Assessing Geomorphic Reclamation in Valley Fill Design for West Virginia

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Leslie Hopkinson[1], John Quaranta[1], Mindy Armstead[2], Jennifer Hause[3], and Nathan DePriest[1]

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[1]West Virginia University, Department of Civil and Environmental Engineering, PO Box 6103
Morgantown, WV 26506; Leslie.Hopkinson@mail.wvu.edu, 304-293-9932

[2]Marshall University, Integrated Science & Technology, One John Marshall Drive, Huntington, WV 25755

[3]Water Research Institute, West Virginia University, PO Box 6064, Morgantown, WV 26506

DISCLAIMER

EXECUTIVE SUMMARY

This work evaluated the potential of the application of geomorphic landform design principles to valley fill design in West Virginia. Although successful in the southwestern United States, challenges with the technique have been identified related to the use in Central Appalachia. Reference design values (drainage density, drainage length) vary by location and need to be quantified at a local scale for site-specific design. Due to the steep slopes, constructing artificial landforms that naturally blend in with the surrounding environment may not ensure stability. Lower gradient, more stable slopes of geomorphic landforms could create greater stream burial to maintain fill volumes. This work had two major objectives to address these challenges: 1) obtain and quantify characteristics of mature landforms in West Virginia; and, 2) generate geomorphic valley fill designs, using data specific to Central Appalachia mining regions.

Field characteristics of reference landforms were measured in three watersheds. Critical design parameters, drainage density and drainage length, were quantified for these locations. Additional channel and landform characteristics were measured: bed slope, bed material grain size, width, hillslope and aspect. Based on the field data and analysis, mean drainage length and mean drainage density were calculated as 408 ft and 61.7 ft/ac, respectively. These served as initial inputs for the landform design process. The variability of channel and landform characteristics was recorded to use in the evaluation of the geomorphic valley fills. Results confirmed geomorphic properties of landforms vary regionally. In Central Appalachia, drainage lengths are longer and drainage density is lower due to differences in vegetation, soil types, and precipitation compared to semi-arid regions.

Using the reference design parameters, a series of valley fill designs were completed, considering two permitted valley fills. The designs were analyzed with respect to fill volume, channel stability, and landform stability. Conditions investigated included: 1) effect of drainage density; 2) maximizing channel stability; 3) maximizing fill volume and hillslope stability; 4) trade-off between stability and fill volume; 5) expanded impact area; and 6) default design criteria. In total, 17 alternative valley fills were designed and evaluated. For the valleys considered in this study, existing channels could not be preserved due to the development of unstable landform slopes. However, a channel could be mitigated on site by creating a stable channel at a higher elevation. When the area of impact of the conventional reclamation was maintained, a geomorphic design could not meet the requirements of channel stability, landform stability, and fill volume simultaneously. These requirements could be achieved by expanding the area of impact, but the design did not comply with regulations in Central Appalachia for the placement of fill. Creating a geomorphic landform using this technique does not as accurately recreate the pre-mined topography of Central Appalachia as geomorphic landforms in the southwestern U.S. due to differences in environmental factors and mining/reclamation techniques. Finally, benefits of geomorphic designs include increased variability in slope and aspect and newly generated stream length.

The series of geomorphic designs confirmed there are challenges associated with the steep slope topography, stability, and stream mitigation, especially if minimizing the area of impact is a priority. Creating a stable geomorphic design as an alternative to a conventional valley fill in Central Appalachia is possible, but compromises must be made with respect to regulations if a geomorphic reclamation is to be implemented. Issues with respect to constructability must be

investigated, and studies quantifying the benefits of geomorphic reclamation in Central Appalachia with respect to erosion and water/contaminant management should be completed to fully assess the practicality of implementing geomorphic reclamation in Central Appalachia.

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INTRODUCTION

Surface mining of coal in Central Appalachia is accomplished by mountaintop mining with valley fills (MTM/VF). MTM/VF is, by regulation, accomplished in accordance with Approximate Original Contour (AOC). The mining process consists of removing overburden from the tops of mountains to expose coal seams. The bulk of mined rock (spoil) is placed on the mined surface while excess spoil is placed in external dumps known as valley fills. Regulations require that valley fills in West Virginia (WV) meet the following specifications: i) minimum long-term static factor of safety of 1.5; ii) maximum 2:1 slopes with 20-ft wide benches every 50 vertical feet; iii) a rock core or underdrain and, iv) drainage for 100-yr, 24-hr rain event (WVDEP, 1993; WVDEP, 1999; WV Coal Surface Mining Rule, 2011). While successful in short-term stability, concerns remain related to long term stability (Michael et al., 2010) and slope failures. In addition, it has been suggested that current surface mine reclamation techniques have been unsuccessful in compensating for lost stream length and forested areas in headwater systems, resulting in altered watershed hydrology and impaired water quality below fills (Bernhardt and Palmer, 2011). According to the U.S. Environmental Protection Agency (USEPA) over 2,300 valley fills have been permitted in WV with an estimated buried stream length of over 1,200 miles (2011). Little is known about the large-scale and long-term hydrologic consequences (both in water quantity and quality) of existing mountaintop mining reclamation practices (Miller and Zégre, 2014). The planar slopes created at the valley fill face and crest also do not accurately recreate the landform aesthetics of the pre-mined topography.

The issues associated with the existing reclamation techniques have prompted an analysis of unconventional reclamation methods, including geomorphic landform design (e.g. Michael et al., 2010; Sears et al., 2013, 2014; Russell et al., 2013; Quaranta et al., 2013). The goal of geomorphic reclamation is to construct artificial landforms in a way that reduces the effect of natural geomorphic processes and replicates a mature landform that is stable and in erosive equilibrium. Geomorphic reclamation attempts to replicate the natural geomorphology of a channel and its adjacent slopes based on on-site pre-disturbed conditions or on existing conditions in nearby undisturbed basins.

Geomorphic reclamation is becoming more widely accepted by the scientific community as an alternative method for reclaiming disturbed landforms (Nicolau, 2003). Application of geomorphic reclamation to date has been in the southwestern United States (e.g. Measles and Bugosh, 2007; Bugosh, 2009; Robson et al., 2009) and in some locations outside of the U.S. (Martin-Duque et al., 2010; Martin-Moreno et al., 2008). Although successful in other regions, many challenges have been recognized that must be addressed prior to use in Central Appalachia. The values for geomorphic design criteria are different in Central Appalachia than in the southwestern United States. Soil types, vegetation, and precipitation differences between the southwestern U.S. and Central Appalachia all have an effect on drainage length and drainage density. Quantifying reference design parameters is necessary for accurate site-specific design (Buckley et al., 2013; Sears, 2014), and available data for Central Appalachia are currently limited. This work quantified these design criteria for locations in southern West Virginia.

Michael et al. (2010) documented potential issues regarding the stability and impact of implementing geomorphic design principles in Central Appalachia. Due to the steep slopes, constructing artificial landforms that naturally blend in with the surrounding environment may not ensure stability. Shallower, more stable slopes of geomorphic landforms could create greater stream burial to maintain fill volumes. The second component of this work quantifies these concerns by evaluating conceptual geomorphic designs.

Specific objectives include:

> *Objective 1:* Obtain and quantify characteristics of mature landforms in West Virginia.
>
> *Objective 2:* Generate geomorphic valley fill designs, using data specific to Central Appalachia mining regions. Specific research questions for this objective included the following:
>
> - Can an existing stream that would be buried in a conventionally constructed valley fill reclamation be preserved or mitigated in a geomorphic design?
> - Can a valley fill with a preserved or re-created channel that is geomorphically designed and geotechnically stable be built that maintains the area of impact associated with an existing conventionally constructed fill?

Marshall University (Marshall) collaborated with West Virginia University (WVU) on this project. Marshall's objective was to establish baseline conditions in the undisturbed watersheds used for geomorphic landform reference for the purpose of future comparison with benthic macroinvertebrate communities established in streams constructed with the geomorphic landform design techniques. Additionally, Marshall has preliminarily evaluated the biological data with respect to specific landform features (e.g. main channel slope, drainage density, channel characteristics, bed size particle distribution, and vegetative zones) to determine if associations and patterns exist between individual taxa or assemblages and landform features which may prove useful in predicting successful outcomes for design.

MATERIALS AND METHODS

Characteristics of landforms were measured in southern West Virginia, and a series of designs were created for valley fills as detailed in the following sections.

Quantifying Reference Landform Characteristics

Reference Landforms

Field data, necessary for the design process, were collected from reference landforms. Two types of landforms were chosen as reference landforms: mature natural landforms and relatively old, conventionally constructed valley fills (hereafter referred to as “long-term reclaimed sites”).

Mature landforms

For this project, the “mature landform” served as the reference landform for the geomorphic design process. A “mature landform” can also be described as a “stable” or “undisturbed” landform. In a mature landform, erosive forces cause a landform to become naturally stable over a long period of time (Ollier, 1967). Effective landforming involves designing surfaces in which erosive forces are minimized (Schor and Gray, 2007). The reference mature landforms used in this work had a minimal level of disturbance through land use, a history of stability, and as much time as possible since major disturbance.

To determine field sites for data collection, criteria for mature landforms and long-term reclaimed sites were defined. The region was evaluated at a landscape scale and then at the individual watershed scale. See Appendix A for details regarding the reference landform selection process.

Three watersheds within two separate areas containing mature landforms were selected for field data collection. These sites were characterized by steep terrain, a temperate climate, mature forest cover, and minimal disturbance; the sites were also easily accessible. The first reference landform was located within Twin Falls State Park in Wyoming County, WV (Fig. 1). Twin Falls State Park (3,776 acres) was established in the 1970s and is predominantly forested. Mean annual temperature is 53^{o}F and mean annual precipitation is 46 in (NOAA, 2014). Watershed evaluations resulted in two selected watersheds. Dixon (235 acres) and Jackson (359 acres) watersheds were forested with minimal anthropogenic disturbance (e.g. access road, recreational campground, and hiking trails). The mean slopes of Dixon and Jackson watersheds were 27% and 32%, respectively.

The second reference landform was located within Cabwaylingo State Forest in Wayne County, WV (Fig. 2). Cabwaylingo State Forest (8,123 acres) was established in the 1930s and is heavily forested. The third watershed (Wiley watershed, 574 acres) was selected because it was minimally disturbed by a few roads and trails. Mean annual temperature is 54˚F, and mean annual precipitation is 47 in (NOAA, 2014). The watershed has steep terrain with a spatial mean slope of 43%.

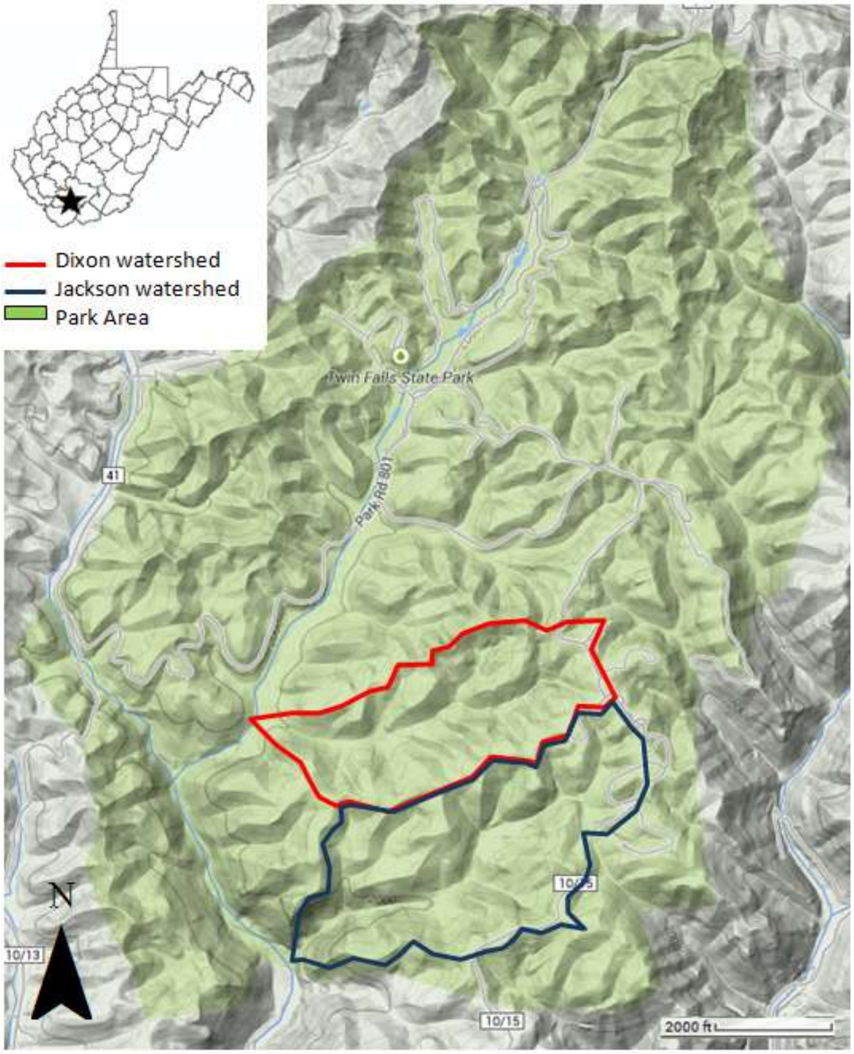


Figure 1. Location of Twin Falls State Park and watersheds.

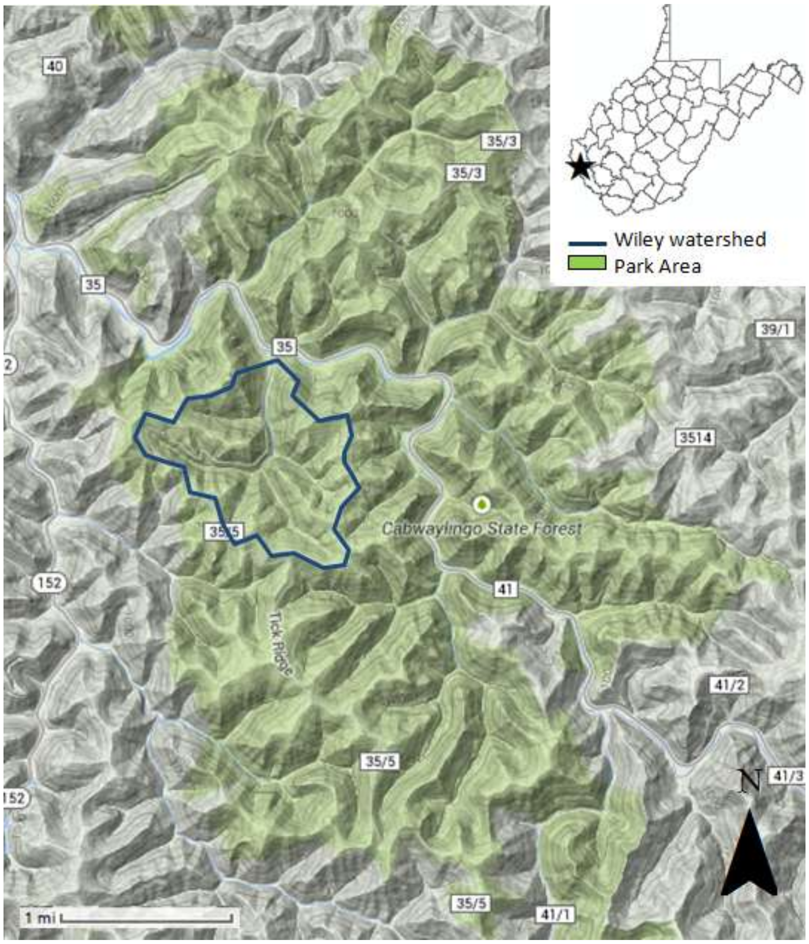


Figure 2. Location of Cabwaylingo State Forest and watershed.

Long-term reclaimed sites

A "long-term reclaimed" site is a surface mine site that has been reclaimed, but enough time has passed for erosive characteristics to be evident. The purpose of the long-term reclaimed site was to quantify erosive features, such as gullies, rills, and signs of mass movement. A reclaimed site in Summersville, WV (Fig. 3) was chosen as the third reference landform for field data collection (See Appendix A for selection criteria). Four valley fills were present at the Summersville long-term reclaimed site, facing in the four directions of northwest, southwest, northeast, and southeast. Data were collected at the two accessible valley fills: the northwest facing valley fill (3.28 acres) and the southwest facing valley fill (1.73 acres).

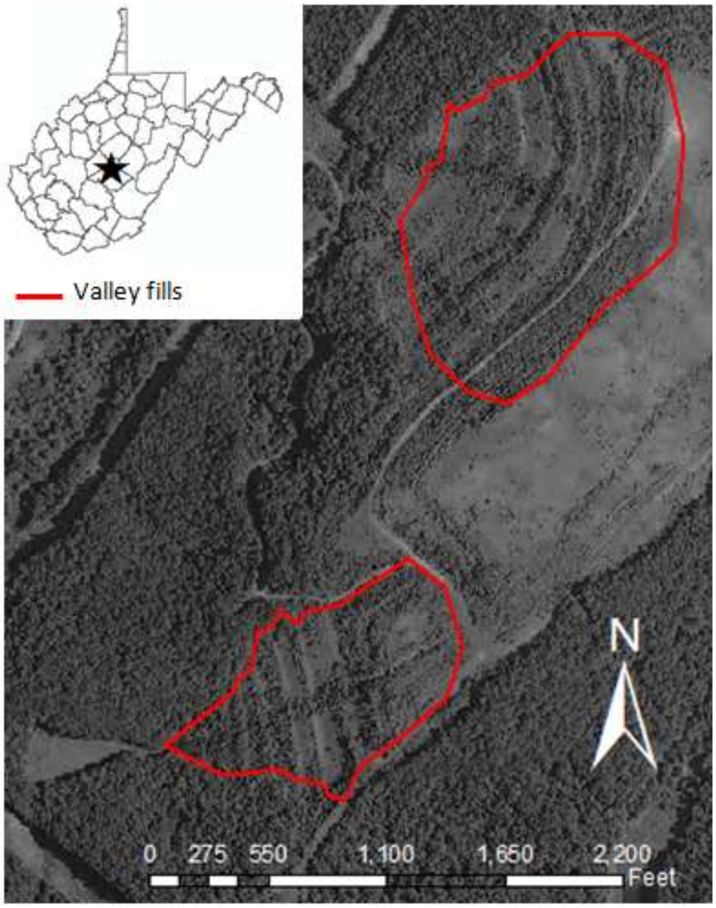


Figure 3. Location of long-term reclaimed site in Summersville, WV and accessible valley fills.

Field methods

At mature landforms, field data were collected at head of channel locations. The head of channel was defined as the location nearest to the drainage divide where channeled morphology occurred (Montgomery and Dietrich, 1988), resulting in concentrated flow and sediment transport (Henkle et al., 2011). Head of channel locations were surveyed by walking down from the drainage divide until a head of channel was identified. For each head of channel site in the watersheds of mature landforms, the location head of channel, and associated ridge point were recorded with Topcon satellite GPS equipment (Tokyo, Japan). Horizontal error was set to 1 ft and vertical error was set to 3 ft, the minimum allowable error with the dense canopy cover at forested field sites.

Left bank slope (looking downstream), right bank slope, left bank vegetation, right bank vegetation, channel width, upstream slope, and downstream slope were recorded at each head of channel location. Pebble counts were completed with a gravelometer in accordance with the modified Wolman (1954) method. Watershed outlet locations were also evaluated following the same procedure. Discharge was also measured with a Sontek Flowtracker when measurable and accessible (Harrelson et al., 1994).

At long-term reclaimed sites, erosive characteristics were measured. This consisted of walking on the sloped face of the valley fill and surveying locations where erosion had initiated by exposing subsurface rock and soil. The same properties evaluated for the mature landforms were evaluated at these sites.

GIS analysis

GIS was used to describe hillslope (%), aspect (^{o}), and vegetation spatially across the reference watersheds. Forest fragmentation data from WVGIS Technical Center (Strager and Maxwell, 2011) provided a distribution of the vegetation cover in each watershed. Watershed characteristics determined with GIS were compared to field observations.

Geomorphic design criteria

Field data were supplemented with spatial analysis to determine the critical design criteria of drainage length (L_D) and drainage density (DD). Drainage length was calculated as the straight line distance between the channel head and associated ridge point of each site, as defined by geomorphic design software (Bugosh, 2006). Locating channel head locations was critical in calculating drainage density (stream length/watershed area) because the National Hydrography Dataset (NHD) under represents headwater stream length (Heine et al., 2004). Streams were delineated from the channel head locations identified within each reference landform and added to the NHD stream network to calculate stream length. Due to access limitations and disturbance, not all channel head locations were identified in the reference watersheds during field work. To account for this difference, channel head locations were generated in the additional locations by applying the mean drainage length of that watershed to each valley. The streams were then delineated and the headwater channels were added to the NHD. DD was then calculated for each reference watershed. This method of identifying head locations, delineating streams, and calculating drainage density was applied to additional watersheds within the reference landform areas to confirm drainage density values. Additional watersheds were evaluated until calculated drainage density resulted in a constant standard deviation. This analysis led to the target drainage density and allowable variance used in design.

Benthic Macroinvertebrate Sampling

Wiley Branch is a first order stream located in Wayne, County West Virginia. Four benthic macroinvertebrate sampling locations were established in this stream which was accessed via the Copley Trail at Cabwaylingo State Forest. Jackson and Dixon Branches are both first order streams which were located in Twin Falls State Park in Wyoming County. Four sampling locations were established in Dixon Branch which was accessed using Hemlock Trail following the stream. No trails provided access to Jackson Branch. Three sampling sites were located in this stream. The first two sampling sites were accessed by hiking upstream from the mouth and the third was accessed by descending the ridge. The mid-region of the stream was inaccessible due to boulders.

Benthic macroinvertebrate communities were evaluated in the first order headwater streams identified by WVU as reference streams for the project. Field sampling included recording habitat conditions, measuring field water chemistry conditions, and the collection of benthic macroinvertebrates. Habitat evaluations were conducted utilizing the USEPA Rapid Bioassessment Methodology (Barbour et al., 1999) with assessments entered into spreadsheets and scored according to the following ratings:

- *Optimal* (total score of 200-166)
- *Suboptimal* (165-113)
- *Marginal* (112-61)
- *Poor* (<61)

Water chemistry measured included pH, dissolved oxygen, temperature, and specific conductance using a YSI multi-meter, calibrated per manufacturer's instructions. Benthic macroinvertebrates were collected in accordance with the single habitat, kick-net sampling technique (Barbour et al., 1999) on sampling dates shortly after the geomorphic data collection. At each of the reference watersheds a sampling location was established in the mouth of the first order stream, and additional sites were established working upstream in the intermittent/perennial stream channel. Four sampling sites were located in the Wiley Branch and Dixon Branch stream channels with sampling occurring on June 5th, and 6th of 2013, respectively. Three sites were established and sampled on Jackson Branch on June 7, 2013.

Benthic macroinvertebrates were sub-sampled, sorted, and identified to the lowest practical taxon, usually genus. Data were evaluated to determine the overall community health in the reference streams using single metric and multi-metric evaluations included in the West Virginia Stream Condition Index (WVSCI) (Tetra Tech, 2000). The WVSCI is a multi-metric index indicating overall community health as a single score calculated by summing individual metrics. The individual metrics included represent the diversity and sensitivity of the macroinvertebrate community as follows. The metrics Taxa Richness and Ephemeroptera, Plecoptera, and Trichoptera (EPT) Taxa Richness indicate overall community diversity and diversity of the sensitive mayfly, stonefly and caddisfly taxa. Composition measures, such as Percent Chironomidae and Percent EPT, provide information on relative contribution of sensitive and tolerant taxa. The Percent 2 Dominant Taxa metric indicates whether the community is diverse or dominated by few tolerant taxa. The Hilsonoff Biotic Index (HBI) is a tolerance measure (Barbour et al., 1999). Metrics are scored on a 0 to 100 point scale and summed to provide a total score which is further assigned a narrative descriptor indicating whether the stream is *Impaired* or *Unimpaired* (Tetra Tech, 2000).

Significant differences between biological communities, water chemistry, and habitat conditions in the three watersheds were determined using one-way analysis of variance procedures where the assumptions of normality and homogeneity were met. A Kruskal-Wallis procedure was utilized as a non-parametric alternative when the assumptions were not met. Results of parametric ANOVA are presented as an F-statistic while the non-parametric tests are presented as an H-statistic. Significant differences were evaluated using Fisher's Least Significant Differences multiple comparison test when the parametric procedure was used and Dunn's Test for the non-parametric alternative. Significant differences between sample locations are indicated by different numbers of "*" in summary tables. Genus level data were used for statistical evaluations for richness measurements to represent a more sensitive endpoint.

Creating Alternative Valley Fill Designs

Field design site

The field site for the generation of geomorphic reclamation designs was a surface mine in Boone Co., WV, in the same ecoregion as the reference landform sites (Fig. 4). Two valley fills (VF1 and VF2) with an existing conventional reclamation plan were used within the permit boundary for geomorphic designs (Fig. 5). Small-scale fills were investigated in this study with the intention of designing a geomorphic landform that shows the practicality of a pilot construction project incorporating geomorphic design principles in southern WV. A third valley fill was evaluated but later excluded because applying geomorphic design principles would have resulted in a valley fill that impacted multiple drainage basins. This work evaluated designs draining to a single outlet.

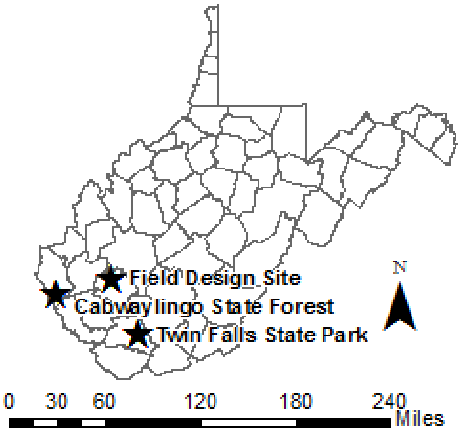


Figure 4. Location of field design site relative to reference landform sites.

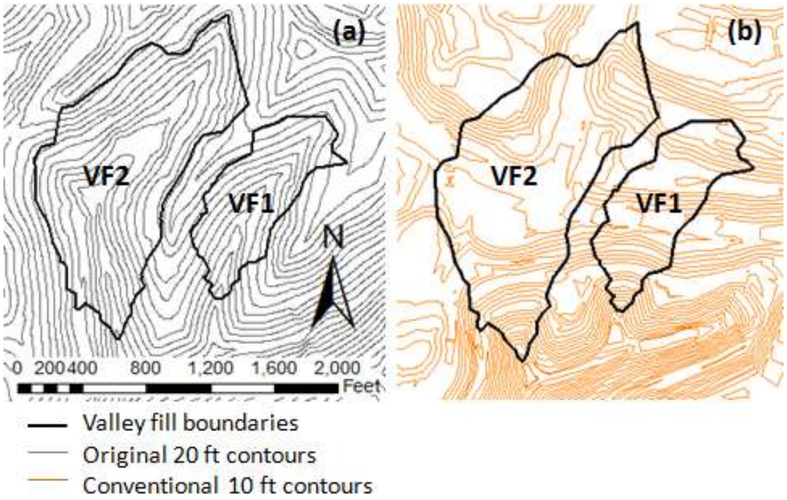


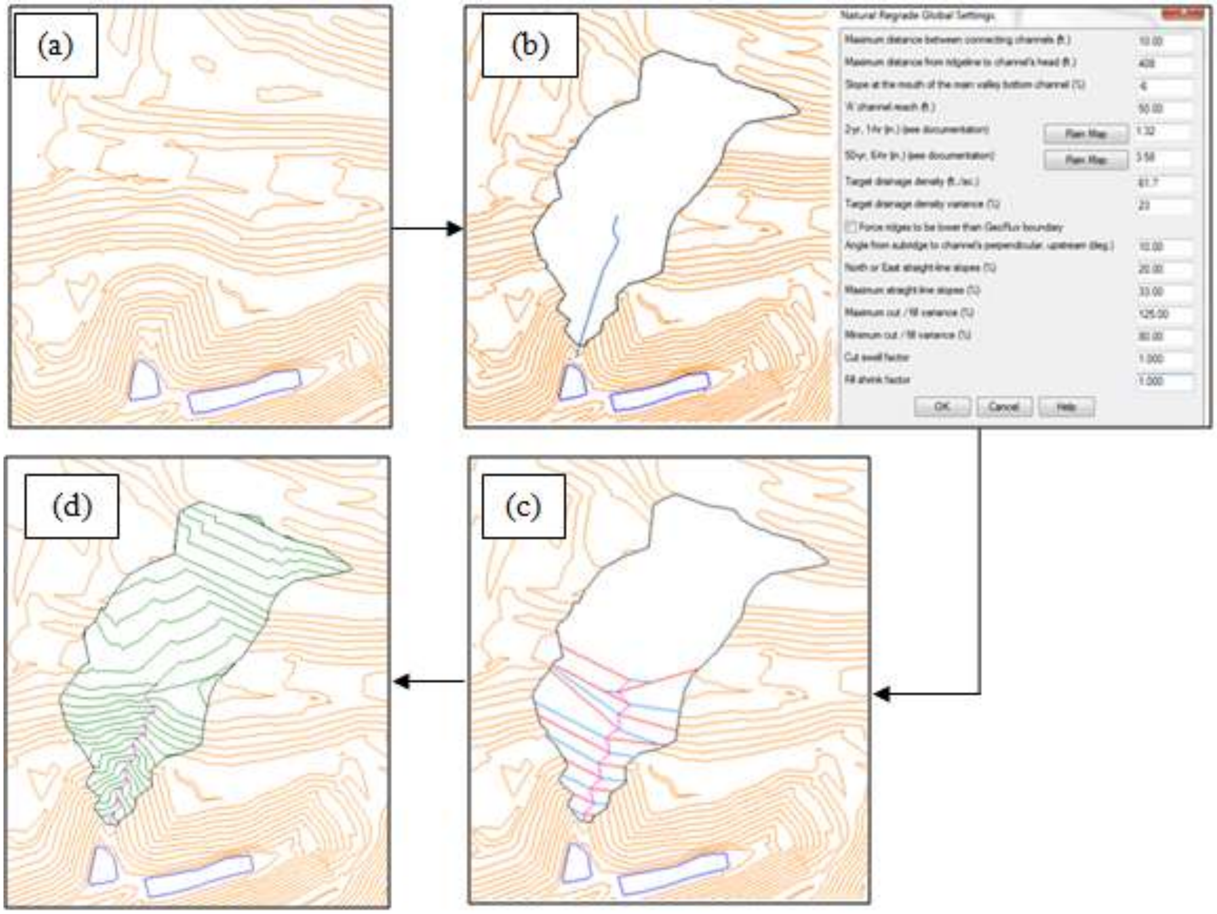
Figure 5. VF1 and VF2 locations on (a) original contours; (b) conventional reclamation contours.

The site is located in the Central Appalachians ecoregion (USEPA, 2013) and has a temperate climate (average annual precipitation = 48 in, average annual temperature = 55°F; NOAA, 2014).

The pre-mined terrain was steep with a spatial mean slope of 41%; 90% of the hillslopes fell within the range of 20-70% grade. The geology of the design site is dominated by gray shale and sandstone. Pre-mining vegetation was predominantly dense core forest. The pre-mining landuse of the design site was forestland, and the planned post-mining landuse was a return to forestland.

Design of geomorphic landforms

Geomorphic landforms were generated using Carlson's Natural Regrade (Fig. 6).



Maximum distance between connecting channels (ft.) 10.00
Maximum distance from ridgeline to channel's head (ft.) 400
Slope at the mouth of the main valley bottom channel (%) 4
'A' channel reach (ft.) 50.00
2yr, 1hr (in.) (see documentation) 1.32
50yr, 6hr (in.) (see documentation) 3.58
Target drainage density (ft./ac.) 61.7
Target drainage density variance (%) 23
☐ Force ridges to be lower than GeoFlux boundary
Angle from subridge 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 1.000
Fill shrink factor 1.000

Figure 6. Natural Regrade design process for generating geomorphic landforms: (a) Given an existing topography; (b) Define landform boundary and create a polyline which satisfies input parameters; (c) generate a stream(s) and corresponding ridges and valleys; (d) develop landform that ties into surrounding topography.

For the purposes of this study, the existing topography was the conventional reclamation. The pre-mined topography was only investigated when calculating cut/fill volumes of the geomorphic designs and comparing them to the cut/fill of the conventional reclamation. Valley fill boundaries from the available WVDEP mining permit boundaries served as the boundaries for geomorphic designs. The polylines used to generate streams followed the path of the streams in the pre-mined topography that were buried in valley fill reclamation. This was accomplished by generating points from the vertices of streams from the National Hydrology Dataset (USGS, 2003) in the pre-mined topography and using those points in Natural Regrade to create the polylines from which streams were generated. The purpose of generating designs was to determine if a geomorphic design could be completed with the same fill volumes as the conventional valley fill reclamation without expanding the footprint of the conventional valley fill.

Quantifying landform design characteristics

Channel stability was evaluated considering the design of a threshold channel; minimal bed material movement was desired. Shields (1936) diagram was used to determine median bed material size for incipient motion. Channels requiring large bed material to limit movement (i.e. boulders, ≥10.1 in) were not considered stable. Channel dimensions were determined conservatively by using a high runoff coefficient (0.89) and intense storms (2-yr, 1-hr storm for bankfull discharge; 50-yr, 6-hr storm for flood prone discharge). The storm durations and intervals used to classify bankfull and floodprone discharges and dimensions were provided by Natural Regrade. Bankfull and flood prone were defined by Natural Regrade according to the dimensions of a trapezoidal channel with 25% side slopes necessary to convey the respective peak flows.

Hillslopes were evaluated for stability to identify potential failure regions. Using the WVDEP design standard factor of safety of 1.5 (WVDEP, 1999), a slope stability analysis was performed on the materials from the design site used to construct fills. Material strength properties of internal friction angle ($\phi = 40^\circ$), cohesion (c = 0 psf), and unit weight ($\gamma = 129.7$ pcf) were obtained from the surface mine permit file. Constant slope profiles with no piezometric surface were modeled, and slope was increased until factor of safety fell below 1.5, which occurred at 50% grade. This 50% threshold is consistent with the WVDEP design standard of a maximum 2:1 slope for a valley fill face (WVDEP, 1999). The area of hillslopes above 50% grade in each geomorphic design was investigated. A fully stable design should have no landforms above 50%. Another challenge associated with the application of geomorphic landform principles to the design of valley fills is the expected increased area of impact for a stable design (Michael et al., 2010). To address this concern, the volume of fill of each alternative design generated in this research was compared to the fill volume of the conventional fill design.

Design iterations

Designs were completed systematically to determine the best possible design for the analyzed fill with respect to fill volume, channel stability, and landform stability. Designs were completed to optimize individual landform characteristics, and then altered to find a compromise among all characteristics through the following steps and summarized in Table 1:

1. <u>Investigating the effect of drainage density</u>: First, the effect of drainage density on fill volume was investigated. For each fill, three cases of drainage density were investigated while leaving stream elevation and location constant. The first design generated a landform with a stream length that resulted in a drainage density value as close to the target drainage density as possible. The target drainage density was calculated using the reference data information. The second and third designs generated landforms with stream lengths that resulted in drainage density values at the upper and lower ends of the target drainage density variance, respectively.

2. Maximizing channel stability: The second set of designs attempted to maximize channel stability by preserving the existing channel. Preserving the existing channel created a design with the shallowest sloped channel possible. The geomorphic landform was created around the existing valley bottom without burying the existing channel. A design was completed for each fill.

3. Maximizing fill volume and hillslope stability: The third set of designs attempted to maximize fill volume and hillslope stability by generating a new channel at the highest elevation possible. The drainage density value associated with the highest fill volume from the first set of designs was used. A design was completed for each fill.

4. Trade-off between stability and fill volume: The next designs investigated trade-offs among channel stability, fill volume, and hillslope stability. These designs were only completed with one fill, choosing the valley fill that showed the most promise with respect to application from initial designs. Channel stability was optimized by decreasing the channel head elevation until the maximum applied shear stress on the channel resulted in a required median bed particle size of cobble (10.1 in) or smaller at either bankfull or flood prone discharges; this corresponded to a maximum applied shear stress of 4.33 psf. One design ensured channel stability at bankfull flow, and another ensured channel stability at both bankfull and flood prone flows.

5. Expanded impact area: Similar design cases were completed with an expanded valley fill footprint to investigate the effect of expanding the impacted area on the ability to reach a target fill volume. The toe of the valley fill was extended to the downstream edge of the valley fill toe pond, the maximum area before additional valleys are impacted. First, channel stability was maximized by preserving the existing channel. Next, channel stability at bankfull flow was ensured while compromising fill volume. The final design ensured channel stability at both bankfull and flood prone flows.

6. Using default design criteria: A design for VF1 was completed using the default inputs in Natural Regrade to investigate the differences between a design using default values and a design using design criteria measured at the reference sites.

Table 1. Summary of valley fill design iterations.

Design number	Valley Fill	Drainage Density	Channel	Channel Stability	Fill volume	Impact Area
Investigating Drainage Density						
1	1	Low	Constructed			Permitted
2	1	Target	Constructed			Permitted
3	1	High	Constructed			Permitted
4	2	Low	Constructed			Permitted
5	2	Target	Constructed			Permitted
6	2	High	Constructed			Permitted
Maximize Channel Stability						
7	1	Low	Preserve	Maximum		Permitted
8	2	Low	Preserve	Maximum		Permitted
Maximize fill volume and hillslope stability						
9	1	Low	Constructed		Maximum	Permitted
10	2	Low	Constructed		Maximum	Permitted
Compromise of stability and fill volume						
11	1	Low	Constructed	Stable (BF)		Permitted
12	1	Low	Constructed	Stable (FP)		Permitted
13	1	High	Constructed	Stable (FP)		Permitted
Expanded impact area						
14	1	Low	Preserve	Maximum		Expanded
15	1	Low	Constructed	Stable (BF)		Expanded
16	1	Low	Constructed	Stable (FP)		Expanded
Default design criteria						
17	1	Default	Constructed			Permitted

Note: BF=bankfull, FP=floodprone

RESULTS AND DISCUSSION

Reference Landform Characteristics

Eight sites in Dixon watershed, 11 sites in Jackson watershed, three sites in Wiley watershed, and five sites in Summersville (conventional valley fills) were used to determine channel properties (Fig. 7, Table 2) and watershed characteristics (Table 3). Additional reference landform data are provided in Appendix B.

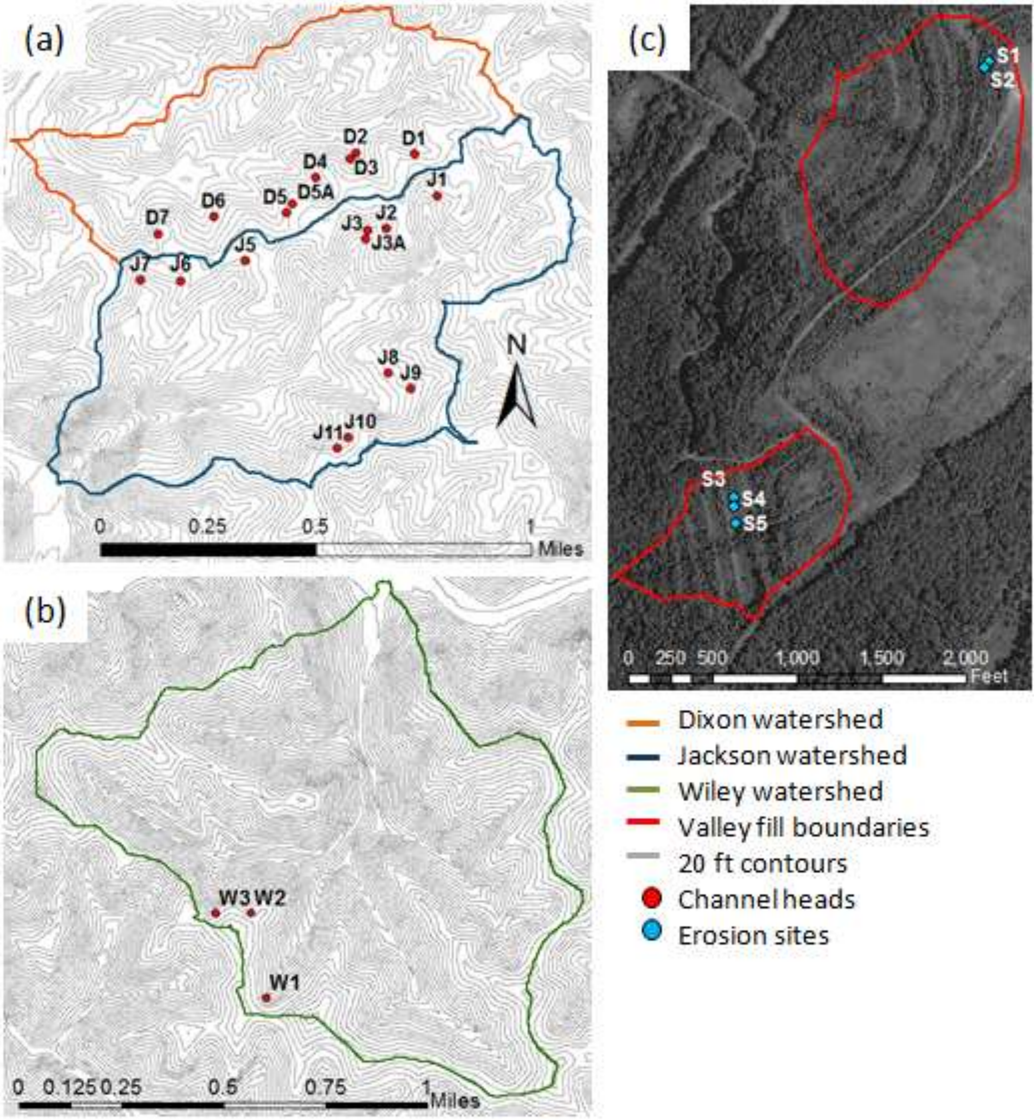


Figure 7. Channel heads and erosion sites at (a) Twin Falls State Park, (b) Cabwaylingo State Forest, (c) Summersville, WV.

Table 2. Mean slope (S_c), width (B), median particle size (D_{50}) and drainage length (L_D) in channel head locations of reference landforms. Standard deviation of each mean value is reported in parentheses.

Watershed	No. of sites	S_C (%)	B (ft)	D_{50} (in)	L_D (ft)
Dixon	8	18.1 (4.2)	3.2 (1.1)	0.03 (0.004)	429 (43)
Jackson	11	23.5 (12.6)	3.8 (1.9)	0.14 (0.10)	404 (113)
Wiley	3	46 (7.2)	4.1 (0.8)	0.03 (0.003)	330 (29)
Valley-fills	5	44 (3.0)	1.9 (0.7)	0.38 (0.07)	NA

At long-term reclaimed valley fills, erosion sites were present approximately halfway between benches. Erosive forces exposed subsurface soil in several locations across each slope between benches. Only five sites of erosion were surveyed, but the prevalence of sites throughout the slope face exhibit the amount of erosion that takes place on conventionally reclaimed valley fills, even those that have had time to develop vegetative coverage.

Channel sinuosity at the mouth of the Wiley Branch was 1.0. Site W1 in the Wiley watershed had a sinuosity of 1.0. Site D5 in the Dixon watershed had a sinuosity of 1.3. All other sites were determined to have a sinuosity of approximately 1 by field observation. Sinuosity was within horizontal error of Topcon measurements at these locations.

The majority of hillslopes for mature sites (Dixon, Jackson, and Wiley watersheds) fell between 20-40% grade, but a moderate amount of slopes were greater than 40% grade (Table 3, Fig. 8a, Fig. 8b) This is indicative of the steep terrain of southern West Virginia. The majority of hillslopes at the Summersville valley fills fell with the 20-60% grade range (Fig. 8c) due to the 2:1 slope face design of conventional valley fills. For both valley fills, fewer than 4% of the slopes were above 50% grade. The small percentage of slopes above the 50% WVDEP threshold were mostly like due to erosion or error in the digital elevation model. Slope data from GIS were consistent with field observations. The difference in slopes between the mature landforms and the long-term reclaimed is apparent.

Table 3. Percent by area of each slope range for each watershed.

Slope (%)	Percent by Area (%)				
	Dixon	Jackson	Wiley	Northwest VF*	Southwest VF*
0-20	27.2	23.4	9.6	9.4	25.8
20-40	59.4	52.8	61.8	59.2	53.3
40-60	13.1	18.7	7.3	31.4**	20.0**
60-80	0.3	3.6	20.1	0	0.9
80-100	0	1.2	1.2	0	0
100-120	0	0.3	0	0	0

* Names for valley fills corresponded to the general cardinal direction in which the face of the slope was facing.

**For both valley fills, fewer than 4% of the slopes were above 50% grade.

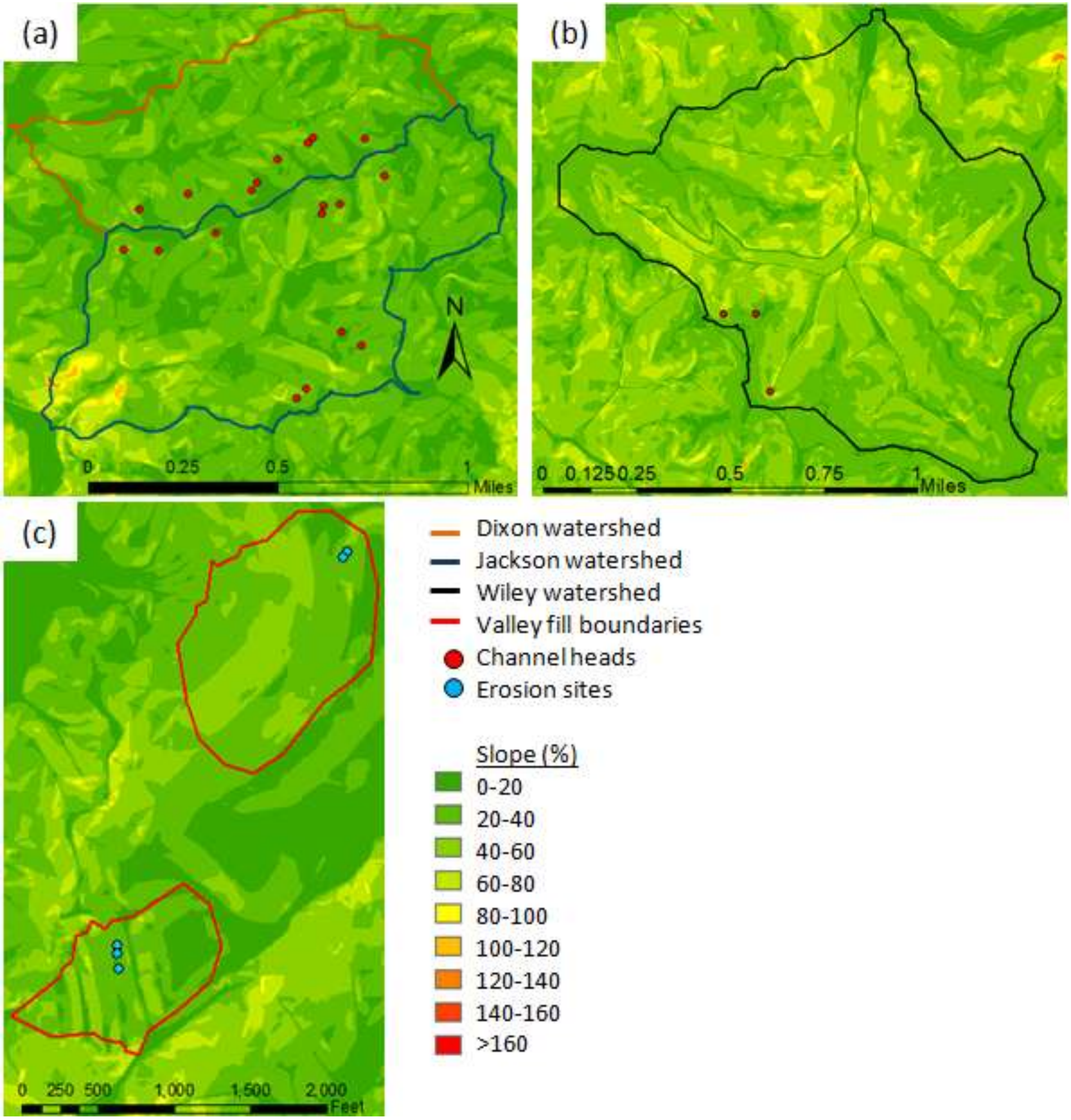


Figure 8. Slope distributions for (a) Twin Falls State Park, (b) Cabwaylingo State Forest, (c) Summersville, WV.

For the mature landforms, aspect was distributed among each direction (Table 4, Fig. 9a, Fig. 9b). No dominant aspect was found; but, it was useful to quantify the variability in aspect for mature landforms. For the reclaimed sites, the majority of the slopes were in the direction that the valley fill was facing (NW for northwest facing fill; west for the southwest facing fill) (Fig. 9c). This was due to the uniform slope construction of valley fills.

Table 4. Distribution of aspect for reference landform sites.

Aspect (°)	Percent by Area (%)				
	Dixon	Jackson	Wiley	Northwest VF	Southwest VF
Flat (-1)	0	0.2	0	0	0
North (0-22.5,337.5-360)	19.0	10.6	11.3	0.3	4.7
Northeast (22.5-67.5)	7.5	2.3	16.6	0.1	1.6
East (67.5-112.5)	4.4	7.2	13.9	0	2.5
Southeast (112.5-157.5)	10.6	14.5	6.9	0.8	10.2
South (157.5-202.5)	13.7	15.6	14.3	0.9	2.0
Southwest (202.5-247.5)	13.3	14.3	12.9	3.2	8.6
West (247.5-292.5)	17.1	15.3	12.7	38.1	59.2
Northwest (292.5-337.5)	14.4	20.0	11.4	56.7	11.2

Note: Names for valley fills correspond to the general cardinal direction of the sloping face

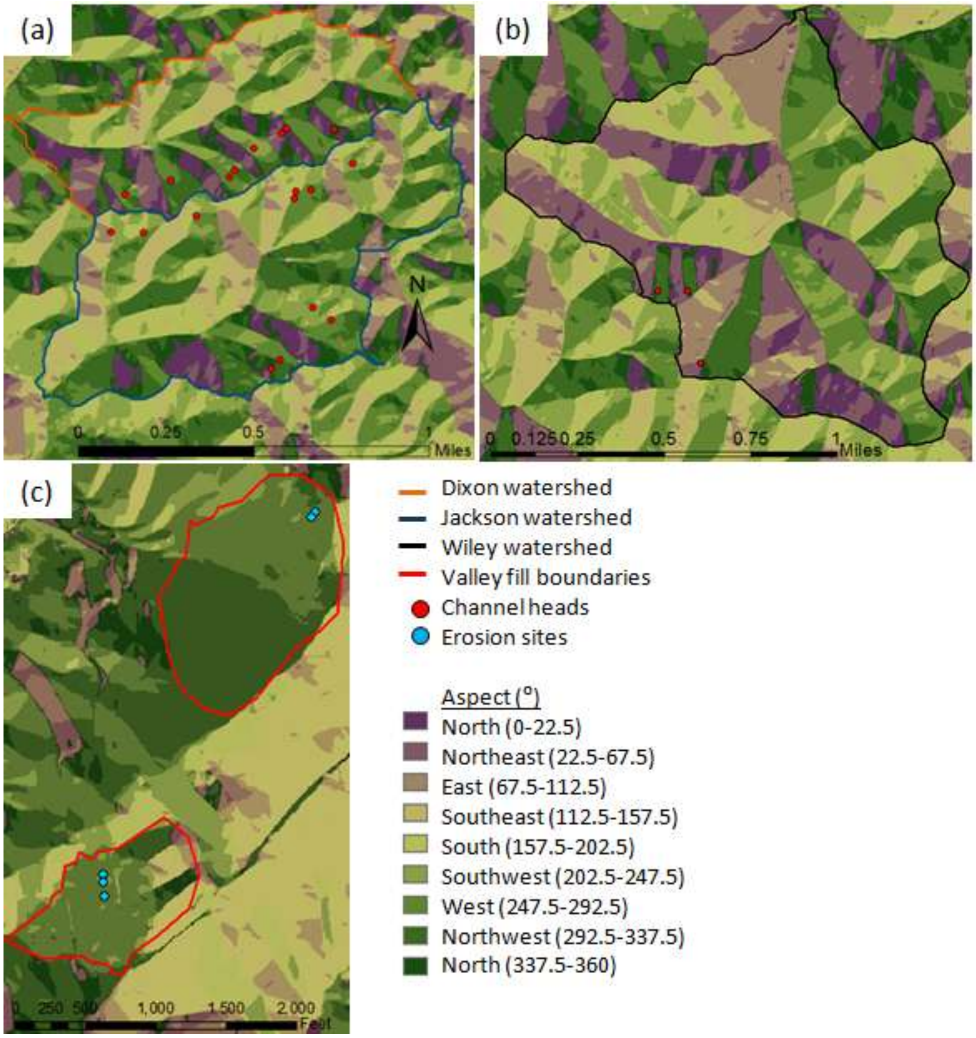


Figure 9. Aspect distributions for (a) Twin Falls State Park, (b) Cabwaylingo State Forest, (c) Summersville, WV.

For all locations, the vegetation was mostly large core forests (Table 5, Fig. 10), consistent with the characteristics considered when evaluating potential reference landforms (Appendix A). The valley fill sites had areas of perforated forest; the fills had been developing vegetation for 20-30 years. Although available GIS data suggested that vegetation was just as mature at the reclaimed sites as at the mature sites, this was not consistent with what was observed in the field. Although long-term reclaimed sites had dense, developed vegetation (Fig. 11a), it was not as mature as the vegetation seen at the mature landform sites (Fig. 11b).

Table 5. Percent by area coverage of vegetation types for each watershed.

Vegetation Type	**Percent by Area (%)**				
	Dixon	**Jackson**	**Wiley**	**West VF***	**South VF***
Perforated	2.1	6.7	25.7	46.7	24.7
Core (>500 acres)	97.9	93.3	74.3	57.3	75.3

Note: Names for valley fills corresponded to the general cardinal direction in which the face of the slope was facing

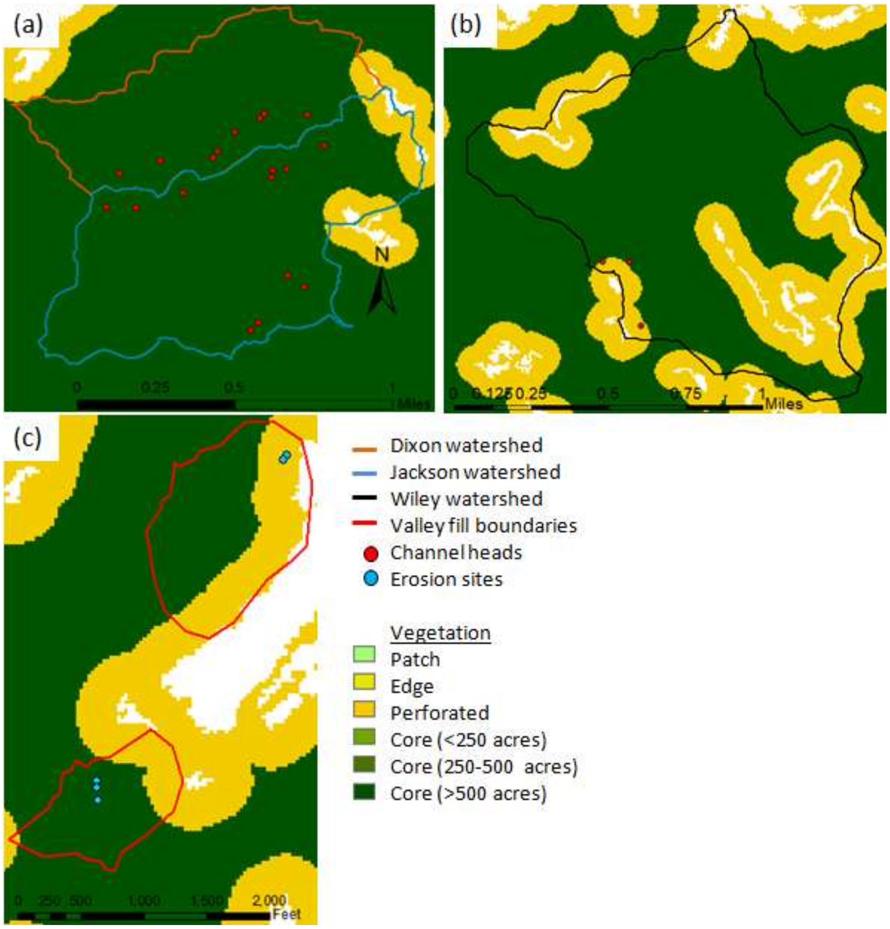


Figure 10. Vegetation distribution at (a) Twin Falls State Park, (b) Cabwaylingo State Forest, (c) Summersville, WV.

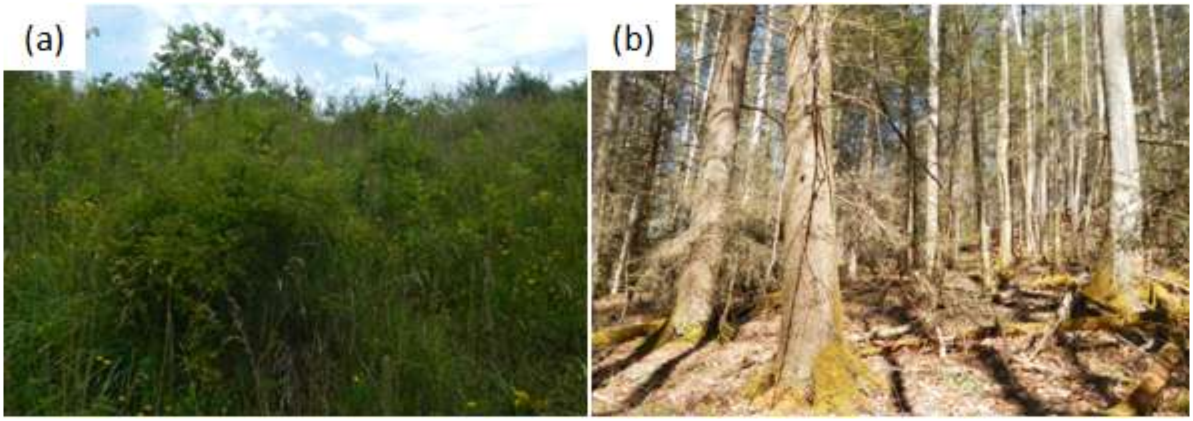


Figure 11. Vegetation at (a) long-term reclaimed site; and (b) mature site.

Critical Design Parameters

Mean drainage length and mean drainage density were calculated as 408 ft and 61.7 ft/ac, respectively. These mean values served as the critical geomorphic design criteria (Table 6). Storm precipitation depths were defined by the National Oceanic and Atmospheric Administration (NOAA) Precipitation Frequency Data Server (PFDS). The closest weather station to the field design site was Madison (Site ID: 46-5563) (NOAA, 2014). Slope at the mouth of the channel was specific to each valley for which a design was being completed. The remaining parameters were left unchanged. For all three watersheds, a significant amount of additional stream length was added to the NHD data by including the headwater channels (Table 7). To allow for natural variability in designs, a range of acceptable drainage density values was created by applying a ±23% variance (two standard deviations) to the mean drainage density value.

Table 6. Summary of existing software design parameters and field measured parameters.

Input Parameter	Natural Regrade value	Field measured value	Final design value used
Maximum distance between connecting channels (ft)	10	NA	10
Ridge to head of channel distance (ft)	80	408	408
Slope at the mouth of main valley bottom channel (%)	-2	-3	Specific to each valley
A' channel reach (ft)	50	NA	50
2-yr, 1-hr precipitation depth (in)	0.6	1.32	1.32
50-yr, 6-hr precipitation depth (in)	2	3.58	3.58
Target drainage density (ft/ac)	100	61.7	61.7
Target drainage density variance (%)	20	23	23
Angle from subridge to channel's perpendicular, upstream (deg)	10	NA	10
North or East straight-line slopes (%)	20	NA	20
Maximum straight-line slopes (%)	33	NA	33
Maximum cut/fill variance (%)	125	NA	125
Minimum cut/fill variance (%)	80	NA	80
Cut swell factor	1	NA	1
Fill shrink factor	1	NA	1

Table 7. Drainage densities for different stream lengths. Starting with the NHD streams first, the streams delineated from field mapped sites are added, and then the streams from GIS mapped sites are added.

Watershed	Watershed Area (ac)	Stream Length (mi)			Drainage Density (ft/ac)		
		NHD data only	Field surveyed streams	GIS mapped streams	NHD data only	Field surveyed streams	GIS mapped streams
Dixon	235	1.06	2.13	3.06	23.9	47.8	68.9
Jackson	359	1.73	3.74	5.02	25.5	55.1	73.8
Wiley	574	4.91	5.09	6.69	45.1	46.8	61.6

Benthic Macroinvertebrates

Dissolved oxygen was sufficient to support a healthy aquatic community in each of the three reference streams and no significant differences were found between the streams (Table 8). The pH at each of the three streams was relatively low indicating poorly buffered water with pH readings below the recommended level of 6 standard units (SU) recorded in each of the streams. Variability in pH was low within the watersheds. Differences in pH between the watersheds were statistically significant but still relatively small. Conductance was highest at the mouth of

Wiley Branch and was significantly higher in Wiley Branch sampling sites than in Dickson and Jackson Branches, which were similar.

Table 8. Average and range (in parentheses) of water quality characteristics of the three reference watersheds evaluated. Watersheds which are not statistically different are represented by the same number of *.

	Wiley Branch	**Dickson Branch**	**Jackson Branch**	**F or H Statistic**	**Probability of Significance**
Dissolved oxygen (mg/l)	7.46* (6.05-9.16)	7.36* (7.07-7.75)	7.14* (6.43-7.81)	0.1	0.91
pH (SU)	6.58* (6.2-6.84)	5.46** (5.17-5.71)	6.00*** (5.81-6.12)	22.93	$p<0.005$
Conductance (μS/cm)	72.92* (58.04-89.01)	26.42** (23.6-30.2)	26.68** (21.4-37.0)	30.2	$p<0.005$
Temperature (^{o}C)	17.32* (15.92-19.00)	13.28* (12.67-13.67)	14.99* (14.66-15.4)		

Although Wiley, Dickson, and Jackson Branches are all considered to be relatively uninfluenced by human activity, significant differences were found in habitat characteristics in the three watersheds. Wiley Branch consistently scored in the *Optimal* and *Sub-Optimal* habitat score ranges (Table 9). This stream scored lower on the Riffle Frequency metric with some distance between the optimal habitat zones in the stream. The farthest downstream sites on Jackson Branch also scored in the *Optimal* habitat range, however the farthest upstream site on this stream scored in the *Marginal* range. Only three sites were sampled on this stream due to the limited access to the mid-stream reaches. The farthest upstream site, JB-4, was accessed via a gas line right-of-way which may have contributed to the *Marginal* habitat score at this site. Metrics which indicated habitat problems at JB-4 included those associated with sediment deposition and embeddedness. Dixon Branch, located in the adjacent watershed in Twin Falls State Park, consistently scored in the *Marginal* range with substantial sediment deposition and interstitial embeddedness by fine particles, and poor substrate and channel integrity at all four of the sampling stations despite good bank vegetation and stability.

Dixon Branch habitat scored significantly lower than one or both of the other streams on five of the 10 habitat metric evaluated and was significantly lower than Jackson and Wiley Branches for the overall habitat score (Table 9). Metrics evaluating velocity to depth regime and available cover, and those representing channel deposition embeddedness, were significantly lower in Dixon Branch. Wiley Branch tended to score better than Jackson Branch for the Embeddedness and Sediment Deposition metrics while Jackson Branch had the highest rating for Channel Flow Status (Table 10).

Table 9. Habitat assessment scores for sampling sites on the three reference streams.

		Sampling Station										
		Wiley Branch				**Dixon Branch**				**Jackson Branch**		
Habitat Category/Parameter	**Max Score**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**4**
Epifaunal Substrate/ Available Cover	**20**	17	17	20	18	4	5	11	5	17	18	9
Embeddedness	**20**	19	19	19	18	11	5	5	4	15	15	9
Velocity/Depth Regime	**20**	15	16	15	17	9	6	6	7	16	19	10
Channel Alteration	**20**	15	20	20	19	12	17	18	19	19	20	15
Sediment Deposition	**20**	18	19	19	19	13	11	5	7	15	18	9
Riffle Frequency	**20**	10	19	19	5	4	6	5	6	17	18	10
Channel Flow Status	**20**	10	10	10	7	6	6	6	5	17	15	10
Bank Stability	**20**	8	18	15	18	16	6	4	4	16	13	8
Bank Vegetative Protection	**20**	10	16	18	16	18	18	18	20	18	16	16
Undisturbed Vegetative Zone	**20**	7	20	20	18	18	18	18	20	18	18	16
Total	**200**	129	174	175	155	111	98	96	97	168	170	112
Assessment category		***SO***	***O***	***O***	***SO***	***M***	***M***	***M***	***M***	***O***	***O***	***M***

Note: *O=Optimal*, *SO=Sub-Optimal*, *M=Marginal*

Table 10. Statistical comparisons of habitat parameters from the 3 reference streams. Test procedures included one way analysis of variance (Reported as F-value) and Kruskal-Wallis procedure (Reported by H-value) followed by multiple comparisons. Watersheds which are not statistically different are represented by the same number of *.

				Sampling Station		
Habitat Category/Parameter	**Test statistic**	**F or H Statistic**	**p value**	**Wiley Branch**	**Dixon Branch**	**Jackson Branch**
Epifaunal Substrate/Available Cover	F	13.6	p<0.005	**	*	**
Embeddedness	F	22.56	p<0.005	*	**	***
Velocity/Depth Regime	F	14.33	p<0.005	**	*	**
Channel Alteration	F	0.57	0.590			
Sediment Deposition	F	9.19	0.008	**	*	*,**
Riffle Frequency	F	4.32	0.053			
Channel Flow Status	F	13.93	p<0.005	*	**	***
Bank Stability	F	2.18	0.180			
Bank Vegetative Protection	H	2.35	0.160			
Undisturbed Vegetative Zone	H	0.33	0.720			
Overall Habitat Score	F	8.19	0.012	**	*	**

Habitat limitations were apparent in the benthic macroinvertebrate community of Dixon Branch with only two of the four sampling sites scoring in *Unimpaired* range of the WVSCI index (Table 11). The upstream site, DB-4, scored just below the cut-off of 68, in what is considered a "gray zone", while, just below it, DB-3 was considered *Impaired*. The "gray zone" is a scoring range where variability in the data can result in healthy communities being designated as *Impaired* so sites scoring in that range are not designated with a narrative description. The benthic community in Wiley Branch scored similarly, despite having much higher habitat scores. Two sites in Wiley Branch were *Unimpaired*, one site scored in the "gray zone" and one site demonstrated impairment. Jackson Branch was the only one of the reference streams which consistently scored in the *Unimpaired* range of the WVSCI.

Table 11. West Virginia Stream Condition Index (WVSCI) scores from sampling sites in the three reference watersheds.

Benthic Macroinvertebrate Metrics	**Sampling Station**										
	Wiley Branch				**Dixon Branch**				**Jackson Branch**		
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**4**
Abundance	166	150	115	155	151	150	150	175	60	143	167
Richness	12	13	17	22	17	22	14	15	16	23	20
Genus Richness	17	17	21	26	19	22	14	17	18	27	21
# EPT taxa	6	7	9	1	12	12	6	7	9	15	12
# EPT taxa -genus	8	7	10	13	13	12	6	7	10	17	12
% EPT	30.72	24.67	18.26	43.87	50.99	46.00	20.57	53.16	63.30	74.83	46.71
% 2 Dominant taxa	74.70	46.00	56.52	37.42	54.30	52.67	76.6	56.00	45.00	44.76	46.71
% Chironomidae	56.02	26.00	0.00	9.03	45.03	39.33	66.67	31.43	0.00	13.99	37.17
HBI	5.16	4.52	3.92	3.85	4.28	4.41	5.19	4.02	3.55	3.50	4.19
WVSCI	47.62	62.69	70.05	87.45	72.15	76.12	44.85	67.07	81.60	94.54	77.19

No significant differences were seen between the benthic communities at the three reference sites (Table 12). The percentage of EPT taxa was slightly higher in Jackson Branch compared to the other sights but the significance was marginal. Overall, the sites demonstrated substantial variability indicating that even streams receiving relatively little anthropogenic influences can demonstrate limitations. Evaluation of the variability in representative metrics indicated no relationship between benthic macroinvertebrate scores and habitat parameters. Regression evaluation of total habitat scores with WVSCI and genus level taxa richness, two sensitive metrics, indicated no relationship to the overall habitat scores (r^2=0.167, p=0.213 and r^2=0.148, p=0.243, respectively). Similarly, no relationship was demonstrated for the WVSCI score and genus level taxa richness with conductance, a water quality characteristic indicative of watershed disturbance (Dow and Zampella, 2000). Regression analysis of the macroinvertebrate metrics with stream conductance showed an r^2 value of 0.0065 (p=0.813) for the taxa richness genus metric and an r^2 of 0.138 (p=0.260) for the comparison of overall WVSCI with stream conductance.

Table 12. Statistical comparisons of benthic macroinvertebrate metrics from the three reference streams. Test procedures included one way analysis of variance (Reportd by an F-statistic) and Kruskal-Wallis procedure (Reported by an H-statistic) followed by multiple comparisons. Watersheds which are not statistically different are represented by the same number of *.

Macroinvertebrate Metric comparisons	Test Statistic	F or H Statistic Value	p value	Sampling Station		
				Wiley Branch	Dixon Branch	Jackson Branch
Abundance	F	0.94	0.43			
Richness	F					
Genus Richness	H	0.86	0.46			
# EPT taxa	F					
# EPT taxa -genus	F	1.5	0.47			
% EPT	H	5.8	0.055	*	*,**	**
% 2 Dominant taxa	H	3.39	0.18			
% Chironomidae	H	3.65	0.16			
HBI	F	1.86	0.28			
WVSCI	F	1.91	0.21			

A separate goal of the biological assessment was to evaluate the biological data with respect to specific landform features such as main channel slope, drainage density, channel characteristics, bed size particle distribution, and vegetative zones to determine whether associations and patterns exist between individual taxa or assemblages which may provide useful in predicting successful outcomes for design. With only three reference streams for use in the statistical analysis, implementation of this goal is not feasible; however, these data are the foundation of a dataset which can be further developed as the methods are further refined and implemented.

Alternative Valley Fill Designs

Channel design

For a given impacted area and drainage density, the channel length and dimensions were constant. Channel slopes varied among designs, impacting applied shear stress. When using the permitted area and low drainage density, channel length was 612 ft. Bankfull width increased from 0.3 ft at the channel head to 5.2 ft at the mouth of the watershed. Bankfull depth ranged from 0.03 ft to 0.52 ft. Within the permitted area and with high drainage density, channel length increased to 881 ft. Bankfull width increased from 0.89 ft at the channel head to 5.2 ft at the mouth of the watershed. Bankfull depth ranged from 0.09 ft to 0.52 ft. Peak flows for both drainage density cases were calculated as 12.0 cfs at bankfull and 32.5 cfs at flood prone. The channel length for the designs using the expanded impact area was 746 ft. Bankfull width and depth ranges were 0.35-5.90 ft and 0.3-0.59 ft, respectively. Peak discharges were 15.6 cfs at bankfull and 42.4 cfs at flood prone. Increasing the impact area resulted in a slightly larger channel due to higher peak flows. The storms used by Natural Regrade do not coincide with the WVDEP design requirement for drainage (100-yr, 24-hr storm). Because channels were designed using the rational method, the intensity of the 100-yr, 24-hr storm (0.22 in/hr) is lower than the intensity of the 50-yr, 6-hr storm (0.60 in/hr) (NOAA, 2013), however, the channel should be properly designed to meet the WVDEP regulations. Although the channel was designed by the software, it could be manually redesigned to accommodate any storm with minimal effect on the landform.

Varying drainage density

For both fills, the ratio of geomorphic design fill volume to conventional fill volume decreased as drainage density increased (Table 13, Fig. 12, Fig. 13). Increasing the stream length created less area in which fill could be placed. Designs 1-6 were the first designs completed with Natural Regrade and resulted in errors in the generation of geomorphic contours (e.g. drastic changes in slope at the boundary). Due to these errors, additional information on landform and channel stability was not recorded, but the relationship between fill volume and drainage density was evident. In all proceeding designs (excluding Design 13), the minimum acceptable drainage density value was used in order to maximize fill volume.

Table 13. Characteristics of landforms developed to investigate drainage density: DD (drainage density), ratio of design fill volume to conventional fill volume (V_{GLD}/V_{CV}). Three designs created for each valley fill: 1 and 2.

Design	Valley fill	DD (ft/ac)	V_{GLD}/V_{CV} (%)
1	1	48.2	83
2	1	60.8	73
3	1	74.8	66
4	2	48.3	77
5	2	60.7	63
6	2	72.4	49

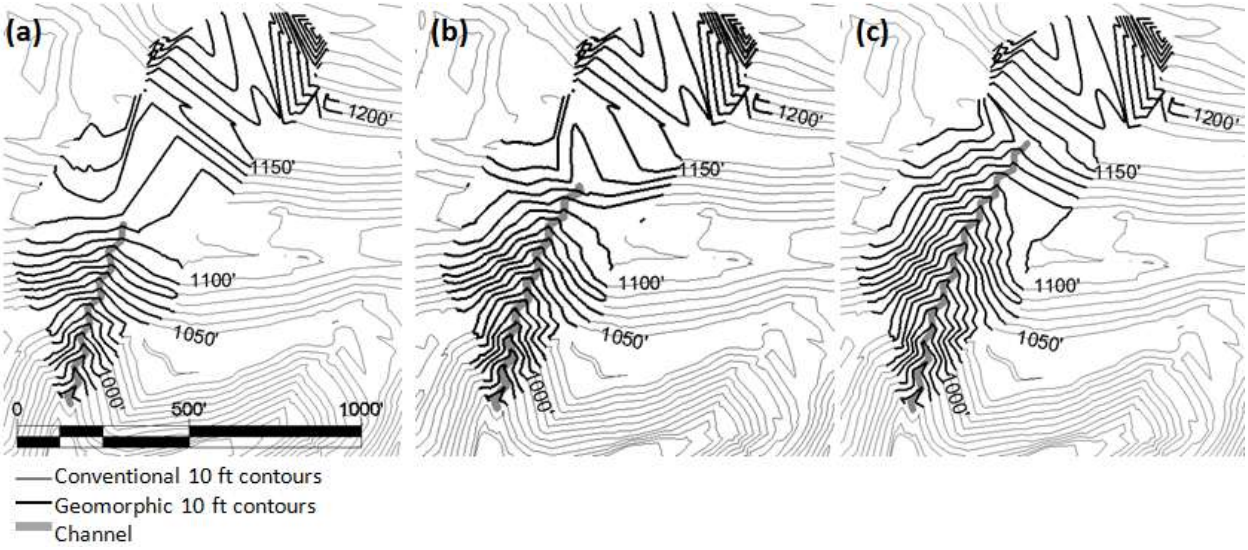


Figure 12. Geomorphic designs for VF1 with varying drainage density: (a) low drainage density (Design 1); (b) target drainage density (Design 2); (c) high drainage density (Design 3).

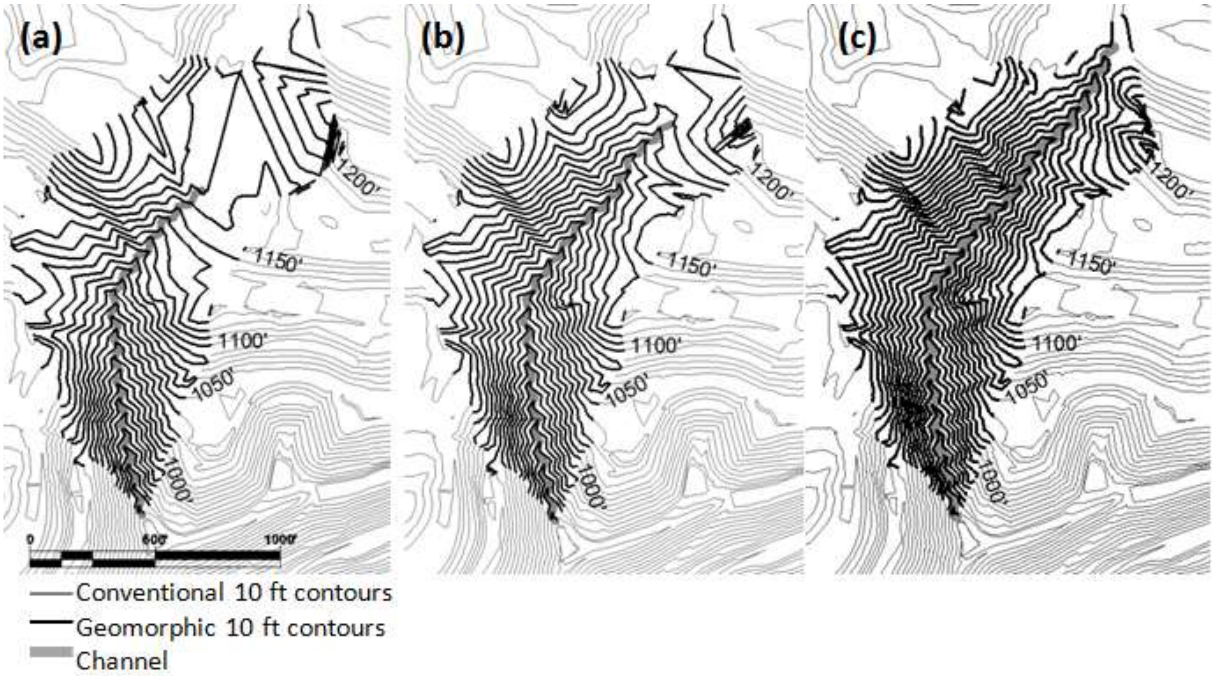


Figure 13. Geomorphic designs for VF2 with varying drainage density: (a) low drainage density (Design 4); (b) target drainage density (Design 5); (c) high drainage density (Design 6).

Maximizing channel stability

To maximize channel stability, the natural channel was preserved and a design was created for valley fills 1 and 2 (Table 14, Fig. 14, Fig. 15). The designed landforms were characterized by the channel profile following the existing topography to the channel head location, followed by a steep hillslope. Channel slopes remained moderate, and stream power remained low. The range in shear stress values suggest that bed material composed of cobble sized particles would result in a threshold channel. While the channels are likely stable, a substantial portion of hillslopes were greater than the 50% grade (2:1) threshold for stability, suggesting that these portions would not meet the WVDEP factor of safety. These steep hillslopes were due to the large elevation differences between the channel and watershed boundary (landform relief of 256 ft and 245 ft for VF1 and VF2, respectively). These steep hillslopes would be difficult to both construct and maintain. Issues with hillslope stability and fill volume suggest that these designs are impractical.

Table 14. Characteristics of landforms developed to maximize channel stability: range in channel slopes (S_c), maximum shear stress (τ_{max}: at bankfull flow; at floodprone flow), percent of unstable hillslopes by area (>50%) (P_{HS}), ratio of design fill volume to conventional fill volume (V_{GLD}/V_{CV}). One design created for each valley fill, 1 and 2.

Design	Valley fill	S_C (%)	τ_{max} (psf)	P_{HS} (%)	V_{GLD}/V_{CV} (%)
7	1	6.7-12	2.84; 3.67	33	65
8	2	6.7-12	4.09; 5.28	26	53

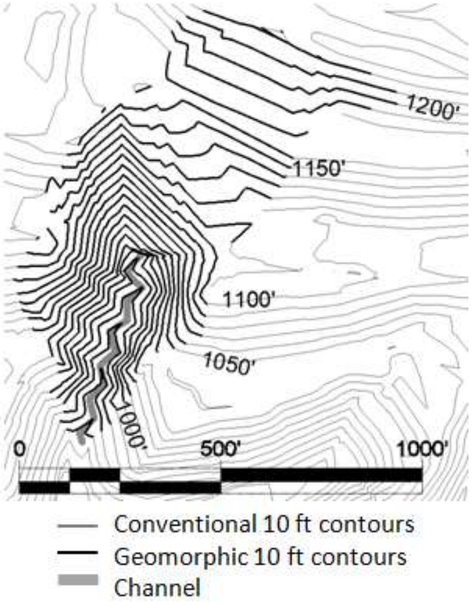


Figure 14. Geomorphic design for VF1 in permitted area with maximum channel stability (Design 7).

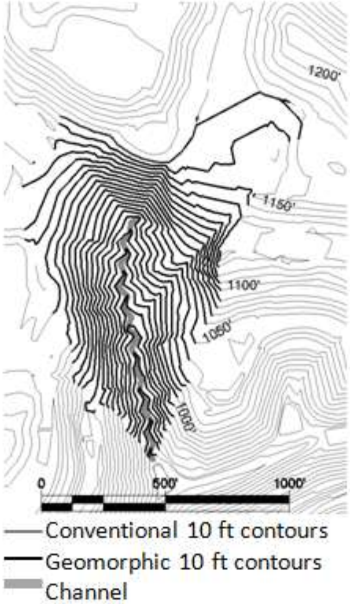


Figure 15. Geomorphic design for VF2 in permitted area with maximum channel stability (Design 8).

Maximizing fill volume and hillslope stability

Designs 9 and 10 maximized fill volume and hillslope stability for valley fills 1 and 2 (Table 15, Fig. 16, Fig. 17). VF1 met fill volume requirements and VF2 was closer to the requirements than when channel stability was maximized. Although hillslope stability was maximized, potentially unstable slopes remain and would have to be corrected independently of the design software to a lower grade. While any steep slopes would need to be mitigated, the area was a small portion of the total design. Manually correcting slopes, however, may create a design that does not follow the geomorphic landform design principles. While meeting volume and landform stability goals, this reclamation design failed in channel stability requirements. The large elevation change from the channel head to channel mouth (166 ft for VF1, 224 ft for VF2) resulted in steep channel slopes (e.g. VF1 valley slope = 33%; Channel slope >30% for approximately 52% of the channel length; maximum slope = 35%). These increased slopes elevated stream power such that applied shear stresses were too high to result in practical bed particle sizes. Despite the high level of landform stability and increased fill volume, the lack of channel stability made these designs impractical.

Table 15. Characteristics of landforms developed to maximize fill volume and hillslope stability: range in channel slopes (S_c), maximum shear stress (τ_{max}: at bankfull flow; at floodprone flow), percent of unstable hillslopes (>50%) (P_{HS}), ratio of design fill volume to conventional fill volume (V_{GLD}/V_{CV}). One design created for each valley fill, 1 and 2.

Design	Valley fill	S_C (%)	τ_{max} (psf)	P_{HS} (%)	V_{GLD}/V_{CV} (%)
9	1	9.7-35	8.24; 10.64	6.1	99
10	2	8.5-24	8.09; 10.45	4.4	85

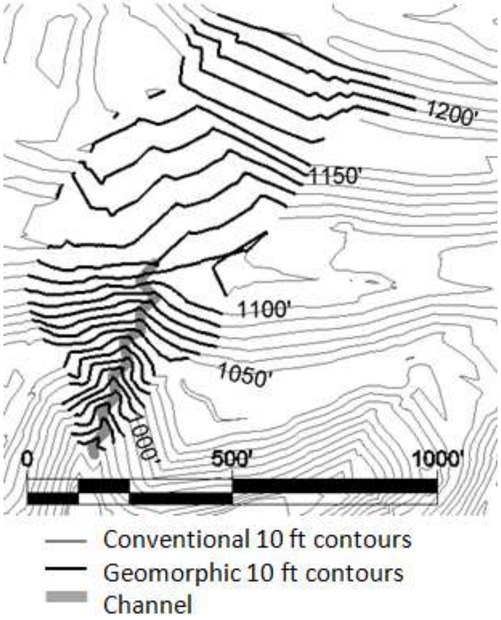


Figure 16. Geomorphic design for VF1 in permitted area with maximum fill volume (Design 9).

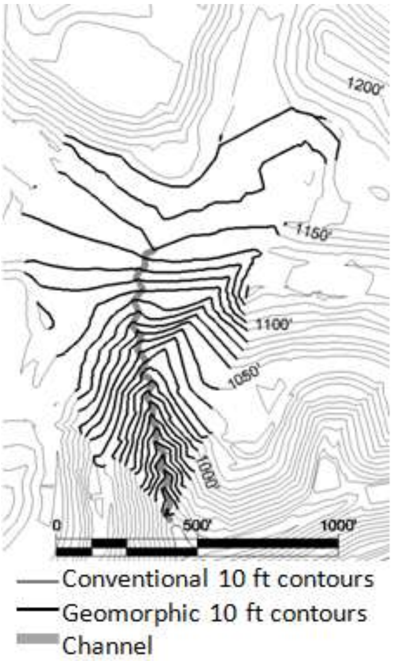


Figure 17. Geomorphic design for VF2 in permitted area with maximum fill volume (Design 10).

Trade-off between channel and landform stability

Designs 11, 12, and 13 had varying levels of channel stability and landform stability (Table 16, Fig. 18, Fig. 19, Fig. 20). Designs were completed for VF1 because it was closer than VF2 to meeting stability and fill volume requirements in previous designs.

Table 16. Characteristics of landforms developed to compromise stability and fill volume for VF1: range in channel slopes (S_c), maximum shear stress (τ_{max}: at bankfull flow; at floodprone flow), percent of unstable hillslopes (>50%) (P_{HS}), ratio of design fill volume to conventional fill volume (V_{GLD}/V_{CV}). BF=bankfull, FP=floodprone, DD=drainage density. Designs were completed for three cases of channel stability.

Design	Channel	S_C (%)	τ_{max} (psf)	P_{HS} (%)	V_{GLD}/V_{CV} (%)
11	Stable at BF	8.6-18	4.30; 5.56	14	78
12	Stable at FP	8.0-14	3.33; 4.30	21	72
13	Stable at FP with high DD	8.2-13	3.33; 4.30	39	54

Design 11 created a stable channel under bankfull flow conditions while considering overall landform stability (Fig.18). The channel was more stable than Design 9 but less stable than the Design 7. Calculated bankfull shear stresses suggest that cobbles could resist motion. The applied shear stress at flood prone discharge (maximum of 5.56 psf) required bed particle sizes of larger than cobble to resist motion (maximum median bed particle size of 13 in) for 46% of the channel length. For this design to be feasible, manual stabilizing measures would be needed on some slopes and along portions of the channel. The difference in fill volume would need to be accounted for in another portion of the reclamation. The occurrence of stable hill slopes did increase as compared to Design 7.

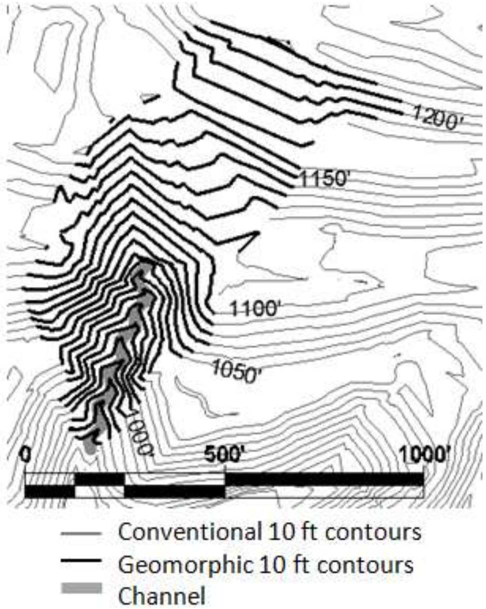


Figure 18. Geomorphic design for VF1 in permitted area with stable channel at bankfull flow (Design 11).

Design 12 created a stable channel under both bankfull and flood prone flow conditions (Fig.19). Calculated shear stresses suggest that cobbles could resist motion at both bankfull and flood prone flows. To reach this level of channel stability, the channel head elevation was reduced an additional 18.5 ft from the Design 11. Landform stability, however, was compromised to reach this desired level of channel stability, with a higher percentage of hillslopes being above the 50%

threshold for stability. These potentially unstable gradients were located towards the middle of the longitudinal profile of hillslopes contributing to the main channel (at the transition point from concave to convex slope profiles) (Fig. 26c). Above the slope increase at the head of the channel, slopes were lower and more closely resembled the conventional reclamation (Fig.26b). Unstable slopes and low fill volumes suggest that landform stability and material volumes are limiting factors in reaching a high level of channel stability. As was the case with the previous design, significant work involving excess material placement and stabilizing hillslopes would be required for this design to be feasible.

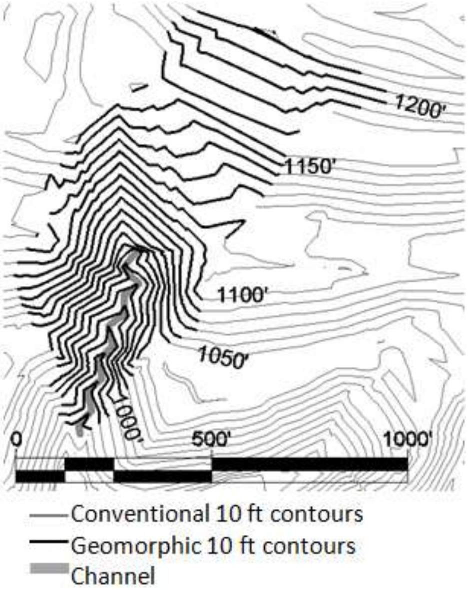


Figure 19. Geomorphic design for VF1 in permitted area with stable channel at flood prone flow (Design 12).

When drainage density was increased and the same channel stability requirements were held (Design 13, Fig. 20), hillslopes became more unstable and more fill volume was compromised. This design confirms that using a low drainage density value provides the most promise in meeting stability and fill volume requirements.

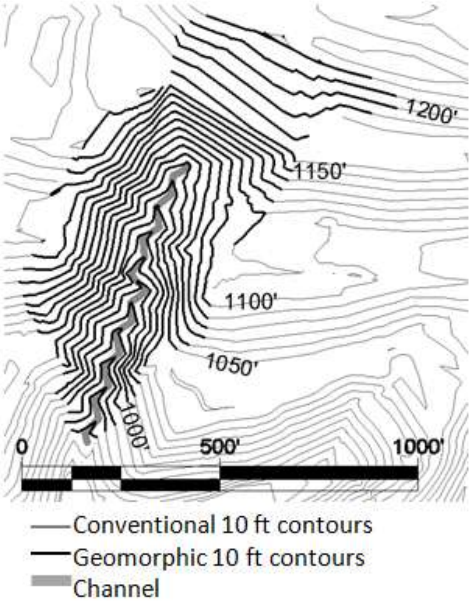


Figure 20. Geomorphic design for VF1 in permitted area with stable channel at flood prone and high drainage density (Design 13).

Expanding impact area

Varying levels of channel stability, landform stability, and fill volume were reached when expanding the impacted area of the fill (Table 17, Fig. 21, Fig. 22, Fig. 23).

Table 17. Characteristics of landforms developed with an expanded impact area for VF1: range in channel slopes (S_c), maximum shear stress (τ_{max}: at bankfull flow; at floodprone flow), percent of unstable hillslopes (>50%) (P_{HS}), ratio of design fill volume to conventional fill volume (V_{GLD}/V_{CV}). BF=bankfull, FP=floodprone. Designs were completed for three cases of channel stability.

Design	Channel	S_C (%)	τ_{max} (psf)	P_{HS} (%)	V_{GLD}/V_{CV} (%)
14	Preserved	6.7-12	3.25; 4.19	27	79
15	Stable at BF	8.2-24	4.33; 5.60	9	114
16	Stable at FP	8.2-12	3.35; 4.32	17	102

Extending the toe of the valley fill created a 31% increase in impacted area to 13.2 ac. (Fig. 21). When the impacted area was expanded and the existing stream was preserved (Design 14, Fig. 22), hillslopes were not as steep as the preserved channel design for the permitted area (Design 7). The risk of landform instability, however, was still evident. The most common slope range was 10-20% grade, but a large portion of hillslopes were distributed in higher slope ranges (e.g. 18% of slopes from 40-50% grade; 15% of slopes from 50-60% grade). The channel was stable; the required mean bed particle size was not larger than cobble for any point in the channel. Fill volume requirements were not met. Despite expanding the impacted area of the fill, a geomorphic design attempting to preserve the existing channel was not feasible.

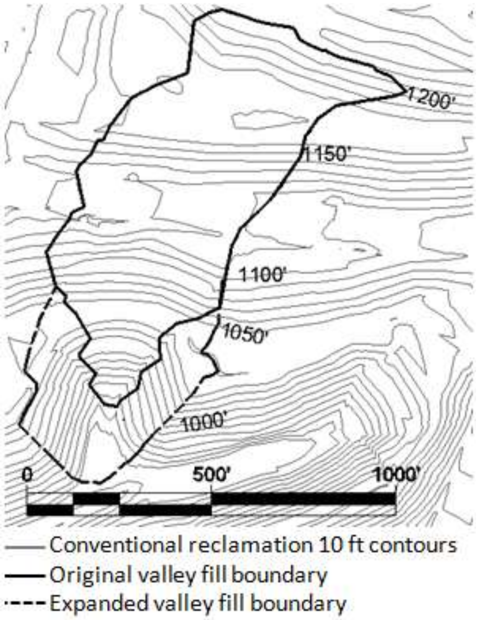


Figure 21. Expanded impacted area of valley fill compared to original valley fill footprint.

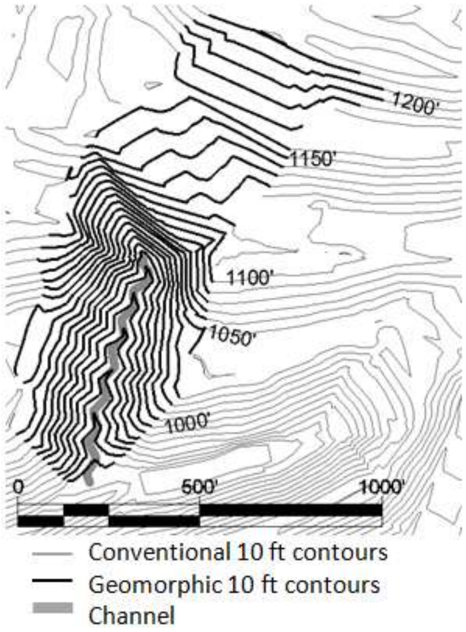


Figure 22. Geomorphic design for VF1 in expanded area with preserved channel and maximum channel stability (Design 14).

If channel stability at bankfull flow was targeted with an expanded impact area (Design 15, Fig. 23), target fill volume was met. As was the case for the designs within the permitted area, this design had more stable hillslopes than the preserved channel design, but potentially unstable slopes still existed. The channel slopes in this design were higher than the slopes in the stable bankfull channel design for the permitted area (Design 11), with portions of the channel requiring larger than cobble median bed particle sizes at flood prone discharge (maximum required median bed particle size of 13 in). For the design to be feasible, additional stabilizing measures would be required for 61% of the channel length and for the portion of slopes above

50% grade. A potentially feasible design, however, would not meet the regulations with respect to impact area.

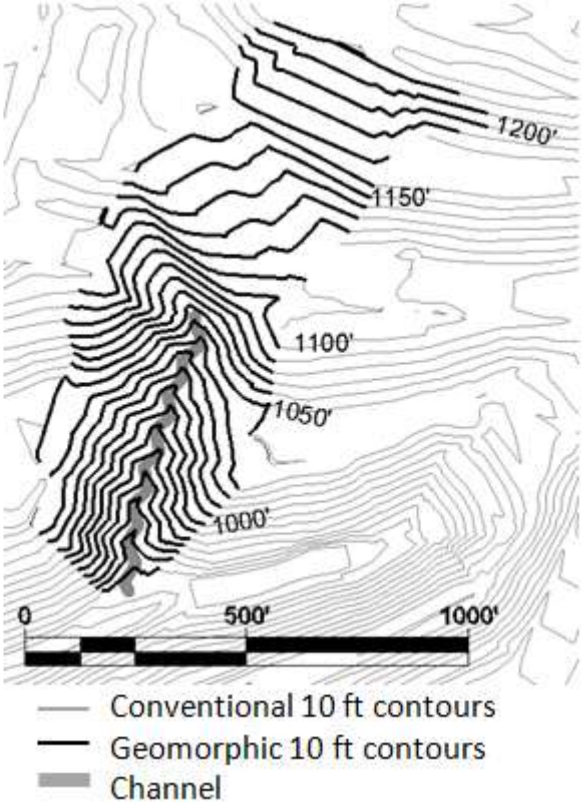


Figure 23. Geomorphic design for VF1 in expanded area with stable channel at bankfull flow (Design 15).

For Design 16 (Fig. 24), fill volume and channel stability requirements were met. To reach this level of channel stability, the channel head elevation was lowered an additional 41 ft from the previous design. The higher flows associated with the increased impacted area required decreasing the elevation of the channel head substantially to ensure full channel stability. Calculated shear stresses suggest that cobbles could resist motion at both bankfull and flood prone flows. Landform stability, however, was compromised to reach this desired level of channel stability, with a greater percentage of slopes exceeding the 50% threshold. Hillslope distribution was similar to the fully stable channel design in the permitted area (Fig. 26d). As was the case with the previous design, this design does not comply with area of impact regulations, and a significant work involving stabilizing hillslopes would be required for this design to be possible.

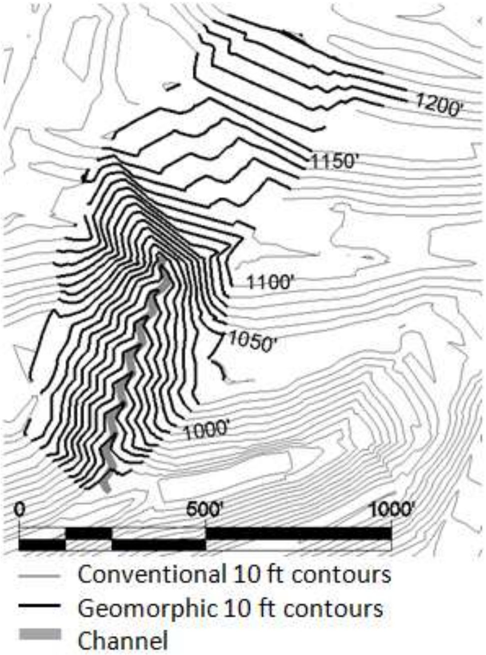


Figure 24. Geomorphic design for VF1 in expanded area with stable channel at flood prone flow (Design 16).

Using default input values

Using the design software's default input values resulted in a design with the same issues with respect to stability and fill volume requirements (Table 18, Fig. 25). Increased drainage density and decreased drainage length resulted in more stream length, lower fill volume, and less stable slopes. Because the drainage lengths are an order of magnitude less than the field-measured reference values, the landform is likely not in erosive equilibrium. The design created a more undulating surface with more ridges/valleys than the geomorphic designs using site-specific parameters, and it did not accurately recreate the drainage pattern of the original topography. The generated stream was longer, more meandering at the mouth, and steeper at the mouth. These stream features would not connect well with the existing valley at the toe of the fill. This design reinforces that using site-specific design criteria is necessary for accurate geomorphic reclamation.

Table 18. Characteristics of landforms developed using default software parameters for VF1: range in channel slopes (S_c), maximum shear stress (τ_b: at bankfull flow; at floodprone flow), percent of unstable hillslopes (>50%) (P_{HS}), ratio of design fill volume to conventional fill volume (V_{GLD}/V_{CV}).

Design	S_C (%)	τ_b (psf)	P_{HS} (%)	V_{GLD}/V_{CV} (%)
17	2.1-25	6.02; 7.77	22	60

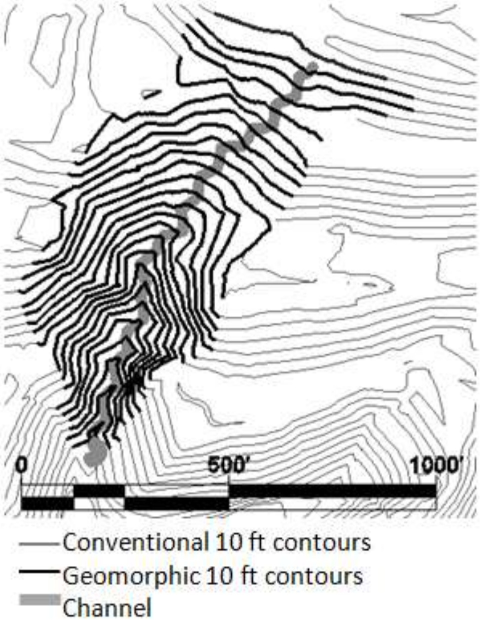


Figure 25. Geomorphic design for VF1 using software's default input values (Design 17).

Slope stability analysis

Slope stability analyses were performed on designs 11 (permitted area, stable channel at bankfull flow), 12 (permitted area, stable channel at floodprone flow), 15 (expanded area, stable channel at bankfull flow), and 16 (expanded area, stable channel at floodprone flow), as they were the designs for each area of impact that were closest to satisfying the criteria of fill volume, landform stability, and channel stability. The slopes above 50% grade were investigated to assess each design's critical areas of instability (Table 19).

Table 19. Distribution of slope ranges between 50-60% grade and minimum Factor of Safety for critical slope profile of each design.

Slope range (%)	**Coverage by area (%)**			
	11	12	15	16
50-52	2.2	3	2	2.9
52-54	1.9	3.3	1.9	2.5
54-56	1.5	2.1	1.9	1.9
56-58	1.6	1.9	1.2	1.3
58-60	1.6	1.5	1	1.3
>60	4.9	9.1	1.4	7.6
FS	1.02	0.93	1.46	1.40

For the designs with stable channels at bankfull conditions (11 and 15), the majority of potentially unstable slopes fell below 60% grade. For the slopes between 50% and 60% grade, a higher percentage of slopes were distributed closer to 50%, which is promising when investigating manual correction of steep slopes. For the designs with completely stable channels (12 and 16), a higher percentage of slopes were above 60% gradient, posing a greater risk for instability and increasing the difficulty in manually correcting unstable areas. The steepest longitudinal profile for each design was analyzed with a two-dimensional finite element slope stability model. Each profile had variable slope longitudinally and was modeled with no piezometric surface. Failure planes were generated for shallow failures at the steepest portion of the profile and for deep failures along the entire profile. The same strength parameters were used as in the initial slope stability analysis ($\phi=40^\circ$, c=0 psf, $\gamma=129.7$ pcf). For these critical profiles, all designs had a factor of safety against failure below the WVDEP standard of 1.5 (Table 19). This was consistent with the findings of the initial stability analysis on the mine spoil. Designs with an expanded area of impact were closer to reaching the design standard factor of safety than designs in the permitted area. Expanding the area of impact appears to be necessary, but not necessarily sufficient, to produce a stable and constructible geomorphic design. If the slopes above 50% grade can be shown to be stable, however, they still do not comply with the WVDEP regulations for maximum slope (2:1) (WVDEP, 1999). The problem may be solvable through manual adjustments to the design.

Application of GLD in Central Appalachia

If all designs are judged according to the criteria of fill volume, landform stability, and channel stability, it is apparent that compromises must be considered for application of this technique in steep terrain and that landform stability is a limiting factor (Table 20). This was consistent with the potential issues documented by Michael et al. (2010). Met, not met, and moderately met are defined for each criteria as follows:

- Fill volume (as a percentage of conventional fill volume)
    - Met: 100%
    - Moderately met: 70-100%
    - Not met: <70%
- Landform stability (as percentage of hillslopes by area above 50% grade)

    - Met: 0%
    - Moderately met: >0% and ≤20%
    - Not met: >20%
- Channel stability
    - Met: Stable at both bankfull and flood prone flows
    - Moderately met: Stable at bankfull flow but not flood prone flow
    - Not met: Not stable at bankfull flow

Table 20. Analysis of design criteria for geomorphic designs for VF1.

Design case	Fill volume	Landform stability	Channel stability
7	x	x	√
9	√	+	x
11	+	+	+
12	+	x	√
13	x	x	√
14	+	x	√
15	√	+	+
16	√	+	√

x	Criteria not met
+	Criteria moderately met
√	Criteria met

The following findings were made from the designs in the permitted area:

- Target fill volume was reached with a moderate level of landform stability but with low channel stability (impractical bed particle size).
- If channel stability was ensured, landform stability and/or fill volume requirements could not be reached.
- A moderate level of all criteria could be met simultaneously with one design. This design, however, had critical unstable slope profiles; and would require manual adjustment to some slopes and stabilizing measures to the channel.
- A design could not be completed in the permitted area that met all three criteria.
- The issues associated with the designs in the permitted area suggest that expanding the impact area of the fill is necessary, but not necessarily sufficient, in meeting the criteria.

The following findings were made from the designs if the impacted area was expanded:

- Target fill volume was reached with moderate landform stability and full channel stability. The critical slopes were shown to be stable (FS >1), but they did not comply with existing reclamation standards of FS ≥ 1.5 and slope ≤ 2:1.
- To alter the design so that hillslopes meet regulations, additional stabilizing measures for the channel must be employed.

- Expanding the impact area resulted in improved conformance with the criteria, but still did not completely comply with the regulations governing excess spoil placement and created additional stream burial .
- The results are specific to the location in which designs were produced. However, it is possible that a design for a different site could completely meet the criteria if the available area of impact is sufficiently large.
- Aesthetically, the geomorphic designs created a more natural looking landform in comparison to the conventional designs, but not a landform that accurately recreated that original valley. The geomorphic designs had more variations in slope gradient than the pre-mined topography. Designing landform that more closely mirrors the original topography may be possible following a more comprehensive analysis of the geomorphic properties of mature landforms in Central Appalachia.

An additional cause of the issues associated with implementing GLD in Central Appalachia that has not yet been documented is the difference in mining and reclamation strategies between Central Appalachia and regions where GLD has been successful (particularly the southwestern U.S.). In the Southwest, surface coal mines are typically open pit mines. For a given area, the surface is excavated to the coal seam, the coal is extracted, and the overburden is placed back into the excavated area. Reclaiming within the mined area allows for accurate recreation of the pre-mined topography and drainage network, which typically involves gentler slopes and multiple channels contributing to one drainage point. In Central Appalachia, however, mountaintop mining involves mining in one area, and incorporating reclamation in additional, undisturbed valleys. The pre-mined topography of the mined area typically consists of a mountaintop draining in multiple directions, while the undisturbed valley exhibits a pre-reclaimed topography draining to one point, often with only one channel. The drainage network and pre-mined topography cannot be recreated in the same location as mining, and the original topography of the undisturbed valley cannot be recreated because it is being filled to a higher elevation. For these reasons, a geomorphic reclamation can more accurately recreate the pre-mined topography in mining regions such as the Southwest than it can in Central Appalachia.

Additional issues have been documented (Michael et al., 2010) that were not addressed in this study and would have to be addressed before implementing geomorphic design principles in Central Appalachia. Aspects of geomorphic reclamation do not coincide with methods allowable under the Federal Surface Mining Control and Reclamation Act regulations which result in broad plateaus, lack of curvilinear shapes, and steep drainage control systems. Cost increases in initial construction have not been quantified and could discourage industry collaboration. Also, more complex and time-consuming earthwork could delay reclamation completion and would require additional training for operators.

Ecological benefits of geomorphic designs will likely result from re-created stream length. The pre-mined topography had 951 ft of intermittent stream length that was being buried and not recreated by the conventional construction of the fill. The geomorphic reclamation within the permitted area with a stable channel, however, created 612 ft of new stream length (i.e., net loss of 339 ft). A net gain in stream length was not possible without exceeding the acceptable drainage density range. The design with highest acceptable DD still only had 874 ft of new stream length, resulting in a net loss of 41 ft. Similarly, 1300 ft of stream length was buried in the expanded area, and 746 ft of new stream length was generated (i.e., net loss of 554 ft). Created headwater channels can provide essential ecological services that are otherwise lost in conventional reclamation. Benefits provided by headwater channels include transporting sediment (Milliman and Syvitski, 1992), processing nutrients (Freeman et al., 2007), and providing habitat diversity (Meyer and Wallace, 2001; Gomi et al., 2002). The amount of stream length generated by a geomorphic fill could be increased by increasing the drainage density of the design to the target drainage density, albeit at the potential cost of reduced fill volume and landform stability.

As compared to the conventional design, the proposed geomorphic designs better recreated the pre-mined topography. Slopes of the pre-mined topography ranged from shallow slopes along the longitudinal profile of the channel to steep slopes in the areas contributing to the channel (Fig 26a). This slope distribution was mimicked by the geomorphic designs (Fig. 26c and 26d), while the slopes of the conventional reclamation were uniform along the face and shallow/flat above the crest (Fig. 26b). The pre-mined topography exhibited stable slopes that were steeper than could be achieved in geomorphic designs due to more mature vegetation and more sound rock than that associated with reclaimed landforms. More variability in the slopes of the geomorphic designs could be obtained by increasing the drainage density to create more ridges and valleys contributing to the main channel; but, the amount of fill volume and landform stability would again be compromised.

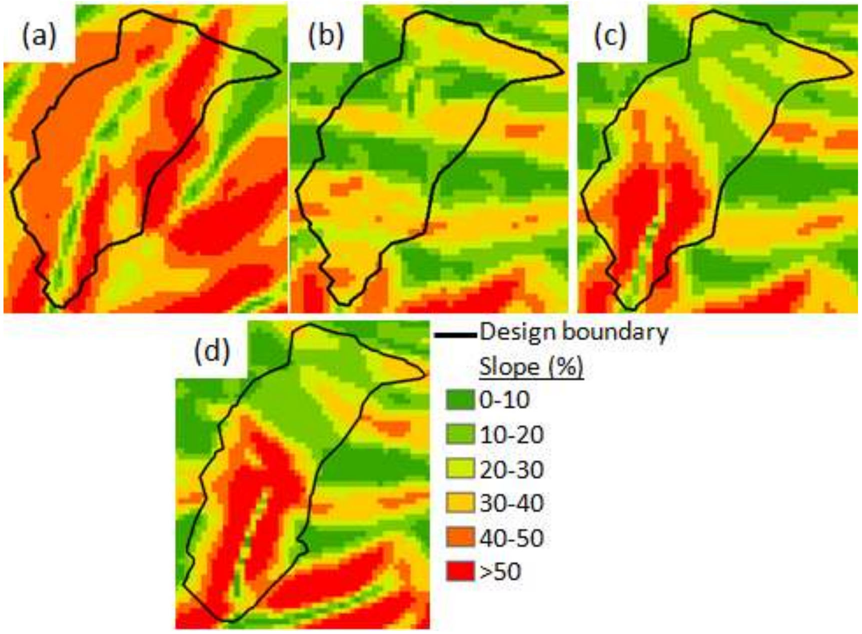


Figure 26. Slope distribution of (a) pre-mined topography; (b) conventional reclamation; (c) geomorphic design 12; (d) geomorphic design 16.

For the pre-mined topography, slope aspect was approximately evenly split between south/southeast on one side of the valley and west/northwest on the opposite side of the valley (Fig. 27a). The channel flowed southwest. This distribution was similar to the aspect distributions of the geomorphic designs (Fig. 27c and 27d); the two sides of the contributing valley faced in mirrored directions. The area above the channel head faced in the same direction as the channel. Aspect variability supports variation in vegetation, an important factor in habitat diversity. As with slope, the variability in the distribution of aspect for the geomorphic designs could even more closely resemble the original topography if the length of the stream was increased. The aspect of the conventional fill lacked variability, with the majority of slopes facing south (Fig 27b).

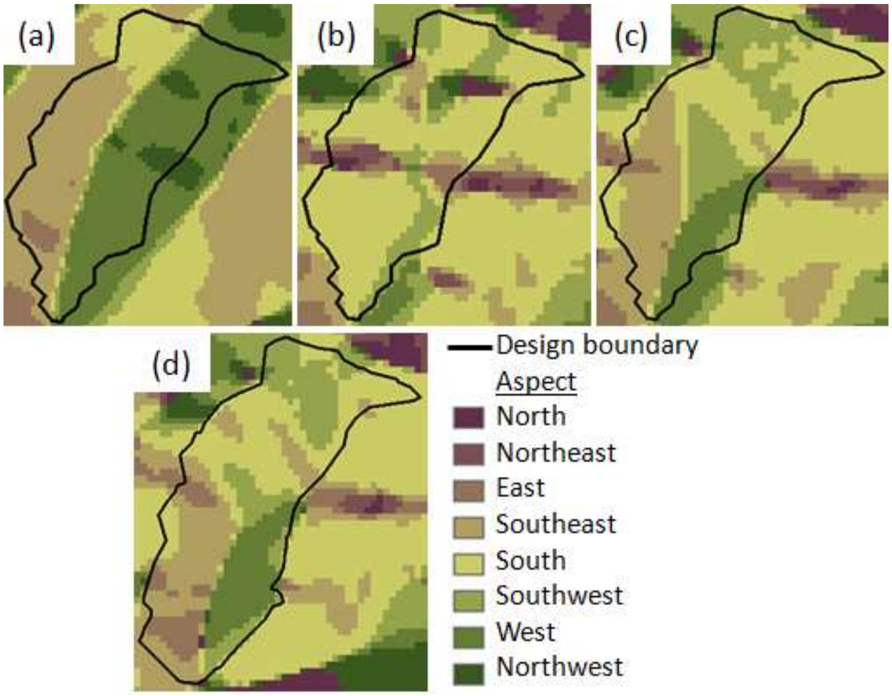


Figure 27. Aspect distribution of (a) pre-mined topography; (b) conventional reclamation; (c) geomorphic design 12; (d) geomorphic design 16.

Additional potential benefits to geomorphic reclamation not investigated in this study are lower erosion rates (Bugosh, 2009), improved management of surface water and groundwater, and enhanced downstream water quality through improved contaminant transport from mine spoil. The effect of geomorphic reclamation on groundwater and contaminant transport, as compared to conventional reclamation in Central Appalachia, would have to be quantified in future studies.

Potential design features

In this work, designs were created for valley fills less than 20 acres in area. Smaller areas were targeted because the location for the first demonstration of GLD application to valley fill construction would likely be small as well. Several design features were not evaluated in this work, because the size, shape, and elevation differences of the fills did not support additional features. These features included multiple channel network and storage ponds. In larger fills, the design might include multiple sub-basins as long as the sub-basin topography blends in with the surrounding terrain. Ponds may be utilized in larger fills to provide surface storage, provided that fill stability concerns are not exacerbated by seepage into the spoil substrate.

CONCLUSIONS AND RECOMMENDATIONS

The objective of this study was to quantify the issues that have been documented with respect to implementing geomorphic design principles in Central Appalachia valley fill reclamation. A series of geomorphic designs have confirmed that the issues associated with the steep slope topography, stability, and stream mitigation are valid, especially if minimizing the area of impact is a priority. The following conclusions are made from this study:

- Geomorphic properties of landforms in Central Appalachia are different than the properties in the southwestern U.S., where geomorphic reclamation has been successful. In Central Appalachia, drainage lengths are longer and drainage density is lower due to differences in vegetation, soil types, and precipitation.
- Benthic macroinvertebrate data are available for future comparisons when geomorphic landform designs are implemented. The three reference stream reaches showed substantial variability in habitat conditions and benthic macroinvertebrate community structure within and between each watershed.
- The stream of the pre-mined topography could not be preserved with geomorphic reclamation due to unstable slopes around the channel.
- Geomorphic reclamation in Central Appalachia can likely mitigate the burial of a pre-existing channel by re-creating a stable channel on spoil at a slightly higher elevation.
- When the area of impact of the conventional reclamation was maintained, a geomorphic design could not meet the requirements of channel stability, landform stability, and fill volume simultaneously for the locations studied.
- Expanding the area of impact of the fill resulted in a landform that better satisfied the three criteria for a successful geomorphic design, but the design still did not completely comply with regulations governing excess spoil placement.
- Creating a geomorphic landform out of an excess spoil fill in Central Appalachia, in which a large volume of spoil is placed in a valley downslope from the mined area, cannot mirror pre-mined topography. This is in contrast to the southwestern U.S. due to environmental factors (e.g. differences in topography) and mining/reclamation methods.
- Potential benefits of geomorphic designs include increased variability in slope gradient and aspect, newly generated stream length, decreased erosion, and improved management of surface water, groundwater, and mine spoil contaminants.

This work quantified challenges related to applying geomorphic landform design to valley fills in Central Appalachia. The design method utilized in this study could be applied to additional valleys throughout the region to determine how to simultaneously meet the fill volume, slope stability, and channel stability criteria. Future work should include field experiments to confirm the input parameter drainage length, and channel design should be addressed. Modeling studies should address groundwater flow, contaminant transport, and hydrologic response. Ultimately, a pilot study is needed to address constructability issues.

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APPENDIX A: REFERENCE LANDFORM SELECTION

A decision procedure was developed to select reference landforms comprised of four phases (Figure 28). The two major landform categories, mature landforms and long-term valley fill reclaimed sites, were under consideration. While the decision procedure was the same for both types of sites, the evaluation tools varied to match the needs of the specific landform. First the region was evaluated at a landscape scale. Then, the region was evaluated at the single watershed scale (1 km^2) to make a final decision on which watersheds from which field data would be collected.

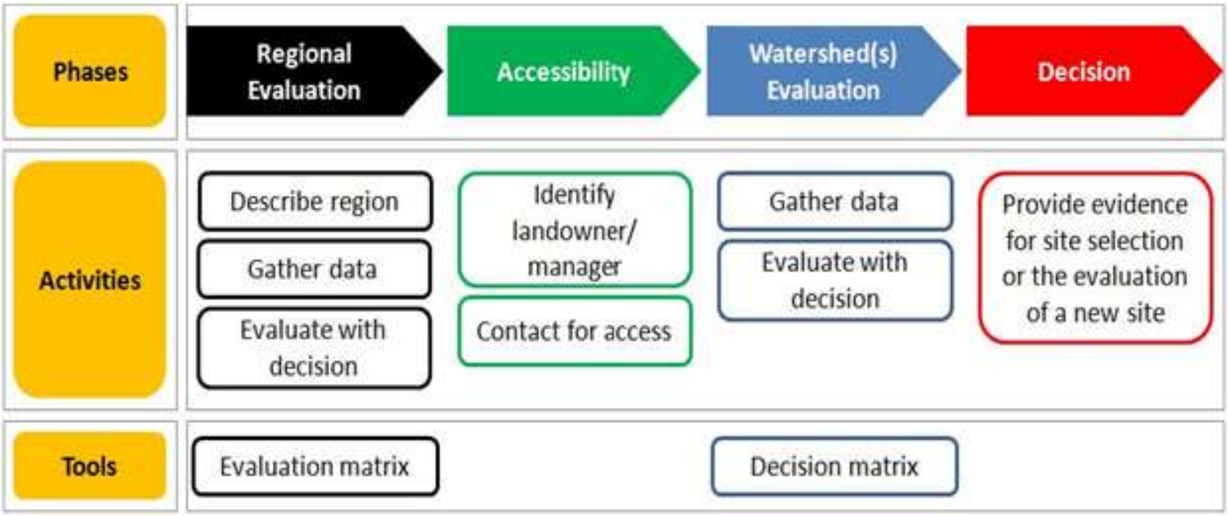


Figure 28. Evaluation procedure guiding field site selection.

Mature landforms

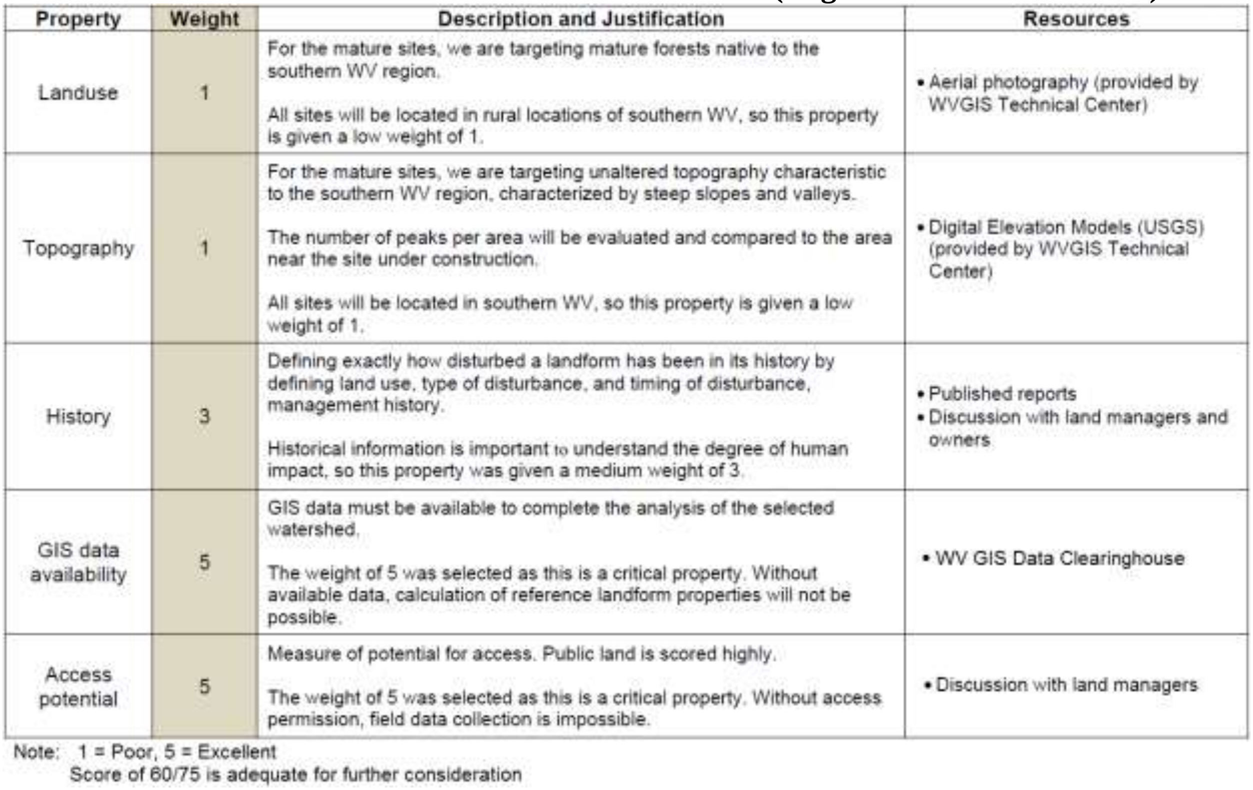
An evaluation matrix was developed to analyze potential field site locations for mature reference landforms at the regional scale by assigning varying weights to landform properties of varying importance (Table 21). Properties included in the evaluation were landuse, topography, history, GIS data availability, and access potential. A score of 60 out of a possible 75 points was required in the Regional Evaluation to proceed to the Watershed Evaluation. The threshold score was taken from scoring 80% (4 out of 5) on each property. As this assessment of landform evaluation has not been performed before, 80% was decided upon as a starting point threshold value. This 80% threshold was used for all evaluation matrices for mature landforms, at both the regional and watershed scale.

Next, a decision matrix was developed to analyze reference landform potential of specific watersheds within regions with adequate scores from the Regional Evaluation. Properties included in the evaluation were accessibility, watershed size, streams/channels, vegetation, and history (Table 22). A score of 84 out of a possible 105 points was required in the Watershed Evaluation Phase to proceed to the field data collection.

The regional (Tables 23-28) and watershed (Tables 29-31) evaluations for the potential field data collection locations are presented in the following tables. Locations that passed the Regional

Evaluation Phase were Twin Falls State Park, Cabwaylingo State Forest, East Lynn Lake Wildlife Management Area, Laurel Lake Wildlife Management Area, and R.D. Bailey Lake. Ultimately, Jackson and Dixon watersheds at Twin Falls State Park and Wiley watershed at Cabwaylingo State Forest were selected for field data collection.

Table 21. Evaluation matrix for mature landforms (Regional Evaluation Phase).



Property	Weight	Description and Justification	Resources
Landuse	1	For the mature sites, we are targeting mature forests native to the southern WV region. All sites will be located in rural locations of southern WV, so this property is given a low weight of 1.	• Aerial photography (provided by WVGIS Technical Center)
Topography	1	For the mature sites, we are targeting unaltered topography characteristic to the southern WV region, characterized by steep slopes and valleys. The number of peaks per area will be evaluated and compared to the area near the site under construction. All sites will be located in southern WV, so this property is given a low weight of 1.	• Digital Elevation Models (USGS) (provided by WVGIS Technical Center)
History	3	Defining exactly how disturbed a landform has been in its history by defining land use, type of disturbance, and timing of disturbance, management history. Historical information is important to understand the degree of human impact, so this property was given a medium weight of 3.	• Published reports • Discussion with land managers and owners
GIS data availability	5	GIS data must be available to complete the analysis of the selected watershed. The weight of 5 was selected as this is a critical property. Without available data, calculation of reference landform properties will not be possible.	• WV GIS Data Clearinghouse
Access potential	5	Measure of potential for access. Public land is scored highly. The weight of 5 was selected as this is a critical property. Without access permission, field data collection is impossible.	• Discussion with land managers

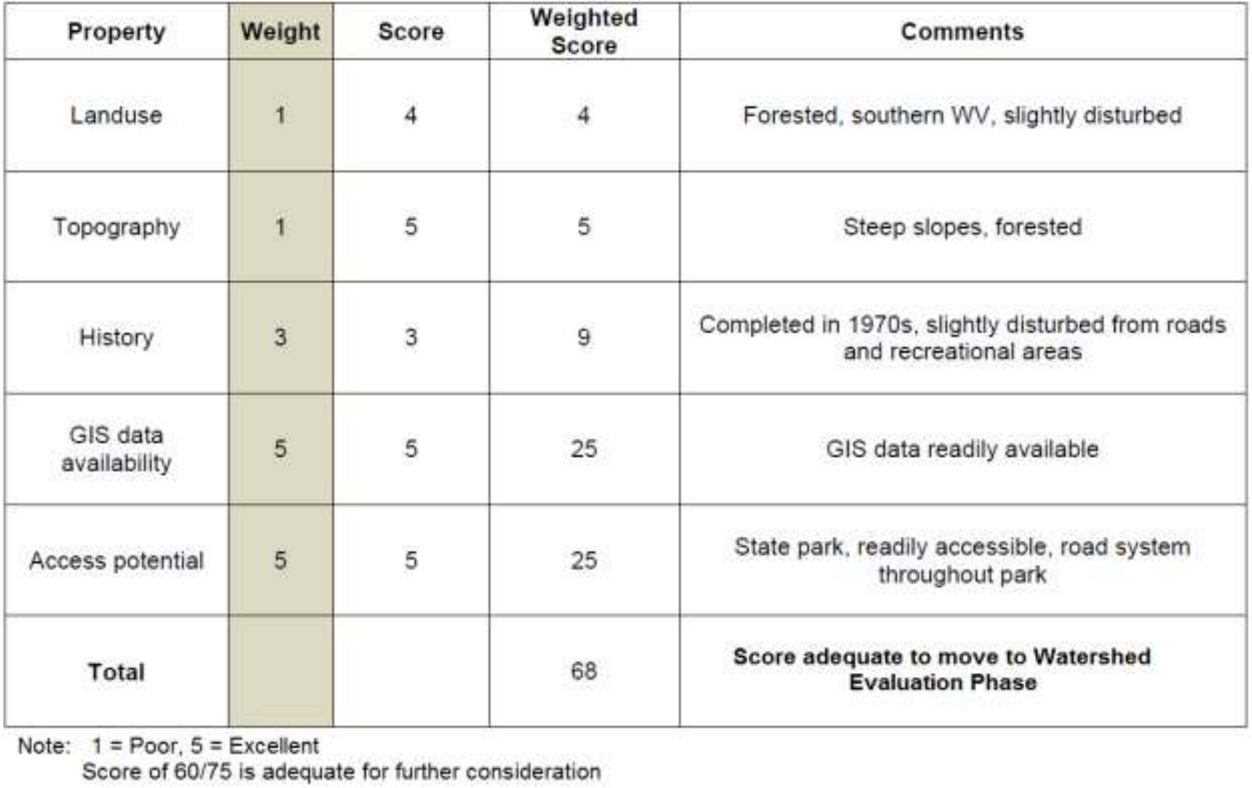
Note: 1 = Poor, 5 = Excellent
Score of 60/75 is adequate for further consideration

Table 22. Description, justification, resources for decision matrix for mature landforms (Watershed Evaluation Phase).

Property	Weight	Description and Justification	Resources
Accessibility	5	While minimal disturbance is ideal, access roads are needed to get access to the watersheds of interest. The weight of 5 was selected as this is a critical property. Without access, field data collection is impossible.	• Discussion with land managers and owners
Watershed Size	5	The target watershed size is 1 km^2. The target watershed size corresponds to the watershed that contains the valley fill of interest. The weight of 5 was selected as this is a critical property. A specific watershed size in necessary to complete a GLD design for the conventional valley fill of interest.	• Digital Elevation Models (USGS) (provided by WVGIS Technical Center)
Streams / Channels	5	We are targeting sites with minimal modification to channel planform and cross-section (e.g. straightening, hardening) The weight of 5 was selected as this is a critical property. Quantifying mature, stable channels in equilibrium is an important goal in field work.	• Aerial photography (provided by WVGIS Technical Center) • Discussion with land managers and owners • On-site evaluation
Vegetation	3	We are targeting mature forests with thick cover. (No evidence of recent timbering or agricultural activities). The weight of 3 was selected as this is a property of secondary importance. Sites that have reached this level of evaluation should have these vegetation characteristics at the regional scale.	• Aerial photography (provided by WVGIS Technical Center) • Discussion with land managers and owners • On-site evaluation
History	3	We are targeting minimal development beyond the forested condition. Disturbance from roads is expected, but disturbance from other human impacts should be minimal. The weight of 3 was selected as this is a property of secondary importance. Sites that have reached this level of evaluation should have these landuse characteristics at the regional scale.	• Aerial photography (provided by WVGIS Technical Center) • Discussion with land managers and owners • On-site evaluation

Note: 1 = Poor, 5 = Excellent
Score of 84/105 is adequate for further consideration

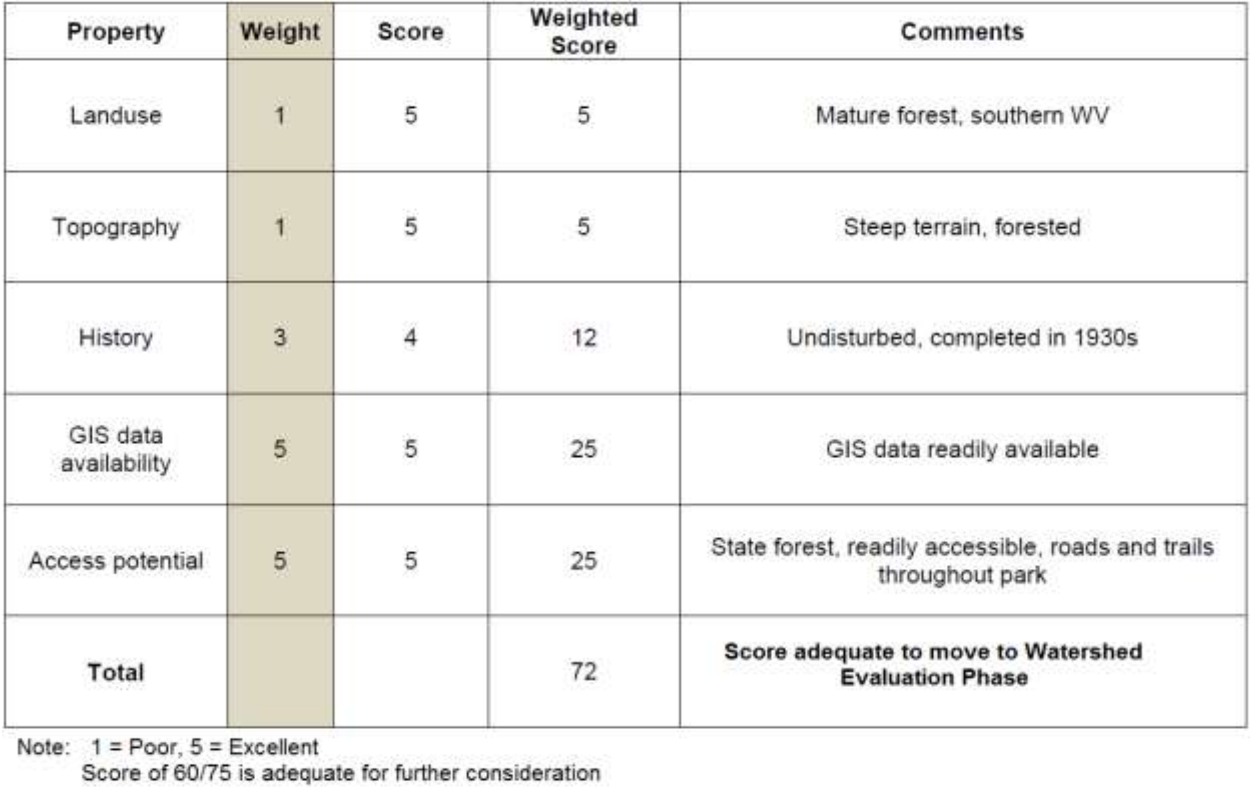
Table 23. Regional evaluation matrix for Twin Falls State Park.



Property	Weight	Score	Weighted Score	Comments
Landuse	1	4	4	Forested, southern WV, slightly disturbed
Topography	1	5	5	Steep slopes, forested
History	3	3	9	Completed in 1970s, slightly disturbed from roads and recreational areas
GIS data availability	5	5	25	GIS data readily available
Access potential	5	5	25	State park, readily accessible, road system throughout park
Total			68	**Score adequate to move to Watershed Evaluation Phase**

Note: 1 = Poor, 5 = Excellent
Score of 60/75 is adequate for further consideration

Table 24. Regional evaluation for Cabwaylingo State Forest.



Property	Weight	Score	Weighted Score	Comments
Landuse	1	5	5	Mature forest, southern WV
Topography	1	5	5	Steep terrain, forested
History	3	4	12	Undisturbed, completed in 1930s
GIS data availability	5	5	25	GIS data readily available
Access potential	5	5	25	State forest, readily accessible, roads and trails throughout park
Total			72	**Score adequate to move to Watershed Evaluation Phase**

Note: 1 = Poor, 5 = Excellent
Score of 60/75 is adequate for further consideration

Table 25. Regional evaluation for East Lynn Lake Wildlife Management Area.

Property	Weight	Score	Weighted Score	Comments
Landuse	1	5	5	Mature forest, southern WV, not disturbed
Topography	1	5	5	Steep, forested, 90% covereage by oak-hickory forest
History	3	4	12	Lake completed in 1970s, owned by USACE, managed by DNR, little disturbance
GIS data availability	5	5	25	GIS data readily available
Access potential	5	5	25	Readily accessible, decent network of roads throughout park
Total			72	**Score adequate to move to Watershed Evaluation Phase**

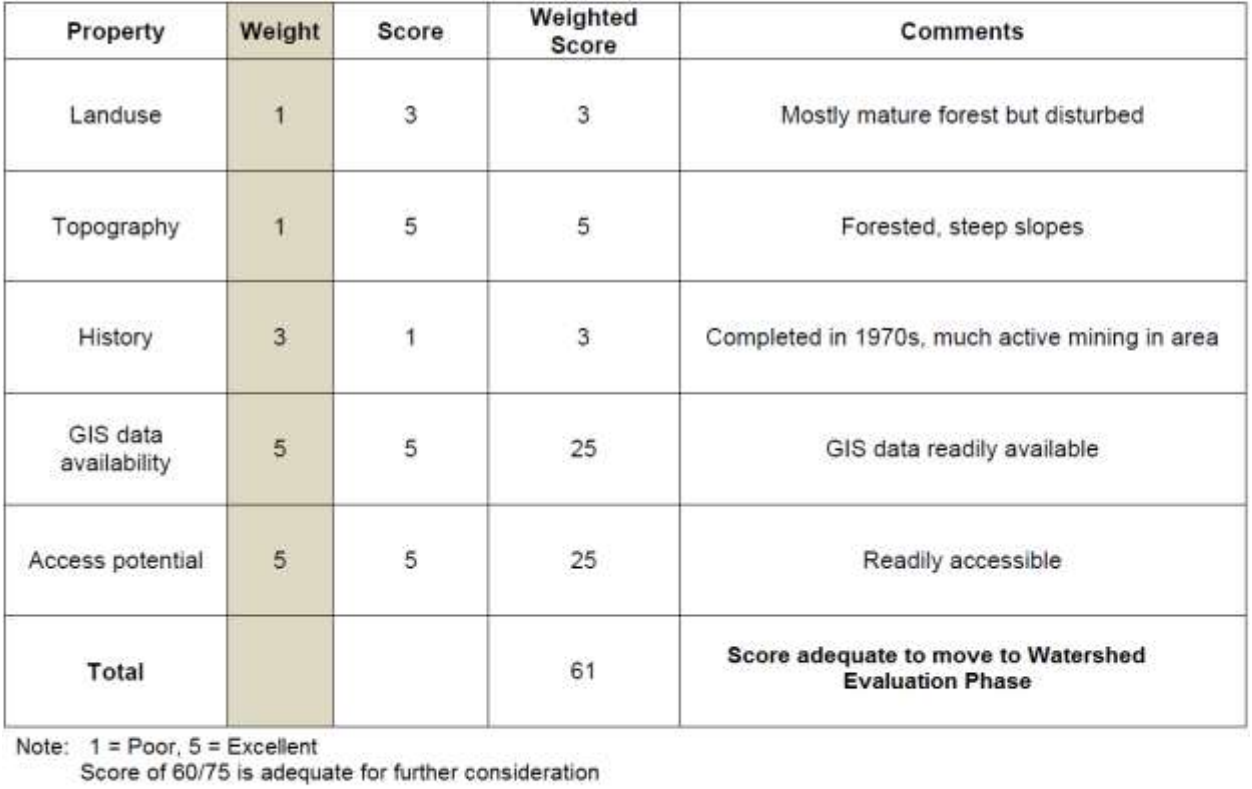
Note: 1 = Poor, 5 = Excellent
Score of 60/75 is adequate for further consideration

Table 26. Regional evaluation for Laurel Lake Wildlife Management Area.

Property	Weight	Score	Weighted Score	Comments
Landuse	1	3	3	Mostly mature forest but disturbed
Topography	1	5	5	Steep terrain and narrow valleys, forested
History	3	1	3	Constructed in 1960s, active mining, slides, valley fills
GIS data availability	5	5	25	GIS data readily available
Access potential	5	5	25	Wildlife Management Area so readily accessible, network of trails throughout park
Total			61	**Score adequate to move to Watershed Evaluation Phase**

Note: 1 = Poor, 5 = Excellent
Score of 60/75 is adequate for further consideration

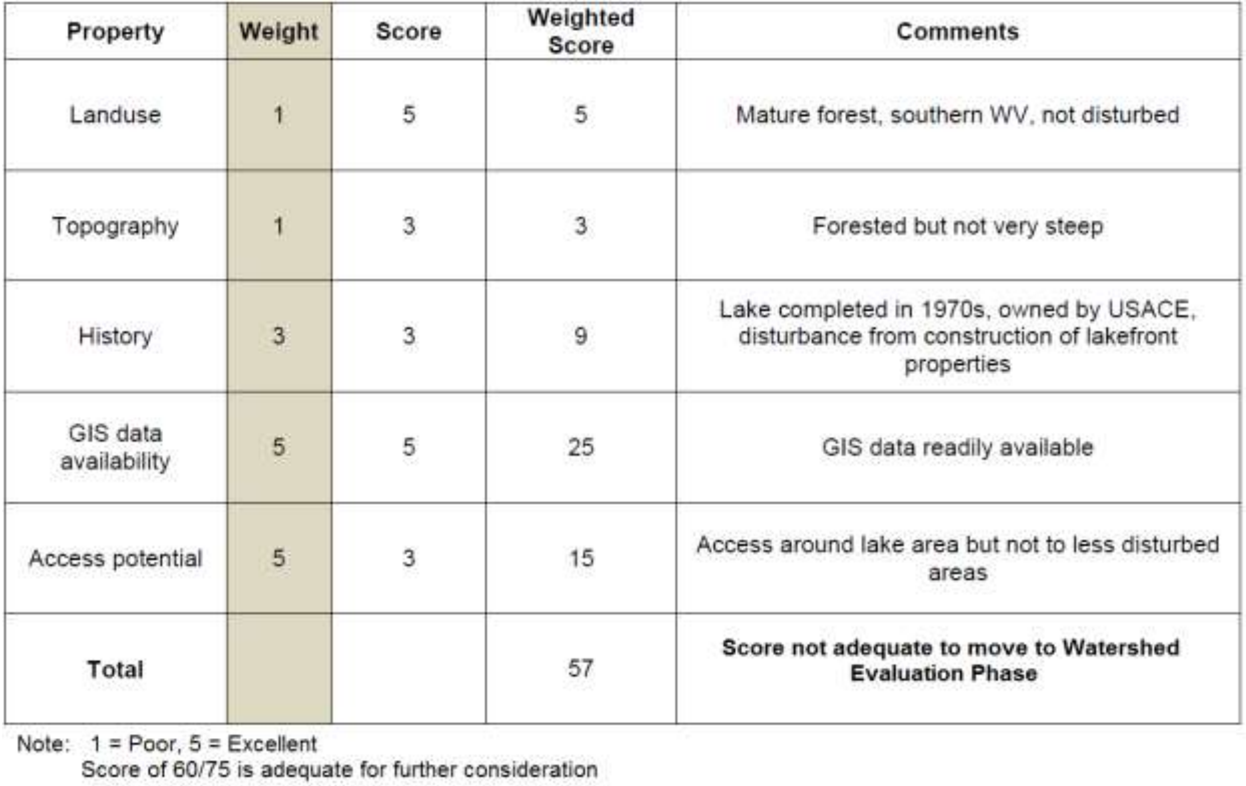
Table 27. Regional evaluation for R.D. Bailey Lake.



Property	Weight	Score	Weighted Score	Comments
Landuse	1	3	3	Mostly mature forest but disturbed
Topography	1	5	5	Forested, steep slopes
History	3	1	3	Completed in 1970s, much active mining in area
GIS data availability	5	5	25	GIS data readily available
Access potential	5	5	25	Readily accessible
Total			61	**Score adequate to move to Watershed Evaluation Phase**

Note: 1 = Poor, 5 = Excellent
Score of 60/75 is adequate for further consideration

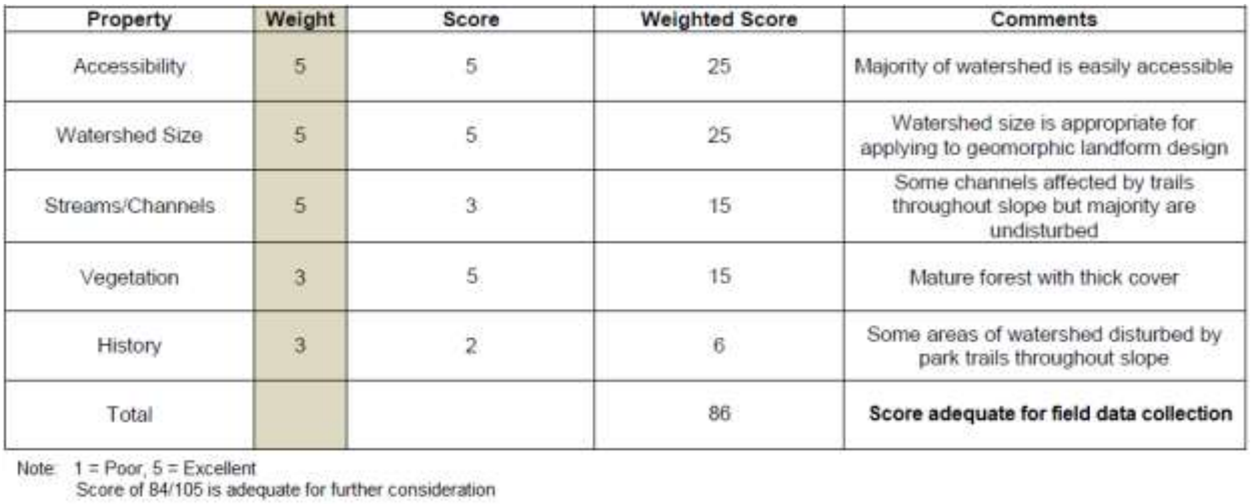
Table 28. Regional evaluation for Beech Fork State Park.



Property	Weight	Score	Weighted Score	Comments
Landuse	1	5	5	Mature forest, southern WV, not disturbed
Topography	1	3	3	Forested but not very steep
History	3	3	9	Lake completed in 1970s, owned by USACE, disturbance from construction of lakefront properties
GIS data availability	5	5	25	GIS data readily available
Access potential	5	3	15	Access around lake area but not to less disturbed areas
Total			57	**Score not adequate to move to Watershed Evaluation Phase**

Note: 1 = Poor, 5 = Excellent
Score of 60/75 is adequate for further consideration

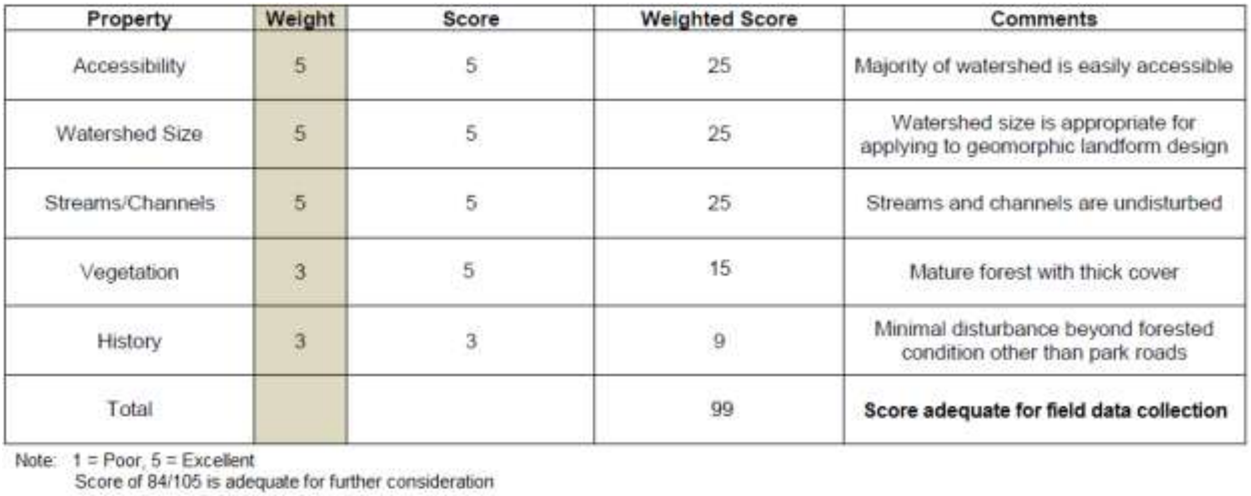
Table 29. Dixon watershed evaluation.



Property	Weight	Score	Weighted Score	Comments
Accessibility	5	5	25	Majority of watershed is easily accessible
Watershed Size	5	5	25	Watershed size is appropriate for applying to geomorphic landform design
Streams/Channels	5	3	15	Some channels affected by trails throughout slope but majority are undisturbed
Vegetation	3	5	15	Mature forest with thick cover
History	3	2	6	Some areas of watershed disturbed by park trails throughout slope
Total			86	**Score adequate for field data collection**

Note: 1 = Poor, 5 = Excellent
Score of 84/105 is adequate for further consideration

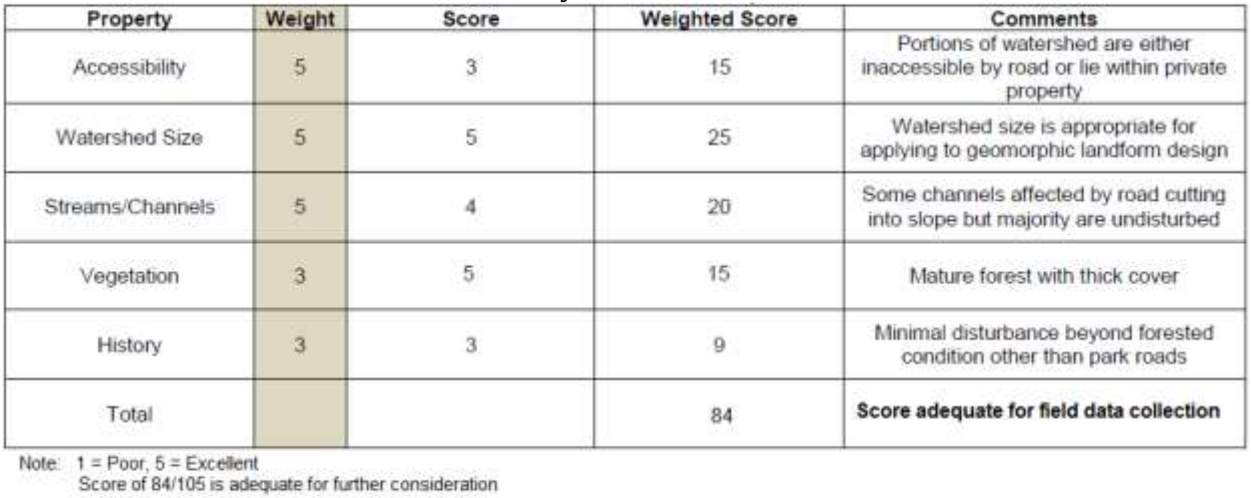
Table 30. Jackson watershed evaluation.



Property	Weight	Score	Weighted Score	Comments
Accessibility	5	5	25	Majority of watershed is easily accessible
Watershed Size	5	5	25	Watershed size is appropriate for applying to geomorphic landform design
Streams/Channels	5	5	25	Streams and channels are undisturbed
Vegetation	3	5	15	Mature forest with thick cover
History	3	3	9	Minimal disturbance beyond forested condition other than park roads
Total			99	**Score adequate for field data collection**

Note: 1 = Poor, 5 = Excellent
Score of 84/105 is adequate for further consideration

Table 31. Wiley watershed evaluation.



Property	Weight	Score	Weighted Score	Comments
Accessibility	5	3	15	Portions of watershed are either inaccessible by road or lie within private property
Watershed Size	5	5	25	Watershed size is appropriate for applying to geomorphic landform design
Streams/Channels	5	4	20	Some channels affected by road cutting into slope but majority are undisturbed
Vegetation	3	5	15	Mature forest with thick cover
History	3	3	9	Minimal disturbance beyond forested condition other than park roads
Total			84	**Score adequate for field data collection**

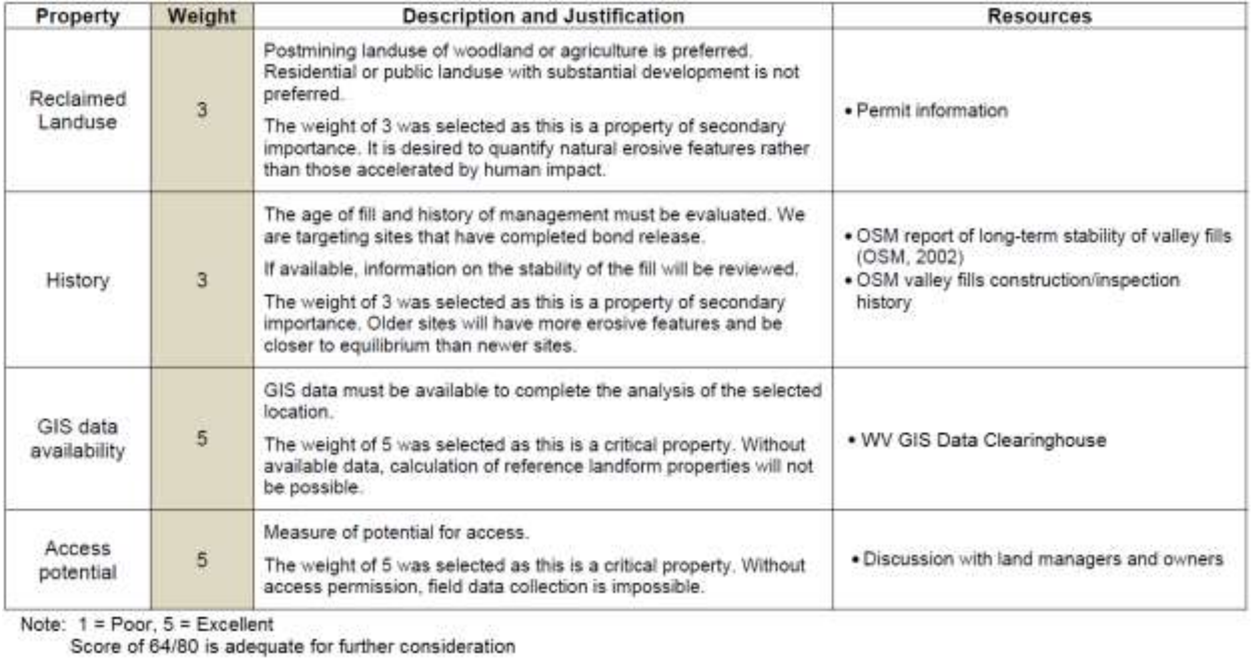
Note: 1 = Poor, 5 = Excellent
Score of 84/105 is adequate for further consideration

Long-term reclaimed sites

The purpose of the long-term reclaimed site was to quantify erosive features, such as gullies, rills, and deflection of trees that eventually result in mature, stable landforms. An evaluation matrix was developed to analyze potential field site locations at the landscape scale for the long-term reclaimed sites (Table 32). Properties included in the evaluation were the reclaimed landuse, history, GIS data availability, and access potential. A score of 64 out of a possible 80 points was required to keep a region for consideration at the watershed scale. The threshold score was taken from scoring 80% (4 out of 5) on each property. This was the same threshold percentage used for the mature landform evaluations. This 80% threshold was used for all evaluation matrices for long-term reclaimed sites, at both the regional and watershed scales. A decision matrix was developed to analyze reference landform potential of specific valley fills from areas that had an adequate Regional Evaluation (Table 33). Properties included in the evaluation were accessibility, watershed size, vegetation, and history. A score of 56 out of a possible 70 points was required in the Watershed Evaluation Phase to proceed to the field data collection.

The regional (Tables 34) and watershed (Tables 35-38) evaluations for the potential field data collection locations are presented in the following tables. A long-term reclaimed site in Summersville, WV passed the regional evaluation. Ultimately, the northwest and southwest facing valley fills were selected for field data collection.

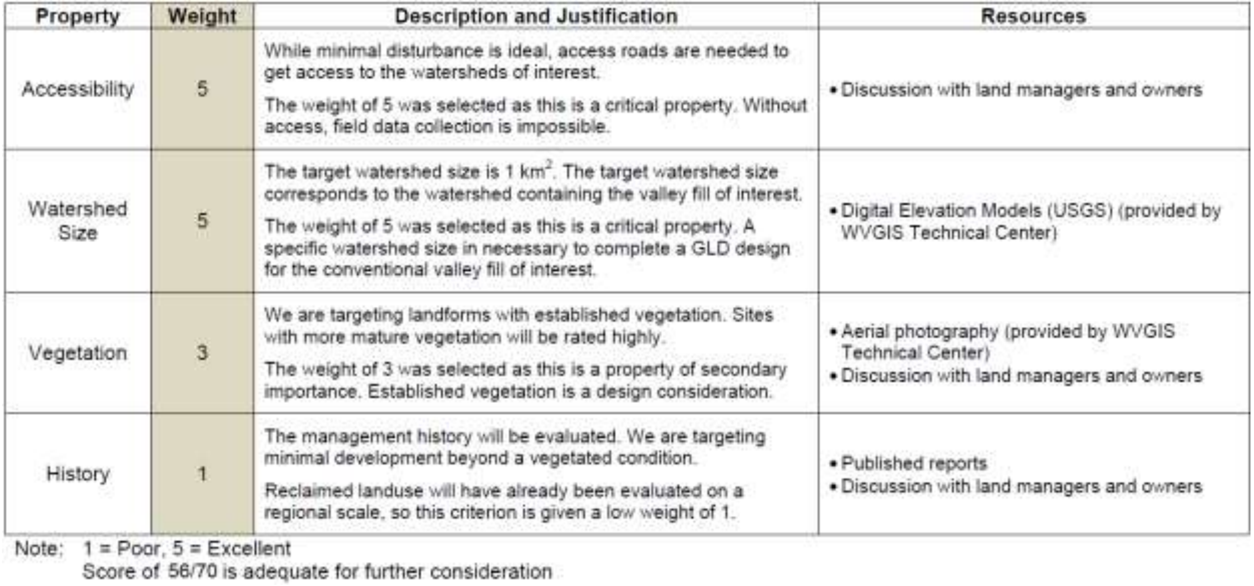
Table 32. Description, justification, resources for evaluation matrix for long-term reclaimed sites (Regional Evaluation Phase).



Property	Weight	Description and Justification	Resources
Reclaimed Landuse	3	Postmining landuse of woodland or agriculture is preferred. Residential or public landuse with substantial development is not preferred. The weight of 3 was selected as this is a property of secondary importance. It is desired to quantify natural erosive features rather than those accelerated by human impact.	• Permit information
History	3	The age of fill and history of management must be evaluated. We are targeting sites that have completed bond release. If available, information on the stability of the fill will be reviewed. The weight of 3 was selected as this is a property of secondary importance. Older sites will have more erosive features and be closer to equilibrium than newer sites.	• OSM report of long-term stability of valley fills (OSM, 2002) • OSM valley fills construction/inspection history
GIS data availability	5	GIS data must be available to complete the analysis of the selected location. The weight of 5 was selected as this is a critical property. Without available data, calculation of reference landform properties will not be possible.	• WV GIS Data Clearinghouse
Access potential	5	Measure of potential for access. The weight of 5 was selected as this is a critical property. Without access permission, field data collection is impossible.	• Discussion with land managers and owners

Note: 1 = Poor, 5 = Excellent
Score of 64/80 is adequate for further consideration

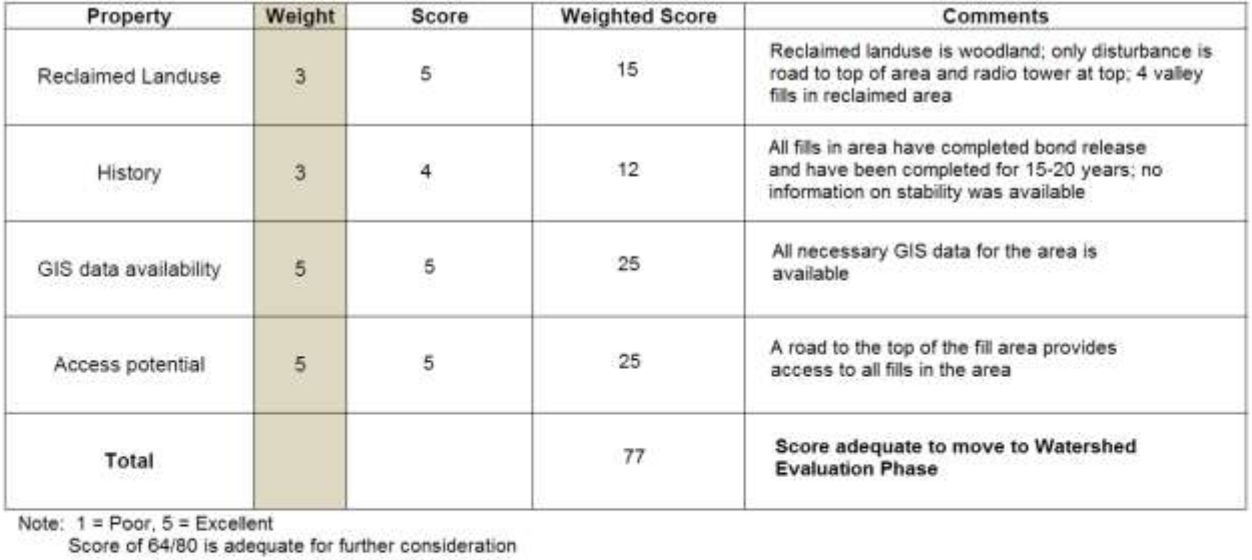
Table 33: Description, justification, resources for decision matrix for long -term reclaimed sites (Watershed Evaluation Phase).



Property	Weight	Description and Justification	Resources
Accessibility	5	While minimal disturbance is ideal, access roads are needed to get access to the watersheds of interest. The weight of 5 was selected as this is a critical property. Without access, field data collection is impossible.	• Discussion with land managers and owners
Watershed Size	5	The target watershed size is 1 km^2. The target watershed size corresponds to the watershed containing the valley fill of interest. The weight of 5 was selected as this is a critical property. A specific watershed size in necessary to complete a GLD design for the conventional valley fill of interest.	• Digital Elevation Models (USGS) (provided by WVGIS Technical Center)
Vegetation	3	We are targeting landforms with established vegetation. Sites with more mature vegetation will be rated highly. The weight of 3 was selected as this is a property of secondary importance. Established vegetation is a design consideration.	• Aerial photography (provided by WVGIS Technical Center) • Discussion with land managers and owners
History	1	The management history will be evaluated. We are targeting minimal development beyond a vegetated condition. Reclaimed landuse will have already been evaluated on a regional scale, so this criterion is given a low weight of 1.	• Published reports • Discussion with land managers and owners

Note: 1 = Poor, 5 = Excellent
Score of 56/70 is adequate for further consideration

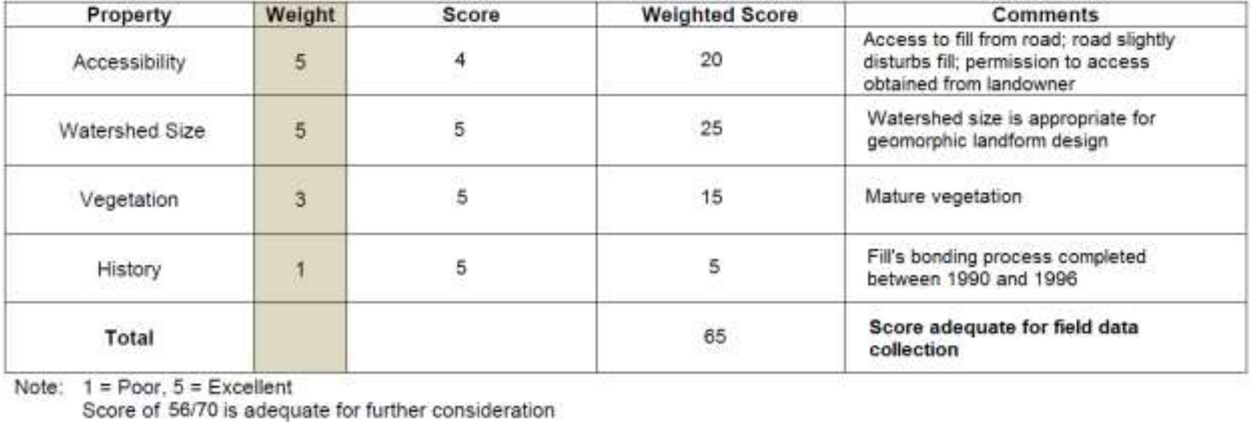
Table 34. Regional evaluation for Summersville long-term reclaimed site.



Property	Weight	Score	Weighted Score	Comments
Reclaimed Landuse	3	5	15	Reclaimed landuse is woodland; only disturbance is road to top of area and radio tower at top; 4 valley fills in reclaimed area
History	3	4	12	All fills in area have completed bond release and have been completed for 15-20 years; no information on stability was available
GIS data availability	5	5	25	All necessary GIS data for the area is available
Access potential	5	5	25	A road to the top of the fill area provides access to all fills in the area
Total			77	**Score adequate to move to Watershed Evaluation Phase**

Note: 1 = Poor, 5 = Excellent
Score of 64/80 is adequate for further consideration

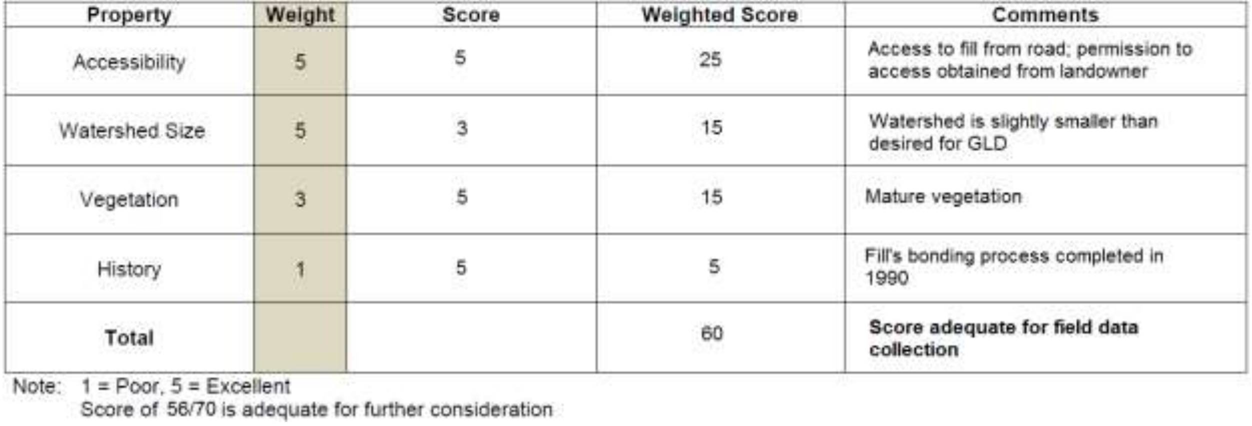
Table 35. Watershed evaluation for northwest facing valley fill in Summersville, WV.



Property	Weight	Score	Weighted Score	Comments
Accessibility	5	4	20	Access to fill from road; road slightly disturbs fill; permission to access obtained from landowner
Watershed Size	5	5	25	Watershed size is appropriate for geomorphic landform design
Vegetation	3	5	15	Mature vegetation
History	1	5	5	Fill's bonding process completed between 1990 and 1996
Total			65	**Score adequate for field data collection**

Note: 1 = Poor, 5 = Excellent
Score of 56/70 is adequate for further consideration

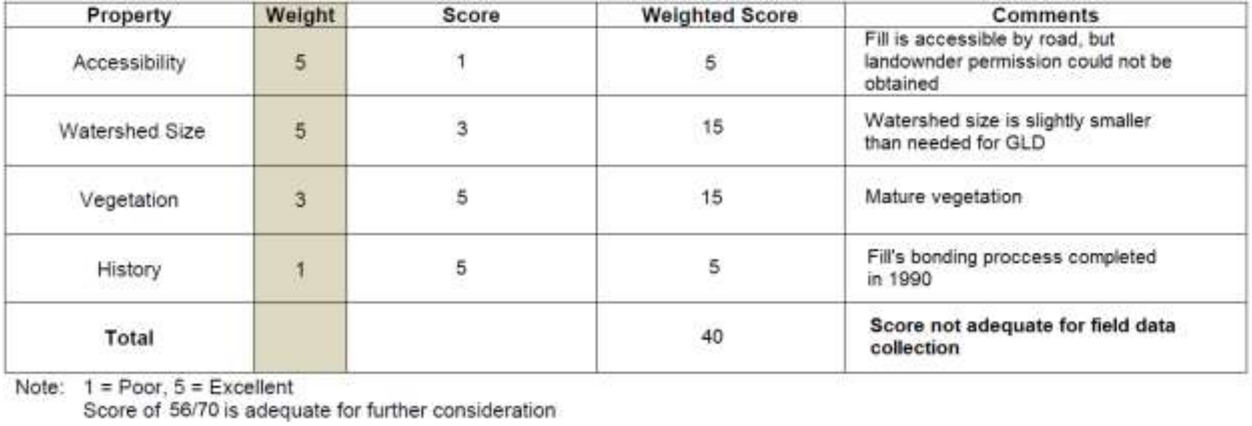
Table 36. Watershed evaluation for southwest facing valley fill in Summersville, WV



Property	Weight	Score	Weighted Score	Comments
Accessibility	5	5	25	Access to fill from road; permission to access obtained from landowner
Watershed Size	5	3	15	Watershed is slightly smaller than desired for GLD
Vegetation	3	5	15	Mature vegetation
History	1	5	5	Fill's bonding process completed in 1990
Total			60	**Score adequate for field data collection**

Note: 1 = Poor, 5 = Excellent
Score of 56/70 is adequate for further consideration

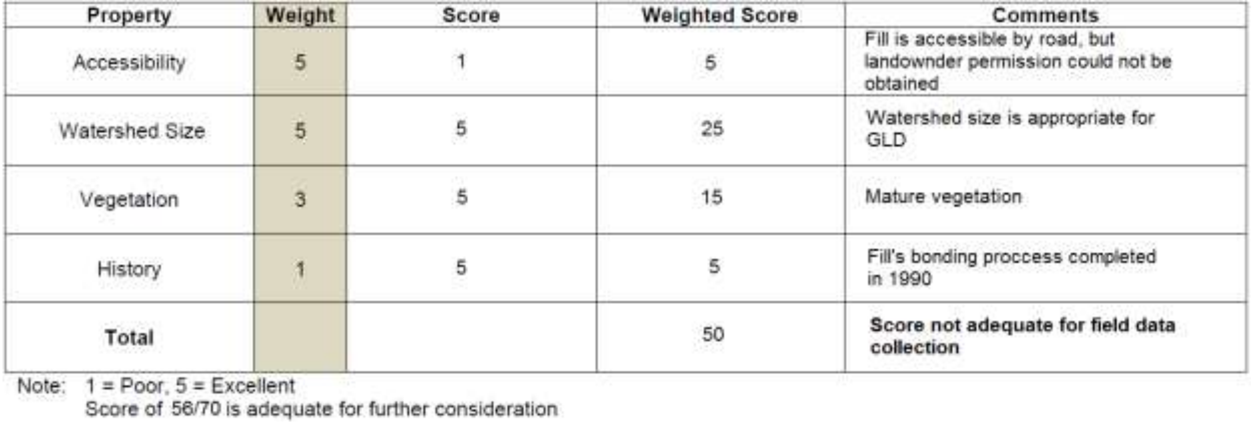
Table 37. Watershed evaluation for northeast facing valley fill in Summersville, WV



Property	Weight	Score	Weighted Score	Comments
Accessibility	5	1	5	Fill is accessible by road, but landownder permission could not be obtained
Watershed Size	5	3	15	Watershed size is slightly smaller than needed for GLD
Vegetation	3	5	15	Mature vegetation
History	1	5	5	Fill's bonding proccess completed in 1990
Total			40	**Score not adequate for field data collection**

Note: 1 = Poor, 5 = Excellent
Score of 56/70 is adequate for further consideration

Table 38. Watershed evaluation for southeast facing valley fill in Summersville, WV



Property	Weight	Score	Weighted Score	Comments
Accessibility	5	1	5	Fill is accessible by road, but landownder permission could not be obtained
Watershed Size	5	5	25	Watershed size is appropriate for GLD
Vegetation	3	5	15	Mature vegetation
History	1	5	5	Fill's bonding proccess completed in 1990
Total			50	**Score not adequate for field data collection**

Note: 1 = Poor, 5 = Excellent
Score of 56/70 is adequate for further consideration

APPENDIX B: REFERENCE LANDFORM CHARACTERISTICS

Table 39. Site properties - Dixon watershed

	Channel Properties					Bank Properties				
Site	**Width (ft)**	**Upstream slope (%)**	**Downstream slope (%)**	**Left slope (%)**	**Right slope (%)**	**Left slope (%)**	**Right slope (%)**	**Left bank veg. (%)**	**Right bank veg. (%)**	**Pebble count?**
D1	4.6	19	14	14	22	0-3	0-3	60-80	60-80	no
D2	22	22	19	30	34	9-15	9-15	60-80	60-80	yes
D3	2.7	31	16	32	34	9-15	9-15	60-80	60-80	yes
D4	3.3	21	18	20	26	4-8	4-8	60-80	60-80	yes
D5	3	19	22	21	15	0-3	0-3	80-100	80-100	no
D5A	NA	NA	NA	NA	NA	NA	NA	NA	NA	no
D6	3	29	12	30	40	4-8	4-8	40-60	40-60	yes
D7	2.1	21	19	26	24	0-3	0-3	40-60	40-60	yes
DM	18.4	6	3	38	11	41532	41532	60-80	60-80	yes
DM-MF	25.4	3	2	37	10	16-25	9-15	80-100	80-100	yes
Dixon Head	5	18	25	17	14	4-8	4-8	60-80	60-80	yes

Table 40. Site properties - Jackson watershed

	Channel Properties					Bank Properties				
Site	**Width (ft)**	**Upstream slope (%)**	**Downstream slope (%)**	**Left slope (%)**	**Right slope (%)**	**Left slope (%)**	**Right slope (%)**	**Left bank veg. (%)**	**Right bank veg. (%)**	**Pebble count?**
J1	2.7	26	26	10	20	9-15	9-15	60-80	60-80	yes
J2	3	22	26	16	23	9-15	9-15	60-80	60-80	yes
J3	NA	NA	NA	NA	NA	NA	NA	NA	NA	no
J3A	4.7	vertical	50	45	0	4-8	4-8	40-60	40-60	yes
J4	2.7	14	9	4	31	9-15	9-15	60-80	60-80	yes
J5	2.6	25	19	15	19	0-3	0-3	20-40	20-40	yes
J6	2.6	20	20	26	25	0-3	0-3	40-60	40-60	no
J7	NA	NA	NA	NA	NA	NA	NA	NA	NA	no
J8	2.4	21	15	8	22	9-15	9-15	40-60	40-60	yes
J9	9	25	5	31	27	9-15	9-15	60-80	40-60	yes
J10	5	35	35	15	10	9-15	4-8	80-100	80-100	no
J11	4	44	32	7	24	4-8	4-8	60-80	60-80	no
J12	3.5	26	21	16	17	4-8	4-8	40-60	40-60	yes

Table 41. Site properties - Wiley watershed

	Channel Properties					Bank Properties				
Site	**Width (ft)**	**Upstream slope (%)**	**Downstream slope (%)**	**Left slope (%)**	**Right slope (%)**	**Left slope (%)**	**Right slope (%)**	**Left bank veg. (%)**	**Right bank veg. (%)**	**Pebble count?**
W1	4	52	44	30	28	16-25	16-25	60-80	60-80	yes
W2	3.4	44	40	30	19	16-25	16-25	40-60	40-60	yes
W3	5	54	54	34	33	16-25	16-25	40-60	40-60	no
WM	7.9	3	2	5	5	16-25	16-25	80-100	80-100	yes

Table 42. Critical grain size distribution for pebble count collection sites.

Site	D_{50} (mm)	D_{84} (mm)	% silt/clay	% sand	% gravel	% cobble	% boulder
D2	0.8	19	0	73	22	5	0
D3	0.72	0.93	0	94	2	4	0
D4	0.87	9.5	0	63	36	1	0
D6	0.95	16	0	54	46	0	0
D7	0.73	0.95	0	90	10	0	0
DM	82	200	0	0	36	51	13
DM-MF	160	320	0	0	19	41	40
Dixon Head	13	100	0	19	59	15	7
J1	0.9	34	0	59	35	5	1
J2	0.92	10	0	57	40	3	0
J3A	3.5	7.6	0	36	64	0	0
J4	4.4	12	0	32	68	0	0
J5	0.92	7.6	0	57	43	0	0
J8	6.7	19	0	42	57	1	0
J9	5.2	73	0	48	34	15	3
J12	6.9	20	0	44	53	3	0
W1	0.88	9.9	0	61	36	3	0
W2	0.79	6.8	0	75	25	0	0
WM	30	58	0	7	80	13	0
S1	11	20	0	23	76	1	0
S3	8.5	16	0	6	93	1	0

APPENDIX C: FIELD PHOTOGRAPHS

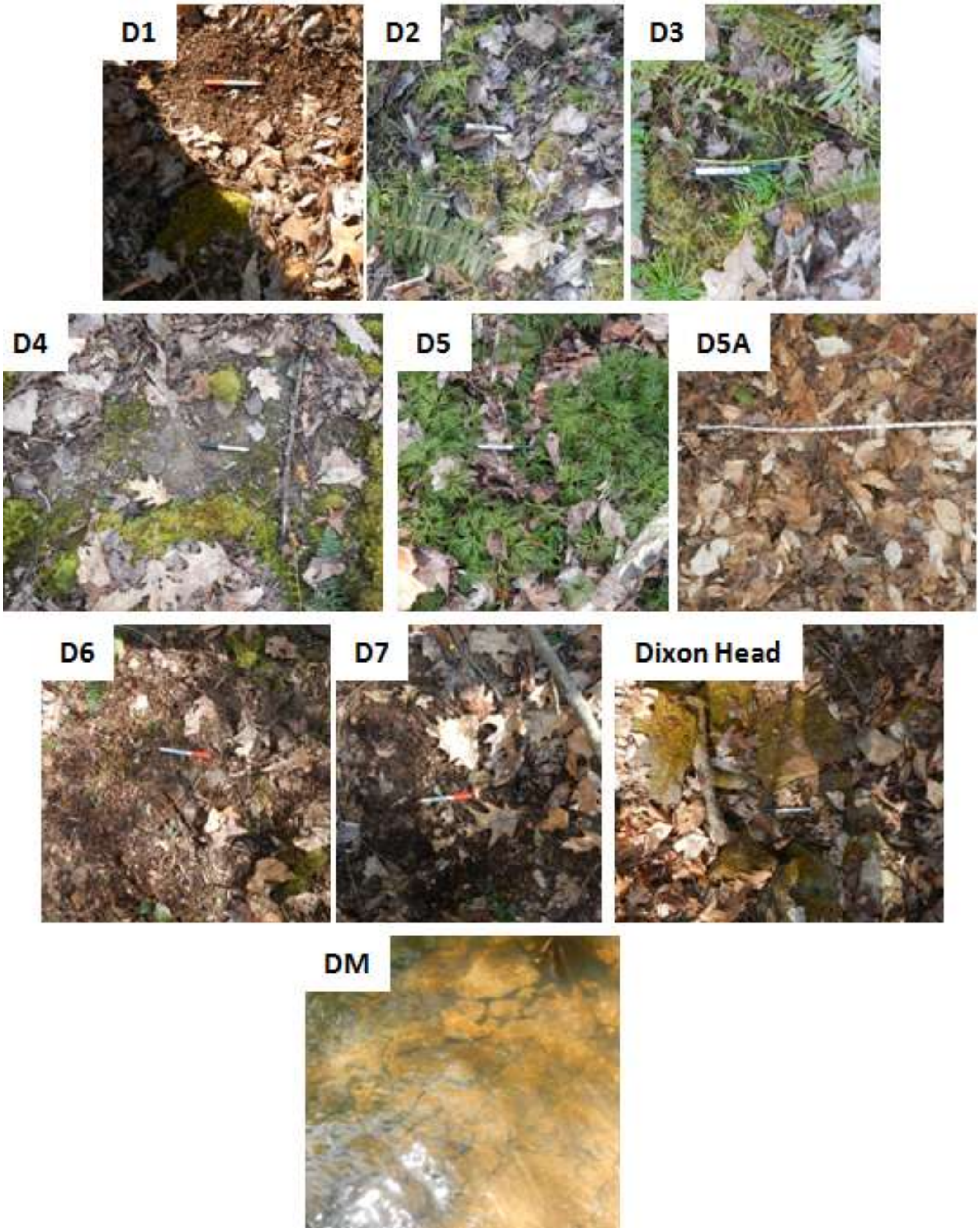


Figure 29. Channel beds at channel heads and mouth of Dixon watershed

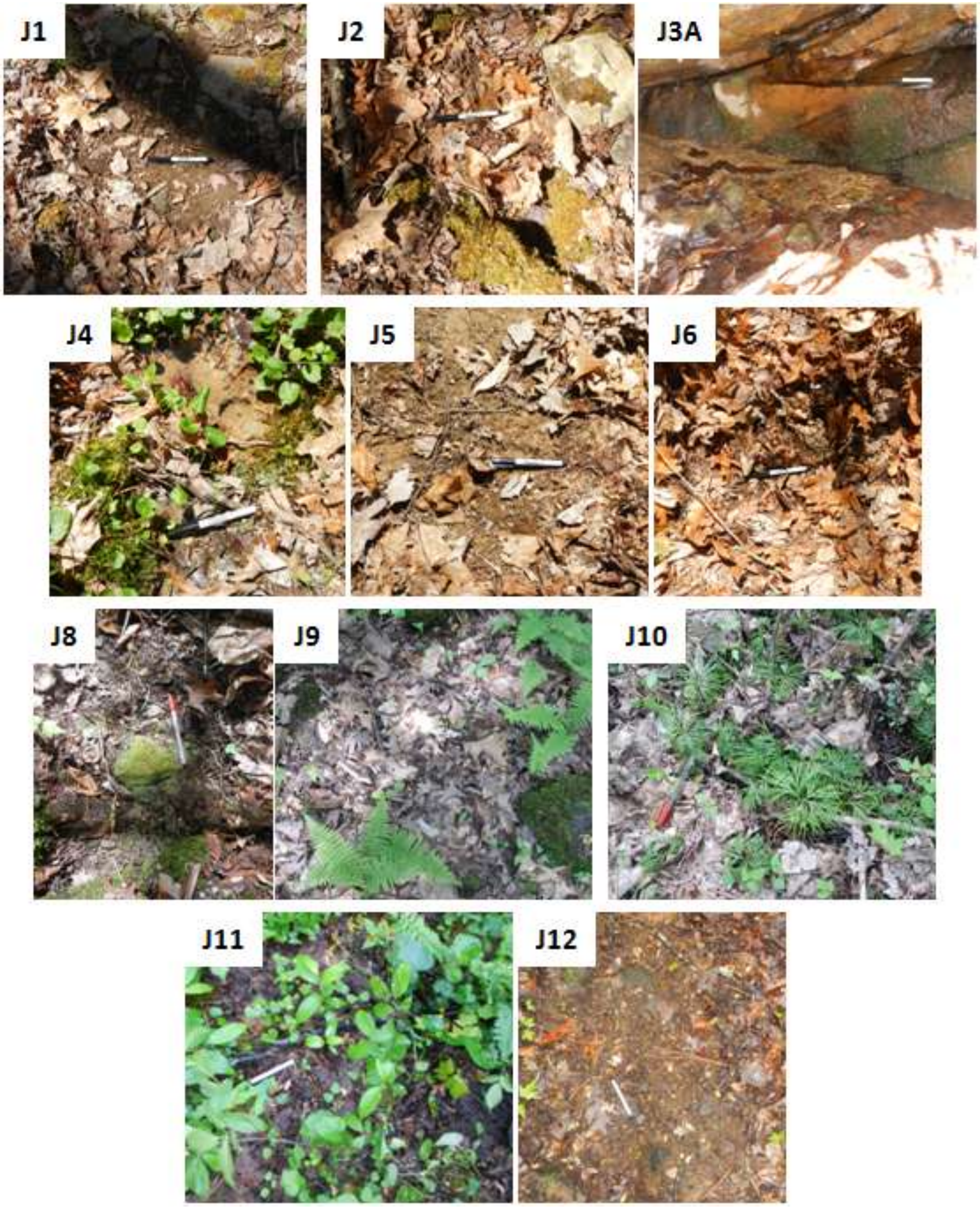


Figure 30. Channel beds at channel heads in Jackson watershed

Figure 31. Channel beds at channel heads and mouth of Wiley watershed

Figure 32. Mouth (looking upstream) of Dixon and Wiley watersheds.

Figure 33. Photos of erosion sites at Summersville valley fills


Setting up surveying equipment

Surveying channel head location

Performing pebble count at channel head

Performing pebble count at watershed mouth

Figure 34. Photos of field data collection

Figure 35. Four sampling sites in Wiley Branch for benthic macroinvertebrate sampling, looking upstream.

Figure 36. Four sampling sites in Dixon Branch for benthic macroinvertebrate sampling, looking upstream.

Figure 37. Three sampling sites in Jackson Branch for benthic macroinvertebrate sampling, looking upstream.