install a perimeter channel. The 30 ft allotment included the interior channel side slopes, bottom channel width and a minimum 2 ft top of embankment width which will be referred to the Catchment Corridor. The Catchment Corridor to the west was designed at a consistent 2% bed slope for 1,700 linear feet, beginning at 3,630 ft. The Catchment Corridor to the east was much steeper exhibiting bed slopes between 6% and 10%.

3.3 Design of topography

Geomorphic landforming principles were applied at the Royal Scot Refuse Facility by implementing several steps to achieve a final design including: 1) defining the area of disturbance (Section 3.2); 2) establishing the maximum extent of each contour that will maintain the desired drainage (Section 3.3.1); 3) creating geomorphic watersheds (Section 3.3.2); and 4) balancing the earthwork.

3.3.1 Maximum bench slope design

A Maximum Capacity Landmass was designed to spatially constrain the geomorphic design efforts (Figure 5). Interior to the Catchment Corridor, eight bench slope profiles were established and serve as the outer bound for future geomorphic landforms. The profiles were limited in slope steepness by the minimum design guidelines from the WV DEP. “For the purpose of determining the backfill volume for the backfill slopes shall consist of a 2 horizontal to a 1 vertical (2H: 1V) slope between the terraces plus a terrace of twenty feet (20 ft) width constructed at each one hundred feet (100 ft) vertical rise above the toe of the backfill.” (WVDEP 1993).

The Maximum Capacity Landmass was created and served as the limits for future design work. Figure 5 depicts eight conventional slope profiles and collectively will be referred to as the Maximum Capacity Landmass. The Maximum Capacity Landmass eliminated the need to iteratively alter the Catchment Corridor. The Catchment Corridor rises 34 ft along the western 1,700 ft section. The magnitude of drop along the Catchment Corridor necessitated multiple interior conventional slope profiles. A constant level bench throughout the landmass was avoided

as it would under-represent the spatial extent of the Maximum Capacity Landmass. Three primary bench profiles were established to the west of the Sediment Pond. The southern face began at the 3,630 ft bench elevation of the Sediment Pond. The eastern Catchment Corridor was routed around the Sludge Pit and contours were established as needed. Radiating any contours away from the peak will alter the drainage capability of the site.

Figure 5. Maximum Capacity Landmass used to spatially define the geomorphic landform design iterations and bench locations (10-ft index contours shown within the landmass)

3.3.2 Geomorphic watersheds

Geomorphic landforming principles were applied by first performing a cut and fill analysis between the Maximum Capacity Landmass and the Existing Landmass. The difference

in elevation between Existing Landmass and the Maximum Capacity Landmass was mapped with Carlson Civil 2013 in AutoCAD producing the cut and fill surface mapped on 5 ft intervals. Major areas of cut and fill zones directly guided the placement of the geomorphic watersheds.

Geomorphic watersheds were designed using Carlson Natural Regrade with GeoFluv™. Each watershed included one central channel and two ridgelines located at the exterior of the boundary. All geomorphic watersheds were designed independently within Natural Regrade™. Design inputs are noted in Table 1.

The watershed was iteratively determined with the addition of point elevation markers and alteration of the Regrade boundary. Outlet elevations for each watershed were defined by the elevation of the Catchment Corridor passing the channel outlet. Watersheds were connected with conventional bench profiles utilizing varying slope angles (14.0° - 26.6°). The conventional faces were radially bound by the Maximum Capacity Landmass surface and guided internally by the Existing Landmass. Varying the slope angle within this zone helped minimize the earth moving requirements.

Table 1. Natural Regrade™ input parameters

Natural Regrade™ Global Settings	Value
Maximum distance between connecting channels (ft.)	10.00
Maximum distance from ridgeline to channels head (ft.)	80.00
Slope at the mouth of the main valley bottom channel (%)	-2.00
"A" channel reach (ft.)	50.00
Precipitation: 2 yr, 1 hr (in.)	1.24
Precipitation: 50 yr, 6 hr (in.)	3.67
Target drainage density (ft./ac)	120.00
Target drainage density variance (%)	20.00
Angle from sub-ridge to channel's perpendicular, upstream (deg.)	10.00
North or East straight line slopes (%)	20.00
Maximum straight line slopes (%)	33.00
Maximum cut : fill variance (%)	125.00
Minimum cut : fill variance (%)	80.00
Cut swell factor	1.00
Fill shrink factor	1.00

3.3.3 Sludge Pit

The disposal area of dredged material from the water treatment ponds is contained within a coarse coal refuse embankment formally referred to as the Sludge Pit (Figure 3). This structure was completely capped within the Design Surface and included zero excavation. All channelized flow paths were routed around the pit. The existing Sludge Pit water level is mapped at 3798 ft and the embankment height is shown at 3702 ft. A minimum cap thickness of 10 ft was placed over the area and blended to existing topography. The maximum burden load for the Sludge Pit cap was not established and did not impact the reclamation design.

3.3.4 Road network

The roads within the Royal Scot site exist to provide access to the adjacent mining permit, the water treatment ponds, and the National Pollutant Discharge Elimination System (NPDES) discharge point. The roads were altered in elevation or alignment as needed to avoid interference with drainage. Discussions with the project team determined the design configuration of the road surface. Access to all areas was maintained in the proposed design.

Minimum construction specifications for mining sites are included West Virginia legislations (WVDEP 1993). The site access road was kept to a maximum 10% grade, with a minimum of 150 ft horizontal radius of curvature which is consistent with the existing road network. A point of departure was defined from the existing structure and a new road centerline was established conforming to the design standards. All roads were sloped to eliminate the use of culverts and maintain the existing surface flow paths.

3.4 Hydraulic structures

The structures used to control stormwater flow at the Royal Scot Refuse Site were designed using the 100 yr, 24 hr peak design discharge. The Type II storm at the Royal Scot location generates 5.44 in of precipitation (NOAA 2015). The area was analyzed within the WinTR-55 program (NRCS 2009). A Curve Number of 89 was used on all sub-areas indicative of hard packed coarse coal refuse (Hopkinson et al. 2015). Other input values were calculated from the design contours.

Channel sizing was completed by classifying each reach into subsections of similar bed slopes. The conservative design of each channel used the maximum slope within the subsection

and the highest peak flow from subsection outlet. Channels were designed using methods detailed by Simons (1982) within the SEDCAD 4 program (Schwab 2010). The design for Riprap channels was completed in SEDCAD 4 using the Simons/OSMRE design option. SEDCAD 4 output a channel lining gradation envelope. The mean riprap particle size was used to calculate the necessary filter between the channel base material and the flow liner per Simons (1982). (Simons 1982, Schwab 2010).

3.4.1 Geomorphic channels

The geomorphic channels and are considered primary channels (first-order) as described in Section 3.4. The geomorphic channel exhibits continually changing profile throughout the watershed as shown in Figure 6. Figure 6 illustrates the channel invert elevation along the flow path and the plan view of the channel alignment. AutoCAD tools provided the average land slope and flow length for the watershed profiles. The profile was grouped into subsections and the channel was dimensioned using SEDCAD 4 including 0.5 ft freeboard (Section 3.4).

Figure 6. Geomorphic watershed boundary plan view and the continuously changing longitudinal channel profile as shown within Natural Regrade™

3.4.2 Drainage ditches

Drainage channels were included to remove water from the conventionally designed faces. The benches are required to have a back slope and cross slope to shed water in a controlled manner as discussed in Section 2.3 (WVDEP 1993). SEDCAD 4 was used to dimension the channels including 0.5 ft freeboard. The area contributing to each respective drainage ditch includes the bench, and the planar slope above it, and the configuration is shown in Figure 8.

3.4.3 Perimeter channels

Perimeter channels were designed to contain the Royal Scot site drainage and convey it to the Sediment Pond. The calculation of the peak channel flow rate and channel characteristic design is described in Section 3.4. The channel flow was determined to be in a transitional state, near the critical flow depth (i.e., Froude Number ≈ 1.0). Channel freeboard of 1.0 ft is recommended for flows with a Froude numbers less than 4.0 to account for water surface undulations (Simons 1982).

3.4.4 Sediment pond

Stormwater was designed to aggregate in the Sediment Pond. The sediment pond size was verified using the storage-indication method for flood routing (Bedient et al, 2008). The flood wave is captured within the Sediment Pond, and discharged through the outlet structure in a controlled manner. The governing mass balance equation used for the analysis is listed below (Bedient et al. 2008):

$$V_{n+1} = V_n + I_n - O_n - S_n - E_n \quad \text{Eq. 3.4.1}$$

where

V_{n+1} = Storage at time $_n$

V_n = Storage at time $_n$

I_n = Pond Inflow at time $_n$

O_n = Pond Outflow at time $_n$

S_n = Pond seepage at time $_n$

E_n = Evaporation at time $_n$

The inflow and outflow hydrographs are continuously varying with respect to time. Equation 3.4.1 analyzes the water as uniform slugs over a small time increment.

The Sediment Pond area was calculated at a 0.5 ft interval and used to define the storage volume as shown in Table 2.

Table 2. Sediment Pond storage capacity (Abridged, See Appendix: B for complete table)

Stage	Elevation	Area	Incremental Storage	Cumulative Volume
[ft]	[ft]	[ft ²]	[ft ³]	[ft ³]
0.0	3,608.0	1,251.9	0.0	0.0
0.5	3,608.5	2,357.1	286.8	286.8
1.0	3,609.0	3,462.2	378.5	665.3
1.5	3,609.5	4,567.4	470.1	1,135.4
2.0	3,610.0	5,672.5	559.0	1,694.5
2.5	3,610.5	6,744.7	648.0	2,342.5
3.0	3,611.0	7,817.0	737.0	3,079.5
14.0	3,622.0	42,905.3	3,673.0	53,266.8
14.5	3,622.5	44,167.3	3,778.5	57,045.2
15.0	3,623.0	45,429.4	3,884.0	60,929.2
15.5	3,623.5	46,691.4	3,989.5	64,918.7
16.0	3,624.0	47,953.4	4,098.9	69,017.6
16.5	3,624.5	49,261.0	4,208.3	73,225.8
17.0	3,625.0	50,568.7	4,317.7	77,543.5
17.5	3,625.5	51,876.3	4,427.1	81,970.6
18.0	3,626.0	53,183.9	4,542.6	86,513.2
18.5	3,626.5	54,563.8	4,658.1	91,171.3
19.0	3,627.0	55,943.7	4,773.7	95,945.0
19.5	3,627.5	57,323.6	0.0	95,945.0

The pond inflow hydrograph was developed by dividing the site into three main watersheds which were referred to in regions as West, South and East. WinTR-55 was used to develop the outlet hydrograph for each of the watersheds (10.0 Appendix: C; WinTR-55 Data). Water is routed into the Sediment Pond, and the watershed outflow hydrographs were used as the Sediment Pond inflow. The hydrologic boundaries are shown in Figure 7. Flow channel measurements were made in AutoCAD to determine the time of concentration for the 100 yr storm event (10.0 Appendix: C; WinTR-55 Data).

Figure 7. Watershed boundaries and reach locations

The Sediment Pond was designed as a dry pond, with zero pool elevation. The 100 yr, 24 hr design storm was designed to be discharged between 48 and 72 hours. The outlet structure was designed using guidance from available current engineering publications (WVDEP 2016, Lindeburg 2014, Bedient et al. 2008; Sturm 2010).

The Royal Scot Sediment Pond was designed with a series of orifices varying both in size and elevation along the standpipe. The top of the standpipe was designed open allowing for an additional, large discharge volume from the pond. The pipe was assumed to be corrugated galvanized steel, and was modelled as a sharp crested weir. Elevations of all orifices, excluding the orifice at the pond invert, were varied in diameter and elevation during the design phase.

The standpipe orifice and weir discharge were calculated using equations 3.4.2 and 3.4.3, respectively. Total discharge from the 17.0 ft tall standpipe was the combined orifice and weir flow is calculated as shown in equation 3.4.4. The Sediment Pond outlet culvert and standpipe were oversized to provide a controlled discharge flow. The termination of the outlet culvert was not defined by the project team and remains an item for design. The outlet culvert was increased by one nominal pipe size from the riser pipe. An emergency overflow spillway was also provided per West Virginia guidelines (WVDEP 2016).

$$Q_{orifice} = C_d A_o \sqrt{2gh} \quad Eq.3.4.2$$

where

$Q_{orifice}$ = orifice outflow (cfs)

C_d = orifice entrance loss coefficient, 0.61 (Sturm 2010, Gray 2000, Lindeburg 2014)

A_o = orifice area (ft²)

g = gravitational acceleration (32.2 ft/s²)

h = depth above the orifice centerline (ft)

$$Q_{weir} = \frac{2}{3} C_e b \sqrt{2g} (H)^{\frac{3}{2}} \quad Eq. 3.4.3$$

where

Q_{weir} = weir outflow (cfs)

C_e = weir entrance loss coefficient, 0.58 (Sturm 2010, Gray 2000, Lindeburg 2014)

b = weir width (standpipe circumference) (ft)

g = gravitational acceleration (32.2 ft/s²)

H = head above the weir crest (ft)

$$Q_{total} = \sum Q_{orifice} + Q_{weir} \quad Eq. 3.4.4$$

where

Q_{total} = quantity of outflow from the Sediment Pond (cfs)

3.5 Cap design

The cap and cover system was designed by Stevens (2016) to provide geotechnical stability, minimize infiltration and sustain vegetation. Geotechnical stability and infiltration were assessed using the SoilVision™ finite element software. Royal Scot does not contain suitable growth media, and Stevens (2016) analyzed a short paper fiber sludge as a soil amendment. MGro™ was donated for research by a WestRock paper mill, and is the expected soil amendment to be used at the project site (Stevens, 2016).

Two cap structures were required for the vegetated areas (one for steep continuous slopes and one for the remainder of the site), and a cap was required for the channel structure and road structure (Stevens, 2016). Details of the cap structure and criteria used to delineate Type 1 and Type 2 cap boundaries can be found in Stevens (2016). The final cap structure and layout were presented in detail within Appendix: A.

4.0 Results

The reclamation design is presented as a complete design package available in 7.0 Appendix: A; Royal Scot Reclamation Design Package. The drawing set includes 30: ARCH D (24 in x 36 in) sized sheets. The drawings will be referred to frequently throughout this chapter by the Section and Number of the Sheet. Sections of drawing types include Title (T), Plan (P), Elevation I and Specification (S). The Existing Surface and Design Surface will be referred to formally within this chapter. The Table of Contents from 7.0 Appendix: A; Royal Scot Reclamation Design Package, Sheet T-1, is listed below in Table 3. Excerpts from the Design Package will be included throughout this chapter to guide the reader through the Design Package. Complete labeling and annotation is included within the Design Package. Excerpts should not be assumed to scale unless otherwise noted.

Table 3. Table of Contents from Design Package in Appendix: A

Sheet	Section	Number
Title Sheet	T -	1
Design Plan	P -	1
Existing Plan	P -	2
Site Overview/Borrow Area	P -	3
Cut Fill Plan	P -	4
Cap Layout Plan	P -	5
Geomorphic Channel Layout	P -	6
Cross Section A-A' and B-B'	E -	1
Cross Section C-C' and D-D'	E -	2
Cross Section E-E' and F-F'	E -	3
Cross Section G-G' and H-H'	E -	4
Cross Section I-I' and J-J'	E -	5
Cross Section K-K' and L-L'	E -	6
Cross Section 1-1' and 2-2'	E -	7
Cross Section 3-3' and 4-4'	E -	8
Cross Section 5-5' and 6-6'	E -	9
Cross Section 7-7' and 8-8'	E -	10
Cross Section 9-9' and 10-10'	E -	11
Cross Section 11-11' and 12-12'	E -	12
Cross Section P-P' (East Access Road)	E -	13
Cross Section Q-Q' (Highwall Access Road)	E -	14
Cross Section R-R', S-S', T-T' (Ditch F, G, H)	E -	15
Cross Section U-U' (Perimeter Channel West)	E -	16
Cross Section V-V' (Perimeter Channel East)	E -	17
Cross Section W-W' (Channel: A)	E -	18
Cross Section X-X' (Channel: B)	E -	19
Cross Section Y-Y' (Channel: C)	E -	20
Cross Section Z-Z' (Channel: D)	E -	21
Channel Schedule	S -	1
Sediment Pond	S -	2

4.1 Overall design characteristics

The Royal Scot Refuse Facility design area encompasses 47.0 acres including four geomorphic watersheds and multiple conventional slope faces connecting geomorphic landforms. Details of the landmass are shown on the site cross section elevation profiles spaced on a 150 ft grid throughout the site. The primary grid was oriented North-South (Sections A-A'

through L-L') and West-East (Sections 1-1' through 12-12'). The grid was oriented in the West Virginia South State Plane, North American Datum 1983 and is shown on the Proposed Site Plan, Existing Site Plan, Cut Fill Plan and Cap Arrangement Plan (P-1, P-2, P-4 and P-5 respectively). Additional sections were constructed along channel centerlines and road alignments as needed to unambiguously define the reclamation design.

The general arrangement of the geomorphic reclamation design is shown on the Proposed Site Plan, Sheet P-1 in Appendix: A, and an excerpt is shown in Figure 8. The geomorphic landforms each contain a channel routing stormwater towards a watershed outlet. The Watersheds listed in Table 4 correspond to the Channel labeled in Figure 8 (Watershed A contains Channel A).

The Design Surface spans elevations between 3,610 ft to 3,780 ft, and water is radially shed by four geomorphic channels (Channels A, B, C and D) and three conventional ditches (Ditch F, G and H). Radial drainage promotes a minimum hydraulic time of concentration and will minimize potential infiltration. The ditch and geomorphic channel flows were routed to either Perimeter Channel East, Perimeter Channel West or directly to the Sediment Pond. Three primary conventional bench slope designs were incorporated in the design and are associated with the location of Ditch F, G and H. Several additional sections of planar slope were used as necessary. Slope face inclination is shown in relative zones in Figure 9.

Table 4. Geomorphic watershed landform characteristics at Royal Scot

Watershed	Peak Flow	Area	Channel Length	Drainage Density	Elevation Relief	Shear Stress (Flood Prone)	Maximum Velocity	Sinuosity
[Name]	[cfs]	[acre]	[ft]	[ft/acre]	[ft]	[lb/ft ²]	[ft/s]	[ft/ft]
A	11.47	3.48	382.29	109.72	73.36	0.34 to 3.69	4.50	1.17
B	10.76	3.27	466.11	142.62	30.15	0.05 to 0.92	4.50	1.30
C	13.02	3.95	494.30	125.00	122.58	0.45 to 5.18	4.50	1.17
D	9.10	2.76	347.05	125.56	100.84	0.56 to 4.88	4.50	1.15

Figure 8. Royal Scot reclamation general arrangement (2 ft contour interval) (Excerpt from Appendix: A; Sheet P-1)

Figure 9. Royal Scot zones of similar percent slope within the Limit of Disturbance (dark blue represents 0% – 15%; cyan represents 15%-25%; green represents 25%-35%; yellow represents 35%-45%; orange represents 45%-50%; red represents 50% and above)

4.1.1 Material Movement

Table 5 summarizes the relevant earthmoving quantities necessary to achieve the Design Surface. The proposed reclamation plan was designed with 21.7 acre of cut and 23.4 acre of fill. The quantity of cut is 267,731 yd³ and the required fill is 295,840 yd³. The importance associated with minimizing infiltration requires that an additional amount of material handling is necessary

to construct the Hydraulic Barrier in cut zones. Over-excavation associated with the Hydraulic Barrier is summarized in Table 6. An undetermined amount of additional material handling will also will be required to mix and place the growth media. The Design Package does not include any mixing or placement calculations as it will be up to the construction team to determine the most cost effective method for the scales at the Royal Scot site. The import material represents the required soil amendment (MGro®). The addition of the import material balanced the site material movement.

Table 5. Earthwork quantity summary (Existing to Design Surfaces)

Description	Unit	Cut	Fill	Total
Area	[acre]	21.67	23.40	47.01
Volume	[yd ³]	267,730.8	295,839.8	(28,109.0)
Avg. Depth	[ft]	7.66	7.84	-
Cut : Fill	[_]	-	-	0.90
Import	[yd ³]	-	-	(28,109.0)

Note: 1.95 acre within the Limit of Disturbance does not require any grade adjustment.

Table 6. Estimated additional excavation required to develop the Hydraulic Barrier

Additional Cut Area	Additional Cut Depth	Estimated Over Excavation	Total Cut
[ft ²]	[ft]	[yd ³]	[yd ³]
943,753	0.00	0.00	267,731
943,753	2.00	69,908	337,638
943,753	2.25	78,646	346,377
943,753	2.50	87,385	355,115
943,753	2.75	96,123	363,854
943,753	3.00	104,861	372,592

The spatial distribution of cut and fill areas are shown in Figure 10 (Excerpt from Appendix: A; Sheet P-4). The areas of cut are shown in red hatch and zones of fill are shown in blue hatch. The sludge pit was covered by a minimum of 10 ft of material. No water was routed over the sludge pit. The maximum cut is 30 ft and is located along Channel C (Section Y-Y'). A 20 ft cut was taken along a significant portion of the access road leading to the adjacent mining permit (Section Q-Q'). The 20 ft cut established open channel flow to the Sediment Pond within

the roadside Perimeter Channel West (Section U-U') and is consistent with the desire to minimize maintenance within geomorphic landforming. The maximum fill is 32 ft and is located above the Sludge Pit. The other major fill area is located south of the Sludge Pit and east of the Sediment Pond.

Figure 10. Zones of cut and fill at the Royal Scot Refuse Disposal Facility (Red areas indicate cut; Blue areas indicate fill) (Excerpt from Appendix: A; Sheet P-4)

4.1.2 Cap and Cover

The design of the cap and cover system throughout the site is shown on Sheet P-5 within Appendix: A. All earth moving quantities discussed have been from Existing Surface to Design Surface. The proper development of the Hydraulic Barrier as shown in Figure 11 and Figure 12 will require an additional excavation quantity. The 2.0 ft Barrier Zone (Figure 11) is primarily located in areas of cut, and increases the required excavation as shown in Table 6. Areas of fill were not included within the over excavation calculation because the fill material handling was already taken into consideration (Appendix: A; Sheet P-4 and Sheet P-5). The over excavation depth specified for construction purposes will be at the discretion of the site owner, and potential depth values and the associated over excavation quantities are displayed in Table 6.

Figure 11. Vegetated Type 1 cap structure. Used on shallow long slopes; short and steep slopes; and the Highwall Access Road (Excerpt from Appendix: A; Sheet E-1)

Figure 12. Vegetated Type 2 cap structure. Used on continuous, steep slopes (Excerpt from Appendix: A; Sheet E-1)

4.1.3 Vegetation and slope characteristics

The application method used to distribute the soil amendment has not been determined at the time of this publication. The mixing of the growth layer may require additional material handling that was not included within the results presented in either Table 5 or Table 6. The distribution of percent slope is shown in Figure 9. Areas exhibiting a slope greater than 25 percent slope (4:1) are not eligible for chemical mulch alone in accordance with West Virginia Code Erosion and Sedimentation Control Manual, Section 3.12 (WVDEP 2016). The majority of the site contains steep slopes and a fiber bonded mulch matrix is recommended to ensure vegetation success. Recommended areas for fiber bonded mulch are shown in Figure 9 by areas of green, yellow, orange and red.

4.2 Drainage

The hydraulic network is labeled on the Proposed Site Plan, Sheet P-1. The site consists of channels leading to a common Sediment Pond. The first order channels include the four geomorphic channels, Channels A, B, C and D; as well as Ditches F, G and H. The final channel designs are summarized in Table 7, Table 8, and Table 9.

The radial design to the drainage network minimized the time of concentration from any point within the area of disturbance. Capturing the stormwater quickly and concentrating the flow in an established channel was considered beneficial to minimize infiltration. The design is a tradeoff between rapid runoff and sediment transport. Rapid runoff prevents infiltration, and minimizes the problematic seeps at the site and the treatment cost associated with them. Sediment transport was mitigated by armoring the channels with large stone to resist the shear force generated during the 100 yr, 24 hr design storm.

The Limit of Disturbance includes 47.01 acres, and 40.94 acres were successfully captured by hydraulic structures discharging into the Sediment Pond. The remaining area is routed through existing surface control structures, ultimately reporting to Pond #1. The project design included 6,588 linear feet of channel which were designed by methods outlined in Section 3.4. The drainage design requires 6,832 yd³ of material to construct the channel liner. One subsection, Channel B-1, was able to satisfy characteristics warranting the use of a vegetative channel liner. Complete channel details can be found in Appendix: A, Sheet S-1.

4.2.1 Drainage ditches

The drainage ditches are used to remove water from the conventionally designed slopes. The upper slope face is limited in sheet flow to 100 ft at a 26.56° (2:1) slope. This is the maximum slope face allowed per WVDEP (1993). Each bench is required to be sloped towards the upper bench, and maintain a positive cross slope leading towards an outlet (WVDEP 1993). This prevents unnecessary sheet flows and pore pressures within the overall structure. The drainage ditches were constructed on the maximum slope of 26.56° (2:1), as they flow straight down the face of the slope. These channels require a much larger size of aggregate as shown in Table 7. A minimum 0.5 ft freeboard was included into the channel depth.

Table 7. Conventional drainage ditch summary at Royal Scot

Flow Reach	Liner	Length	Peak Flow	Bottom Width	Channel Depth	Bed Slope	Bedding D ₅₀	Filter D ₅₀
[Name]	[Material]	[ft]	[cfs]	[ft]	[ft]	[ft/ft]	[in]	[in]
Ditch F	Rip Rap	155	16.9	4.0	1.1	0.50	18.0	3.0
Ditch G	Rip Rap	160	5.9	2.0	1.1	0.50	18.0	3.0
Ditch H	Rip Rap	130	7.8	3.5	1.1	0.50	15.0	3.0

4.2.2 Perimeter channels

The Royal Scot hydraulic network contains two second order channels and are named Perimeter Channel West and Perimeter Channel East. The Perimeter Channel West was designed with a steady 2.0% bed slope for 1,750 ft of the channel length. The Perimeter Channel West bed slope was increased to 15.0% as the existing topography dictated. Perimeter Channel East has two slope sections, 10% and 6.0% as shown in Table 8. The channels were designed with a consistent side slope ratio of 2:1, and the bottom width was varied as shown in Table 8. The Froude number was estimated at various points within the channel and calculations fell within the transitional range (0.8-4.0), which warranted 1.0 ft of freeboard per Simons (1982). The design goal of minimizing maintenance was honored with the use of open channels throughout the site.

Table 8. Perimeter channel summary at Royal Scot

Flow Reach	Liner	Length	Peak Flow	Bottom Width	Channel Depth	Bed Slope	Bedding D ₅₀	Filter D ₅₀
[Name]*	[Material]	[ft]	[cfs]	[ft]	[ft]	[ft/ft]	[in]	[in]
P. Ch. West - 1	Rip Rap	756	108.8	10.5	1.8	0.02	9.0	3.0
P. Ch. West - 2	Rip Rap	1,514	68.3	7.0	1.8	0.02 - 0.15	9.0	3.0
P. Ch. East - 1	Rip Rap	350	69.6	8.0	1.7	0.10	12.0	3.0
P. Ch. East - 2	Rip Rap	1,142	57.7	8.0	1.7	0.06	9.0	3.0

*Name-1 denotes the most downstream sub-reach of the channel, (i.e. Channel Mouth).

4.2.3 Geomorphic channels

The geomorphic channels have a continuously changing bed slope, as compared to the constant bed slope in Ditch F, G and H and the Perimeter Channels. The channel alignment meanders as indicated by the varying sinuosity values in

Table 4. The primary channel lining material was rip rap except for Channel B-1, which is a vegetated liner. Freeboard was included within the minimum channel depth as 0.5 ft. The geomorphic channels summary is presented in Table 9.

Table 9. Geomorphic channel summary at Royal Scot

Flow Reach	Liner	Length	Peak Flow	Bottom Width	Channel Depth	Bed Slope	Bedding D ₅₀	Filter D ₅₀
[Name]*	[Material]	[ft]	[cfs]	[ft]	[ft]	[ft/ft]	[in]	[in]
Channel A – 1	Rip Rap	399	23.4	6.0	0.8	0.12 - 0.20	9.0	3.0
Channel A – 2	Rip Rap	114	5.0	5.0	0.6	0.19	9.0	3.0
Channel B – 1	Vegetated	475	19.3	4.5	2.3	0.02 - 0.03	GRASS	
Channel B – 2	Rip Rap	190	11.1	4.0	0.9	0.04 - 0.09	9.0	3.0
Channel B – 3	Rip Rap	67	5.9	3.5	0.7	0.12	9.0	3.0
Channel C – 1	Rip Rap	519	25.9	6.0	0.8	0.12 - 0.24	12.0	3.0
Channel C – 2	Rip Rap	103	3.5	4.0	0.6	0.20	12.0	3.0
Channel D – 1	Rip Rap	313	18.2	5.5	0.8	0.12 - 0.27	12.0	3.0
Channel D – 2	Rip Rap	201	7.0	4.5	0.6	0.26	12.0	3.0

*Name-1 denotes the most downstream sub-reach of the channel, (i.e. Channel Mouth).

4.3 Sediment pond

The Sediment Pond is designed to handle the design storm with the series of orifices proposed in Table 10. The flood routing procedure resulted in a complete drawdown in 68.0 hr as shown in Figure 13 and Figure 14. The maximum stage in the Sediment Pond was calculated at

16.94 ft; assuming a dry initial pond condition. The Sediment Pond is capable of discharging more flow in a controlled manner than needed in the event that the 100 yr, 24 hr storm when the pond had an initial pool elevation. 8.0 Appendix: B; Sediment Pond Data contains the figures and tables representing the calculations performed during the storage indication flood routing procedure. The procedure used to determine the pond capacity is described in Chapter 3.0.

The Sediment Pond inflow hydrograph was created by aggregating the East, West and South Watershed outflow hydrographs. 40.9 acres of the design area report to the Sediment Pond. The peak flow rate into the pond is 207.9 cfs and the peak is observed 12.0 hours after the beginning of the storm. The Sediment Pond is completely drained within 68.0 hours and discharges at a maximum flow rate of 4.4 cfs. The combination of inflow and outflow are shown graphically in Figure 13 and Figure 14. Figure 14 displays the inflow and outflow with an enlarged vertical scale to better depict the variation of outlet flow.

The outlet structure includes 16 orifices at nine different elevations along the height of the Sediment Pond riser pipe. Two inch diameter orifices are present at four stages, and one inch diameter orifices are present at 5 discharge stages. The riser is detailed in Table 10. The top of the riser was hydraulically modeled as a sharp crested weir. It is able to handle large flows, but was not needed to route the design storm from a dry condition. The Sediment Pond buffers a peak flow of 207.91 cfs by storing 438,801 ft³ of water.

Table 10. Outlet structure modeled in the Sediment Pond

Stage	Number of Flow Openings	Diameter of Each Orifice	Length of Weir Flow
[ft]	[Qty]	[in]	[in]
0.0	6	2.0	-
1.0	-	-	-
2.0	2	2.0	-
3.0	-	-	-
4.0	2	1.0	-
5.0	-	-	-
6.0	1	1.0	-
7.0	-	-	-
8.0	1	1.0	-
9.0	-	-	-
10.0	1	1.0	-
11.0	-	-	-
12.0	1	1.0	-
13.0	1	2.0	-
14.0	1	2.0	-
15.0	-	-	-
16.0	-	-	-
17.0	1	-	42.0
18.0	-	-	-
19.0	-	-	-
19.5	EMERGENCY OVERFLOW INVERT

Figure 13. Flood routing procedure graphical result

Figure 14. Flood routing procedure graphical result, detail view

5.0 Conclusions

Geomorphic landforming principles were demonstrated in West Virginia on a coarse coal refuse pile. The completed reclamation design included within Appendix: A has been technically verified with currently accepted engineering methods. The geomorphic reclamation plan for the Royal Scot Refuse Disposal Facility located near Rupert, WV has accomplished the design objectives as described below.

1. Apply geomorphic landforming principles: Four geomorphic areas were established with continuously changing slope profiles and self-healing channel liners. The watersheds drain the rainfall in a centrally located outlet.
2. Reduce stormwater infiltration: Engineered cap systems were applied throughout the entire 47 acre site and each cap includes a Barrier Zone designed to minimize infiltration. Radially draining the site quickly into armored channels minimizes the contact time with the refuse. The Sediment Pond seepage was mitigated by designing an engineered fill above the fractured bedrock with a Barrier Zone. The Sediment Pond was designed as a dry pond and completely dewatered in 68 hours.
3. Segregate stormwater and groundwater flows: The radially draining hydraulic network captures 87% of rainfall within the Limit of Disturbance and centralizes all flow at the Sediment Pond.
4. Establish sustainable vegetative cover reducing mass wasting: Type 1 and Type 2 cap structures include a Growth Zone, combined they cover 96.2% of the studied area. The MGro™ soil amendment is included to promote vegetation growth. The hydraulic channels have been designed with flexible channel lining, promoting “self-healing liners” instead of lead to further erosion.
5. Minimize earthmoving quantities: The design surface alone is achieved by excavating 267,731 yd³ of material and placing 295,840 yd³ of material. The quantity difference (28,109 yd³) is explained with the inclusion of the MGro™ soil amendment.

6. Minimize import material: Onsite material is used throughout the site. Sandstone is available for the channel liner and channel filter material. The coal refuse was used in an engineered manner to create 100% of the Barrier Zone and 60% of the Growth Zone.

The Royal Scot Reclamation Plan aggregates currently accepted engineering methods focused on the sustainability of the hydrologic balance and consequent mass wasting. Successful field application of the Royal Scot Reclamation Design Package will provide an opportunity for governing agencies to assess the future of geomorphic landforming in Central Appalachia. Any economic benefit realized will be a point of discussion regarding future geomorphic applications.

Geomorphic landforming principles has potential to be applied in various sectors such as mining, municipal landfills, dams, large scale commercial development and in transportation projects such as highways. The aesthetics of a project are easily deprioritized when balancing the project budget and maximizing the amount of features including during construction. The lasting benefit of well-planned landforming is that man-made structures tend to disappear into the surroundings (Schor and Gray 2007). Many similar abandoned sites exist throughout the region, and the results from Royal Scot may easily influence future reclamation activities and other landforming activities.

5.1 Future work

Recommendations for future work include routine measurements of the hydraulic network and documentation of erosion evident at the site. Quantification of the hydraulic system and the reduction of seep flow rates would measure the success of the cap and cover system and the hydraulic network designed for the Royal Scot Site. Continued site inspection and records documenting runoff volume, erosion rates, water treatment activities and performance of the channels would promote further use of geomorphic landforming techniques in steep regions experiencing high annual precipitation.

Many iterations were required prior to the Design Package. Industry application of geomorphic landform design is possible with further study and possibly a guidance manual. The trial and error procedure endured during the creation of the Royal Scot Reclamation Plan is not conducive to a for-profit entity.

The design encompasses both currently practiced conventional planar bench profiles and the investigated geomorphic landforms. The unique combination of conventional and geomorphic landforms adjacent on the same site presents an ideal case study scenario to compare and contrast the long term performance of the two types of landforming. Ambiguities associated with multiple site locations include variation in things such as site materials, construction methods, and most importantly weather differences. A well-documented side by side comparison will be extremely beneficial in further understanding geomorphic landforming within Central Appalachia.

6.0 References

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7.0 Appendix: A; Royal Scot Reclamation Design Package

Royal Scot Reclamation Design Package consisting of 30 Sheets. (24" x 36" size)

To acquire the referenced drawing package in full size, please contact:

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Phone: [304-293-9932](tel:304-293-9932)

8.0 Appendix: B; Sediment Pond Data

Sediment Pond information used during the flood routing procedure is presented herein.

Table 11. Sediment Pond capacity information

Stage	Elevation	Area	Incremental Storage	Cumulative Volume
[ft]	[ft]	[ft ²]	[ft ³]	[ft ³]
0.0	3,608.0	1,251.9	0.0	0.0
0.5	3,608.5	2,357.1	286.8	286.8
1.0	3,609.0	3,462.2	378.5	665.3
1.5	3,609.5	4,567.4	470.1	1,135.4
2.0	3,610.0	5,672.5	559.0	1,694.5
2.5	3,610.5	6,744.7	648.0	2,342.5
3.0	3,611.0	7,817.0	737.0	3,079.5
3.5	3,611.5	8,889.2	826.0	3,905.5
4.0	3,612.0	9,961.5	985.3	4,890.8
4.5	3,612.5	11,881.4	1,144.7	6,035.5
5.0	3,613.0	13,801.4	1,304.2	7,339.7
5.5	3,613.5	15,721.3	1,463.6	8,803.3
6.0	3,614.0	17,641.3	1,564.5	10,367.8
6.5	3,614.5	18,854.5	1,665.4	12,033.2
7.0	3,615.0	20,067.7	1,766.3	13,799.5
7.5	3,615.5	21,280.9	1,867.3	15,666.8
8.0	3,616.0	22,494.1	2,000.0	17,666.8
8.5	3,616.5	24,089.8	2,132.8	19,799.6
9.0	3,617.0	25,685.4	2,265.6	22,065.2
9.5	3,617.5	27,281.1	2,398.4	24,463.7
10.0	3,618.0	28,876.8	2,587.1	27,050.8
10.5	3,618.5	31,144.2	2,775.9	29,826.6
11.0	3,619.0	33,411.5	2,964.6	32,791.3
11.5	3,619.5	35,678.9	3,153.5	35,944.8
12.0	3,620.0	37,946.3	3,257.0	39,201.7
12.5	3,620.5	39,186.0	3,360.5	42,562.2
13.0	3,621.0	40,425.8	3,464.0	46,026.2
13.5	3,621.5	41,665.6	3,567.6	49,593.7
14.0	3,622.0	42,905.3	3,673.0	53,266.8
14.5	3,622.5	44,167.3	3,778.5	57,045.2
15.0	3,623.0	45,429.4	3,884.0	60,929.2

15.5	3,623.5	46,691.4	3,989.5	64,918.7
16.0	3,624.0	47,953.4	4,098.9	69,017.6
16.5	3,624.5	49,261.0	4,208.3	73,225.8
17.0	3,625.0	50,568.7	4,317.7	77,543.5
17.5	3,625.5	51,876.3	4,427.1	81,970.6
18.0	3,626.0	53,183.9	4,542.6	86,513.2
18.5	3,626.5	54,563.8	4,658.1	91,171.3
19.0	3,627.0	55,943.7	4,773.7	95,945.0
19.5	3,627.5	57,323.6	0.0	95,945.0

Figure 15. Sediment Pond Stage Storage Curve

Figure 16. Sediment Pond Discharge Capacity

Figure 17. Sediment Pond Storage Indication Curve

10.0 Appendix: C; WinTR-55 Data

WinTR-55 Current Data Description

--- Identification Data ---

```

User:      Jlorimer                      Date:      10/30/2016
Project:   Royal Scot                   Units:     English
SubTitle:  East Watershed               Areal Units: Acres
State:     West Virginia
County:    Greenbrier West NOAA
Filename:  C:\Users\user\Desktop\JL GLD\6-28-2016\Hydrology\East Watershed 6-30-2016.w55

```

--- Sub-Area Data ---

Name	Description	Reach	Area (ac)	RCN	Tc
East 1	GLD East	3e	3.33	89	.152
East 2		2e	6.19	89	.22
East 3		0e	4.44	89	.328

Total area: 13.96 (ac)

--- Storm Data ---

Rainfall Depth by Rainfall Return Period

2-Yr (in)	5-Yr (in)	10-Yr (in)	25-Yr (in)	50-Yr (in)	100-Yr (in)	1-Yr (in)
2.76	3.32	3.78	4.4	4.91	5.44	2.32

```

Storm Data Source:      User-provided custom storm data
Rainfall Distribution Type: Type II
Dimensionless Unit Hydrograph: <standard>

```

Figure 18. WinTR-55 Output, East Watershed; Sub-area data and storm data

```

JLorimer
                                Royal Scot
                                East Watershed
                                Greenbrier West NOAA County, West Virginia

                                Storm Data

                                Rainfall Depth by Rainfall Return Period

                                2-Yr      5-Yr      10-Yr     25-Yr     50-Yr     100-Yr     1-Yr
                                (in)      (in)      (in)      (in)      (in)      (in)      (in)
                                -----
                                2.76      3.32      3.78      4.4       4.91      5.44      2.32

Storm Data Source:              User-provided custom storm data
Rainfall Distribution Type:     Type II
Dimensionless Unit Hydrograph:  <standard>

```

Figure 19. WinTR-55 Output, East Watershed; Design storm precipitation

```

JLorimer
                                Royal Scot
                                East Watershed
                                Greenbrier West NOAA County, West Virginia

                                Watershed Peak Table

                                Sub-Area      Peak Flow by Rainfall Return Period
                                or Reach      100-Yr
                                Identifier      (cfs)
                                -----
SUBAREAS
East 1      18.97
East 2      32.25
East 3      20.00

REACHES
0e          69.78
  Down      69.78
1e          50.64
  Down      50.64
2e          50.64
  Down      50.64
3e          18.97
  Down      18.96

OUTLET      69.78

```

Figure 20. WinTR-55 Output, East Watershed; Peak design flows

JLorimer

Royal Scot
East Watershed
Greenbrier West NOAA County, West Virginia

Hydrograph Peak/Peak Time Table

Sub-Area or Reach Identifier	Peak Flow and Peak Time (hr) by Rainfall Return Period 100-Yr (cfs) (hr)
------------------------------------	---

SUBAREAS

East 1	18.97 11.97
--------	----------------

East 2	32.25 12.01
--------	----------------

East 3	20.00 12.08
--------	----------------

REACHES

0e	69.78 12.04
Down	69.78 12.04

1e	50.64 12.00
Down	50.64 12.02

2e	50.64 12.00
Down	50.64 12.00

3e	18.97 11.97
Down	18.96 11.98

OUTLET	69.78
--------	-------

Figure 21. WinTR-55 Output, East Watershed; Peak flow and time of peak flow

JLorimer

Royal Scot
East Watershed
Greenbrier West NOAA County, West Virginia

Sub-Area Summary Table

Sub-Area Identifier	Drainage Area (ac)	Time of Concentration (hr)	Curve Number	Receiving Reach	Sub-Area Description
East 1	3.33	0.152	89	3e	GLD East
East 2	6.19	0.220	89	2e	
East 3	4.44	0.328	89	0e	

Total Area:	13.96 (ac)				

Figure 22. WinTR-55 Output, East Watershed; Sub-area summary data

JLorimer

Royal Scot
East Watershed
Greenbrier West NOAA County, West Virginia

Reach Summary Table

Reach Identifier	Receiving Reach Identifier	Reach Length (ft)	Routing Method
0e	Outlet	1	CHANNEL
1e	0e	646	CHANNEL
2e	1e	341	CHANNEL
3e	2e	419	CHANNEL

Figure 23. WinTR-55 Output, East Watershed; Channel summary data

JLorimer

Royal Scot
East Watershed
Greenbrier West NOAA County, West Virginia

Sub-Area Time of Concentration Details

Sub-Area Identifier/	Flow Length (ft)	Slope (ft/ft)	Mannings's n	End Area (sq ft)	Wetted Perimeter (ft)	Velocity (ft/sec)	Travel Time (hr)

East 1							
SHEET	100	0.0600	0.150				0.113
SHALLOW	159	0.0690	0.050				0.010
CHANNEL	182	0.0604	0.058	7.77	9.01	5.617	0.009
CHANNEL	303	0.0264	0.058	10.08	10.05	4.208	0.020
						Time of Concentration	.152
							=====
East 2							
SHEET	100	0.0400	0.150				0.133
SHALLOW	390	0.1256	0.050				0.019
CHANNEL	312	0.0576	0.250	10.12	11.92	1.275	0.068
						Time of Concentration	.22
							=====
East 3							
SHEET	100	0.0300	0.150				0.150
SHALLOW	132	0.0100	0.050				0.023
CHANNEL	193	0.0500	0.249	10.12	11.92	1.191	0.045
CHANNEL	747	0.1000	0.249	13.78	13.82	1.886	0.110
						Time of Concentration	.328
							=====

Figure 24. WinTR-55 Output, East Watershed; Flow data and time of concentration data

JLorimer

Royal Scot
East Watershed
Greenbrier West NOAA County, West Virginia

Sub-Area Land Use and Curve Number Details

Sub-Area Identifier	Land Use	Hydrologic Soil Group	Sub-Area Area (ac)	Curve Number
East 1	CN directly entered by user	-	3.33	89
	Total Area / Weighted Curve Number		3.33 =====	89 ==
East 2	CN directly entered by user	-	6.19	89
	Total Area / Weighted Curve Number		6.19 =====	89 ==
East 3	Pasture, grassland or range	(poor) D	4.444	89
	Total Area / Weighted Curve Number		4.44 =====	89 ==

Figure 25. WinTR-55 Output, East Watershed; Curve number assignment data

JLorimer

Royal Scot
East Watershed
Greenbrier West NOAA County, West Virginia

Reach Channel Rating Details

Reach Identifier	Reach Length (ft)	Reach Manning's n	Friction Slope (ft/ft)	Bottom Width (ft)	Side Slope
0e	1	0.04	0.1	8	2 :1
1e	646	0.035	0.1	8	2 :1
2e	341	0.035	0.05	8	2 :1
3e	419	0.035	0.055	7	2 :1

Reach Identifier	Stage (ft)	Flow (cfs)	End Area (sq ft)	Top Width (ft)	Friction Slope (ft/ft)
0e	0.0	0.000	0	8	0.1
	0.5	30.565	4.5	10	
	1.0	101.391	10	12	
	2.0	355.600	24	16	
	5.0	2181.836	90	28	
	10.0	10013.006	280	48	
	20.0	51829.610	960	88	
1e	0.0	0.000	0	8	0.1
	0.5	34.931	4.5	10	
	1.0	115.875	10	12	
	2.0	406.400	24	16	
	5.0	2493.526	90	28	
	10.0	11443.435	280	48	
	20.0	59233.840	960	88	
2e	0.0	0.000	0	8	0.05
	0.5	24.700	4.5	10	
	1.0	81.936	10	12	
	2.0	287.369	24	16	
	5.0	1763.189	90	28	
	10.0	8091.731	280	48	
	20.0	41884.650	960	88	
3e	0.0	0.000	0	7	0.055
	0.5	22.799	4	9	
	1.0	76.227	9	11	
	2.0	271.498	22	15	
	5.0	1719.173	85	27	
	10.0	8090.185	270	47	
	20.0	42706.984	940	87	

Figure 26. WinTR-55 Output, East Watershed; Channel rating data

Figure 27. WinTR-55 Output, East Watershed; Watershed outlet hydrograph

WinTR-55 Current Data Description

--- Identification Data ---

```

User:      Jlorimer                      Date:      10/30/2016
Project:   Royal Scot                   Units:     English
SubTitle:  South Watershed              Areal Units: Acres
State:     West Virginia
County:    Greenbrier West NOAA
Filename:  C:\Users\user\Desktop\JL GLD\6-28-2016\Hydrology\South Watershed 6-30-2016.w55
    
```

--- Sub-Area Data ---

Name	Description	Reach	Area(ac)	RCN	Tc
South 1		Outlet	3.86	89	.242
South 2		Outlet	5.58	89	.14
Total area: 9.44 (ac)					

--- Storm Data --

Rainfall Depth by Rainfall Return Period

2-Yr (in)	5-Yr (in)	10-Yr (in)	25-Yr (in)	50-Yr (in)	100-Yr (in)	1-Yr (in)
2.76	3.32	3.78	4.4	4.91	5.44	2.32

```

Storm Data Source:      User-provided custom storm data
Rainfall Distribution Type: Type II
Dimensionless Unit Hydrograph: <standard>
    
```

Figure 28. WinTR-55 Output, South Watershed; Sub-area data and storm data

```

JLorimer                      Royal Scot
                              South Watershed
                              Greenbrier West NOAA County, West Virginia

                              Storm Data

                              Rainfall Depth by Rainfall Return Period

                              2-Yr      5-Yr      10-Yr      25-Yr      50-Yr      100-Yr      1-Yr
                              (in)      (in)      (in)      (in)      (in)      (in)      (in)
                              -----
                              2.76      3.32      3.78      4.4        4.91      5.44      2.32

Storm Data Source:      User-provided custom storm data
Rainfall Distribution Type: Type II
Dimensionless Unit Hydrograph: <standard>
    
```

Figure 29. WinTR-55 Output, South Watershed; Design storm precipitation

JLorimer

Royal Scot
South Watershed
Greenbrier West NOAA County, West Virginia

Sub-Area Summary Table

Sub-Area Identifier	Drainage Area (ac)	Time of Concentration (hr)	Curve Number	Receiving Reach	Sub-Area Description
South 1	3.86	0.242	89	Outlet	
South 2	5.58	0.140	89	Outlet	
Total Area: 9.44 (ac)					

Figure 32. WinTR-55 Output, South Watershed; Sub-area summary data

JLorimer

Royal Scot
South Watershed
Greenbrier West NOAA County, West Virginia

Sub-Area Time of Concentration Details

Sub-Area Identifier/	Flow Length (ft)	Slope (ft/ft)	Mannings's n	End Area (sq ft)	Wetted Perimeter (ft)	Velocity (ft/sec)	Travel Time (hr)
South 1							
SHEET	100	0.0800	0.150				0.101
SHALLOW	108	0.2403	0.050				0.004
CHANNEL	263	0.2741	0.250	1.18	6.39	1.015	0.072
CHANNEL	211	0.1326	0.250	1.98	7.34	0.902	0.065
Time of Concentration							.242
							=====
South 2							
SHEET	100	0.0600	0.150				0.113
SHALLOW	182	0.3681	0.050				0.005
SHALLOW	25	0.0810	0.050				0.002
CHANNEL	118	0.3904	0.250	2.82	6.18	2.185	0.015
CHANNEL	21	0.1000	0.250	2.82	6.18	1.167	0.005
Time of Concentration							.14
							=====

Figure 33. WinTR-55 Output, South Watershed; Flow data and time of concentration data

JLorimer

Royal Scot
South Watershed
Greenbrier West NOAA County, West Virginia

Sub-Area Land Use and Curve Number Details

Sub-Area Identifier	Land Use		Hydrologic Soil Group	Sub-Area Area (ac)	Curve Number
South 1	Pasture, grassland or range	(poor)	D	3.859	89
	Total Area / Weighted Curve Number			3.86 =====	89 ==
South 2	Pasture, grassland or range	(poor)	D	5.578	89
	Total Area / Weighted Curve Number			5.58 =====	89 ==

Figure 34. WinTR-55 Output, South Watershed; Curve number assignment data

Figure 35. WinTR-55 Output, South Watershed; Watershed outlet hydrograph

WinTR-55 Current Data Description

--- Identification Data ---

User: Date: 10/30/2016
 Project: Royal Scot Units: English
 SubTitle: West Watershed Areal Units: Acres
 State: West Virginia
 County: Greenbrier West NOAA
 Filename: C:\Users\user\Desktop\JL GLD\6-28-2016\Hydrology\West Watershed 6-30-2016.w55

--- Sub-Area Data ---

Name	Description	Reach	Area(ac)	RCN	Tc
W1		5w	3.73	89	.221
W2		5w	3.34	89	.191
W3		4w	1.63	89	0.1
W4		3w	1.2	89	0.1
W5		2w	1.25	89	.164
W6		2w	2.58	89	.111
W7		1w	2.31	89	.11
W8		0w	0.94	89	.198
W9		0w	0.4	89	0.1

Total area: 17.38 (ac)

--- Storm Data --

Rainfall Depth by Rainfall Return Period

2-Yr (in)	5-Yr (in)	10-Yr (in)	25-Yr (in)	50-Yr (in)	100-Yr (in)	1-Yr (in)
2.76	3.32	3.78	4.4	4.91	5.44	2.32

Storm Data Source: User-provided custom storm data
 Rainfall Distribution Type: Type II
 Dimensionless Unit Hydrograph: <standard>

Figure 36. WinTR-55 Output, West Watershed; Sub-area data and storm data

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Storm Data

Rainfall Depth by Rainfall Return Period

2-Yr (in)	5-Yr (in)	10-Yr (in)	25-Yr (in)	50-Yr (in)	100-Yr (in)	1-Yr (in)
2.76	3.32	3.78	4.4	4.91	5.44	2.32

Storm Data Source: User-provided custom storm data
Rainfall Distribution Type: Type II
Dimensionless Unit Hydrograph: <standard>

Figure 37. WinTR-55 Output, West Watershed; Design storm precipitation

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Watershed Peak Table

Sub-Area or Reach Identifier	Peak Flow by Rainfall Return Period 100-Yr (cfs)

SUBAREAS	
W1	19.40
W2	18.06
W3	10.13
W4	7.47
W5	6.99
W6	15.73
W7	14.10
W8	5.03
W9	2.50
REACHES	
5w	37.35
Down	37.33
4w	45.60
Down	45.56
3w	51.37
Down	51.35
2w	70.35
Down	70.35
1w	81.47
Down	81.46
0w	88.12
Down	88.12
OUTLET	88.12

Figure 38. WinTR-55 Output, West Watershed; Peak design flows

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Hydrograph Peak/Peak Time Table

Sub-Area or Reach Identifier	Peak Flow and Peak Time (hr) by Rainfall Return Period 100-Yr (cfs) (hr)
------------------------------------	---

SUBAREAS

W1	19.40 12.01
W2	18.06 11.99
W3	10.13 11.93
W4	7.47 11.93
W5	6.99 11.97
W6	15.73 11.93
W7	14.10 11.94
W8	5.03 11.99
W9	2.50 11.93

REACHES

5w	37.35 12.01
Down	37.33 12.02
4w	45.60 12.01
Down	45.56 12.03
3w	51.37 12.02
Down	51.35 12.05
2w	70.35 12.02
Down	70.35 12.04
1w	81.47 12.02
Down	81.46 12.04
0w	88.12 12.03
Down	88.12 12.03

Figure 39. WinTR-55 Output, West Watershed; Peak flow and time of peak flow

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Sub-Area Summary Table

Sub-Area Identifier	Drainage Area (ac)	Time of Concentration (hr)	Curve Number	Receiving Reach	Sub-Area Description
W1	3.73	0.221	89	5w	
W2	3.34	0.191	89	5w	
W3	1.63	0.100	89	4w	
W4	1.20	0.100	89	3w	
W5	1.25	0.164	89	2w	
W6	2.58	0.111	89	2w	
W7	2.31	0.110	89	1w	
W8	.94	0.198	89	0w	
W9	.40	0.100	89	0w	

Total Area: 17.38 (ac)

Figure 40. WinTR-55 Output, West Watershed; Sub-area summary data

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Reach Summary Table

Reach Identifier	Receiving Reach Identifier	Reach Length (ft)	Routing Method
5w	4w	158	CHANNEL
4w	3w	391	CHANNEL
3w	2w	377	CHANNEL
2w	1w	411	CHANNEL
1w	0w	348	CHANNEL
0w	Outlet	1	CHANNEL

Figure 41. WinTR-55 Output, West Watershed; Channel summary data

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Sub-Area Time of Concentration Details

Sub-Area Identifier/	Flow Length (ft)	Slope (ft/ft)	Mannings's n	End Area (sq ft)	Wetted Perimeter (ft)	Velocity (ft/sec)	Travel Time (hr)

W1							
SHEET	100	0.0400	0.150				0.133
SHALLOW	80	0.0875	0.050				0.005
SHALLOW	155	0.3152	0.050				0.005
CHANNEL	381	0.1102	0.250	5.18	9.13	1.357	0.078
						Time of Concentration	.221
							=====
W2							
SHEET	100	0.1200	0.150				0.086
SHALLOW	371	0.1751	0.050				0.015
CHANNEL	119	0.1601	0.250	1.98	7.34	1.002	0.033
CHANNEL	109	0.0460	0.250	1.98	7.34	0.531	0.057
						Time of Concentration	.191
							=====
W3							
SHEET	100	0.3000	0.150				0.060
SHALLOW	85	0.3297	0.050				0.003
SHALLOW	64	0.0317	0.050				0.006
CHANNEL	117	0.3340	0.250	3.12	6.68	2.031	0.016
						Time of Concentration	0.1
							=====
W4							
SHEET	100	0.3800	0.150				0.054
SHALLOW	20	0.0506	0.050				0.002
CHANNEL	381	0.3813	0.250	6.88	10.58	2.785	0.038
						Time of Concentration	0.1
							=====
W5							
SHEET	100	0.3200	0.150				0.058
SHALLOW	63	0.3168	0.050				0.002
CHANNEL	246	0.0200	0.250	9.68	14.08	0.657	0.104
						Time of Concentration	.164
							=====
W6							
SHEET	100	0.3100	0.150				0.059
SHALLOW	123	0.3255	0.050				0.004
CHANNEL	73	0.2721	0.250	1.13	6.14	1.014	0.020
CHANNEL	116	0.2159	0.250	1.68	6.34	1.151	0.028
						Time of Concentration	.111
							=====
W7							
SHEET	100	0.2000	0.150				0.070
SHALLOW	86	0.4639	0.050				0.002
SHALLOW	141	0.0141	0.050				0.020
CHANNEL	134	0.3745	0.250	1.92	4.68	2.068	0.018
						Time of Concentration	.11
							=====

Figure 42. WinTR-55 Output, West Watershed; Flow data and time of concentration data

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Sub-Area Time of Concentration Details (continued)

Sub-Area Identifier/	Flow Length (ft)	Slope (ft/ft)	Mannings's n	End Area (sq ft)	Wetted Perimeter (ft)	Velocity (ft/sec)	Travel Time (hr)
SHEET	100	0.4300	0.150				0.052
CHANNEL	346	0.0200	0.250	9.68	14.08	0.658	0.146
Time of Concentration							.198
							=====
W9							
SHEET	100	0.2700	0.150				0.062
SHALLOW	65	0.2619	0.050				0.002
SHALLOW	47	0.1276	0.050				0.002
Time of Concentration							0.1
							=====

Figure 43. WinTR-55 Output, West Watershed; Flow data and time of concentration data (continued)

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Sub-Area Land Use and Curve Number Details

Sub-Area Identifier	Land Use		Hydrologic Soil Group	Sub-Area Area (ac)	Curve Number
W1	Pasture, grassland or range	(poor)	D	3.726	89
	Total Area / Weighted Curve Number			3.73 =====	89 ==
W2	Pasture, grassland or range	(poor)	D	3.336	89
	Total Area / Weighted Curve Number			3.34 =====	89 ==
W3	Pasture, grassland or range	(poor)	D	1.634	89
	Total Area / Weighted Curve Number			1.63 =====	89 ==
W4	Pasture, grassland or range	(poor)	D	1.203	89
	Total Area / Weighted Curve Number			1.2 =====	89 ==
W5	Pasture, grassland or range	(poor)	D	1.251	89
	Total Area / Weighted Curve Number			1.25 =====	89 ==
W6	Pasture, grassland or range	(poor)	D	2.584	89
	Total Area / Weighted Curve Number			2.58 =====	89 ==
W7	Pasture, grassland or range	(poor)	D	2.311	89
	Total Area / Weighted Curve Number			2.31 =====	89 ==
W8	Pasture, grassland or range	(poor)	D	.938	89
	Total Area / Weighted Curve Number			.94 =====	89 ==
W9	Pasture, grassland or range	(poor)	D	.401	89
	Total Area / Weighted Curve Number			.4 =====	89 ==

Figure 44. WinTR-55 Output, West Watershed; Curve number assignment data

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Reach Channel Rating Details

Reach Identifier	Reach Length (ft)	Reach Manning's n	Friction Slope (ft/ft)	Bottom Width (ft)	Side Slope
5w	158	0.249	0.2	7	2 :1
4w	391	0.249	0.2	7	2 :1
3w	377	0.249	0.2	7	2 :1
2w	411	0.249	0.2	10.5	2 :1
1w	348	0.249	0.2	10.5	2 :1
0w	1	0.249	0.9	10.5	2 :1

Reach Identifier	Stage (ft)	Flow (cfs)	End Area (sq ft)	Top Width (ft)	Friction Slope (ft/ft)
5w	0.0	0.000	0	7	0.2
	0.5	6.111	4	9	
	1.0	20.432	9	11	
	2.0	72.773	22	15	
	5.0	460.810	85	27	
	10.0	2168.507	270	47	
	20.0	11447.252	940	87	
4w	0.0	0.000	0	7	0.2
	0.5	6.111	4	9	
	1.0	20.432	9	11	
	2.0	72.773	22	15	
	5.0	460.810	85	27	
	10.0	2168.507	270	47	
	20.0	11447.252	940	87	
3w	0.0	0.000	0	7	0.2
	0.5	6.111	4	9	
	1.0	20.432	9	11	
	2.0	72.773	22	15	
	5.0	460.810	85	27	
	10.0	2168.507	270	47	
	20.0	11447.252	940	87	
2w	0.0	0.000	0	10.5	0.2
	0.5	9.031	5.8	12.5	
	1.0	29.580	12.5	14.5	
	2.0	101.035	29	18.5	
	5.0	584.014	102.5	30.5	
	10.0	2543.487	305	50.5	
	20.0	12599.964	1010	90.5	
1w	0.0	0.000	0	10.5	0.2
	0.5	9.031	5.8	12.5	
	1.0	29.580	12.5	14.5	
	2.0	101.035	29	18.5	
	5.0	584.014	102.5	30.5	
	10.0	2543.487	305	50.5	
	20.0	12599.964	1010	90.5	
0w	0.0	0.000	0	10.5	0.9
	0.5	19.159	5.8	12.5	
	1.0	62.748	12.5	14.5	
	2.0	214.327	29	18.5	
	5.0	1238.881	102.5	30.5	
	10.0	5395.550	305	50.5	
	20.0	26728.560	1010	90.5	

Figure 45. WinTR-55 Output, West Watershed; Channel rating data

Figure 46. WinTR-55 Output, West Watershed; Watershed outlet hydrograph