Investigating regional design parameters in the design of West Virginia valley fills to support application of geomorphic landform design principles

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ABSTRACT

Fluvial geomorphic landform design has the potential to improve water quality while restoring productive stream channels in the reclaimed landscape. The technique is difficult to apply in the southern West Virginia coal fields in part due to the absence of unaltered landform data to serve as reference design values. This research examined the application of geomorphic landform design principles to valley fills. The objectives of this research were to quantify mature landform features in an undisturbed watershed in southern West Virginia and compare these characteristics to default parameters utilized in a current design tool. Reference landform characteristics were quantified in the Whetstone watershed located in the Panther Wildlife Management Area in southern West Virginia. A topographic survey was completed to quantify ridge to head of channel distance, channel slope, and hillslope profile. Channel grain size distributions and cross sectional geometry were quantified in both head of channel and watershed outlet locations. Findings suggest that the slope at the head of channel ranges between 35 and 50 percent, with the slope at the mouth remaining at 8 percent. Drainage density was calculated as 5.3 km^{-1}, and sinuosity remained close to one at 1.03. These design parameters substantially differ from design inputs of current design tools and will be utilized to calibrate future conceptual valley fill designs.

INTRODUCTION

Approximately 2,000 km of headwater streams were lost by 2002 due to surfacing mining disturbance in the central Appalachian region (USEPA 2011). Typically, the horizontally bedded seams are removed sequentially as overburden is placed both on the pit floor and in external, valley fill dumps. Conventional valley fills under West Virginia regulations, are designed to meet minimum design requirements to achieve geotechnical stability and to control surface runoff. State regulations (WVDEP 1993) require:

- A long-term static factor of safety of 1.5;
- 2:1 slopes with minimum 20-ft wide benches installed within every 50 vertical feet;
- Internal drainage provided by a vertical rock chimney (minimum width of 16 ft); and,

- Surface drainage for a 100-yr, 24-hr precipitation event.

The resulting surfaces often have planar slope profiles which contrast with the surrounding landscape, and their increasing size has resulted in an increasing loss of headwater streams. Studies have shown that streams below valley fills often have elevated dissolved ion concentrations resulting from water contact with the overburden (Hartman et al. 2005; Pond et al. 2008; Petty et al. 2010). Additionally, research has documented that surface mining and reclamation increase stormflow response compared to the undisturbed condition (Bonta et al. 1997; Messinger 2003; Messinger and Paybins 2003; Negley and Eshleman 2006), and selenium leaching from spoil related to coal mining is of increasing concern (e.g. Ziemkiewicz et al. 2011).

Fluvial geomorphic landform design has the potential to improve water quality while restoring productive stream channels in the reclaimed landscape. Under natural conditions, landforms develop a balance between erosive and resistance forces, resulting in a system in dynamic equilibrium with low erosion rates. The fluvial geomorphic landform design approach attempts to design landforms in this steady-state condition, considering long-term climatic conditions, soil types, slopes, and vegetation types (Toy and Chuse 2005; Bugosh 2009). Relative to traditional reclaimed landforms, fluvial geomorphic landform design appears natural, reduces long-term maintenance, requires fewer artificial elements, and supports long-term stability (Martin-Duque et al. 2009).

This design approach has been used with success (e.g. Toy and Chuse 2005; Measles and Bugosh 2007; Martin-Moreno et al. 2008; Bugosh 2009; Robson et al. 2009; Marin-Duque et al. 2009) but has not been utilized in Appalachian surface mining reclamation. The complexity of mature landform design in steep terrain presents challenges. In addition, current regulations do not support the utilization of the of the design technique (Michael et al. 2010).

Geomorphic landform design uses a reference landform approach which requires pre-development, geomorphic data. The data needed for design are similar to those needed for stream classification systems (e.g. Schumm and Mosley1977; Rosgen 1994, 1996; Montgomery and Buffington 1997) and stream assessments (e.g. Kaufmann and Robison 1998; VANR 2004):

- main channel slope;
- drainage density;
- longitudinal profile shape;
- channel characteristics (bankfull width, width to depth ratio, sinuosity, meander belt width, “A” channel length); and,
- ridge to head of channel distance.

Limited geomorphic data are available in West Virginia, especially in the southern coal fields (e.g. Wiley et al. 2001). This region has a history of surface mining and logging, often requiring changes of the steep terrain for site access, which has rendered limited unaltered land profiles.

The overall goal of this research was to quantify geomorphic features in an undisturbed watershed in southern West Virginia that will inform geomorphic landform design for valley fills in Central Appalachia. This research quantified geomorphic characteristics in the Whetstone watershed located in the Panther Wildlife Management Area (WMA). These characteristics were then compared to design inputs used in a recent alternative valley fill design developed by Sears et al. (2012).

METHODS

The Whetstone Branch watershed located in the Panther Wildlife Management Area in McDowell County located near the southern border of West Virginia was the experimental watershed for this research (Figure 1). The study site was identified using aerial photography, topographic maps, and communication with area officials. The Panther WMA site is managed by the West Virginia Division of Natural Resources and since the 1920's has had only minor terrain impacts, mostly due to road construction.

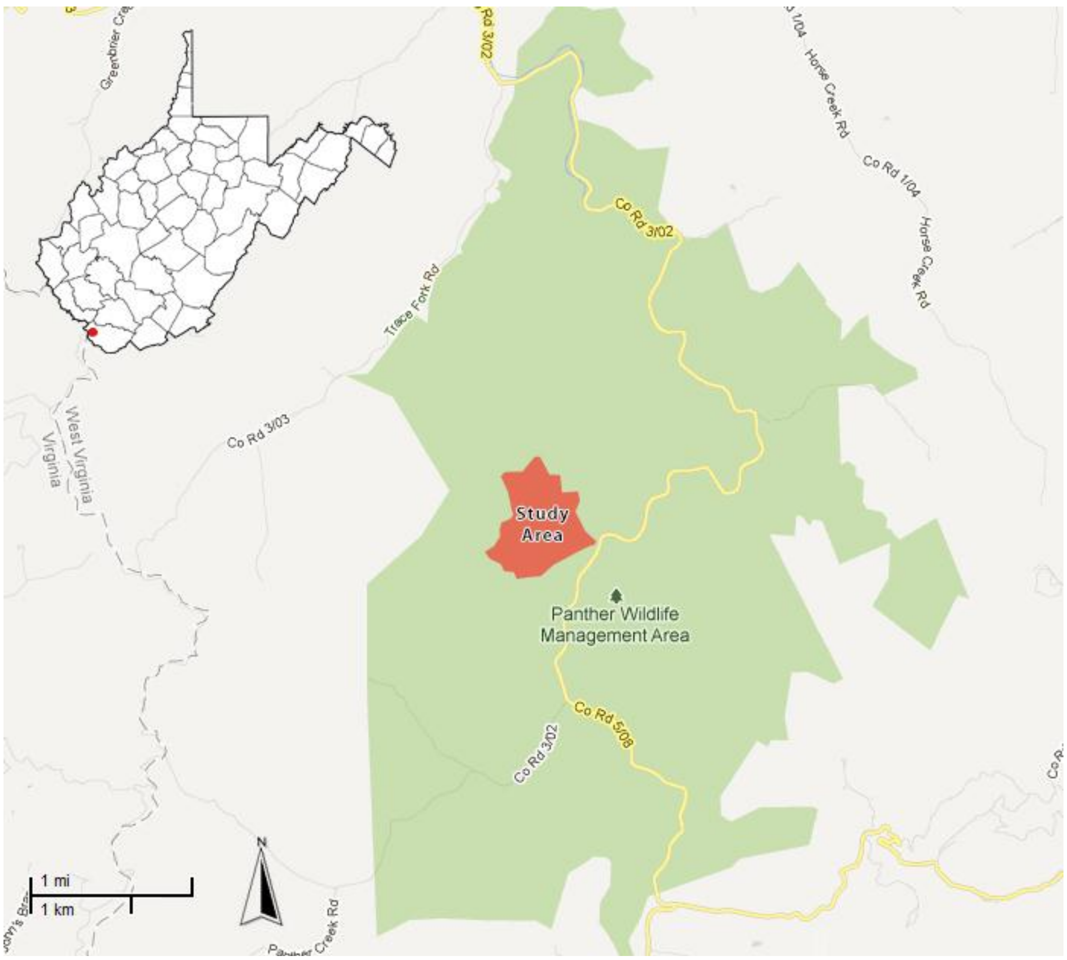

Figure 1. Location of experimental watershed in Panther Wildlife Management Area, West Virginia

The experimental watershed (0.75 km^2) is characterized by a mixed mesophytic forest. Invasive species are also common to the area, including *Elaeagnus umbellate* (autumn olive), *Ailanthus altissima* (tree of heaven), and *Rosa multiflora* (multiflora rose). The Whetstone Branch watershed consists mainly of an extremely steep and stony soil (Pineville-Berks), with a small portion fine sandy loam (Yeager) located around the mouth of the stream. The study area receives an average of 100-122 cm of precipitation annually with a strong seasonal pattern (USDA-NRCS, NWCC 2012).

The Whetstone Branch watershed includes nine major unnamed tributaries. Seven of these branches were selected for study based on accessibility (Figure 2). Field data collection was completed June-July 2012. Geomorphic characteristics were quantified at the seven head of channel locations (I, II, III, IV, V, VI, VII) as well as the watershed outlet (M for main channel outlet; Figures 2-3). The characteristics were determined through a combination of field surveys and existing GIS data as described in the following sections.

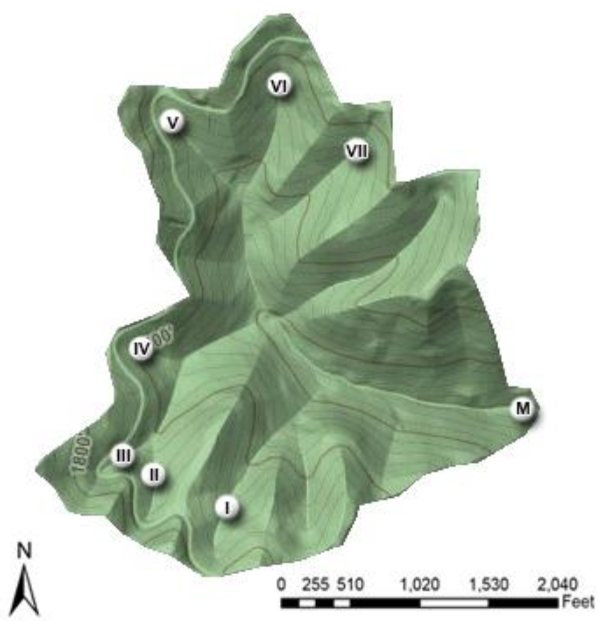

Figure 2. Head of channels surveyed in experimental watershed

Figure 3. Experimental field sites for the head of channel sampling stations (I, II, III, IV, V, VI, VII) and the watershed outlet (M)

Data Collection and Analysis

Field data needed to quantify grain size distribution, hillslopes, ridge to head of channel distance, channel slope, and cross-sectional geometry were collected in head of channel and watershed outlet locations (Figure 2). A field survey was completed using a Topcon FC-100 and Hyperlite+ receivers (Topcon, Paramus, New Jersey) using a 0.6 m horizontal error and a 1.5 m vertical accuracy; this error represented the minimum allowable error to complete measurements within the dense vegetation cover. Study reaches were surveyed to quantify slopes, sinuosity, ridges, and channel head locations. The location of the watershed ridge and head of channel locations were identified and recorded as points; these data were used to calculate ridge to head of channel distance. Roads that altered the natural topography were also recorded. A minimum of five points were taken downslope from the start of channel to identify the channel slope and sinuosity (i.e. channel length/valley length). Bank slopes were determined through points taken a minimum of 7.5 m from the start of channel on either side of the channel. A clinometer was used to verify slope measurements. Channel dimensions were measured at the head of each channel as well as the mouth of the watershed. These sections were taken by placing an adjustable measuring rod horizontally and perpendicular to the stream; the distance from the rod to the streambed were measured and recorded at 0.3 m intervals.

Particle size distributions of bed material were quantified at the eight sampling locations (Figure 2) using modified Wolman (1954) pebble count (Harrelson et al. 1994). Bank materials were also observed and recorded. Riparian trees, shrubs, and herbaceous plants were characterized at each head of channel location through sketching sections, highlighting plant types and observations of plant cover. Additionally, a percentage of each type of cover (trees, shrubs, low lying plants) was estimated based on observation.

ArcMap was used in conjunction with digital spatial datasets for elevation (U.S. Geological Survey, WV SAMB), hydrology (U.S. Geological Survey, WV SAMB), and soils (NRCS). The field measurements were downloaded into a GIS desktop application and georeferenced with the field data. GIS was used to verify slope and sinuosity measurements. Slope and aspect maps were created and drainage density (i.e. valley length/watershed area) was calculated. Ridge to head of channel distances were calculated using survey data.

RESULTS AND DISCUSSION

Stream Pattern and Profile

Sinuosity, a measure of channel curvature, was calculated as nearly one when using both survey data (average sinuosity = 1.01) and GIS data (average sinuosity = 1.05) (Table 1). Channels with a sinuosity greater than 1.3 are considered meandering (FISRWG 1998); therefore, no meandering channels were observed in the steep, headwater watershed. The sinuosity measurements calculated with field measurements were slightly smaller than those derived from GIS. This is expected because the survey only accounted for a small stretch at the beginning of the stream (where slopes are greater) while the GIS measurements represented the entire branch.

The ridge to head of channel distance represents the distance required to form channelized flow and is essential to understand watershed runoff processes (Hancock and Evans 2006). The head of channel was determined by identifying the location where soil began to give way to gravel and there was an apparent change in slope. An apparent v-notch began to form at the head of each channel as well. The distance from the ridge to the head of channel remained relatively constant with one outlier (Table 1). The average distance recorded from the ridge to the head of channel was 121 m. When neglecting the outlier, the average was 114 m. All points were influenced by a road that ran along the slope of the site. In the sites where the outlier was measured, the road was further from the ridge.

For the seven headwater tributary locations, channel slope was greater than 16%. At the watershed outlet, the main channel had a slope of 8%, characteristic of a non-meandering stream.

Table 1. Ridge to head of channel distance, sinuosity, and channel slope for each field site

Site	**Ridge to channel head distance (m)**	**Sinuosity** (from survey)	**Sinuosity** (from GIS)	**Channel Slope (%)**
I	112	1.05	1.08	16
II	113	1.01	1.12	18
III	163	1.00	1.05	21
IV	108	1.00	1.02	27
V	106	1.00	1.00	42
VI	136	1.01	1.06	34
VII	110	1.01	1.02	36
M	NA‡	1.01	1.03	8

‡NA=not applicable

Channel Material and Hillslope

Median particle size (D50) ranged from 19 to 34 mm for all headwater locations (I-VII, Table 2), representing gravel bed channels. The median particle size for the watershed outlet was also in the gravel size range (D50=20 mm). The head of channel bed material was colluvial according to the Montgomery-Buffington classification (Montgomery and Buffington 1993); it originated from hillslope debris and was formed by gravity.

Table 2. Gran size distributions for each field site

Site	**D16 (mm)**	**D50 (mm)**	**D84 (mm)**
I	9.1	31	72
II	9.4	21	59
III	11	33	66
IV	9.4	22	62
V	8.7	19	51
VI	8.3	27	76
VII	8.4	34	63
M	10	20	32

Banks primarily consisted of sand and tended to have slopes from 9%-25%. The heads of the channels tended to start out broad (1.8-3 m) and narrowed as they traveled down the slope (Table 3). Channel slopes were also very steep, reaching as high as 42% grade (Table 1). The steep valley slopes are also presented in Figure 4. Much of the watershed has greater than a 50%

incline, with very few areas less than 30% (Figure 4). The complexity of the watershed arrangement is apparent through the aspect distribution; the watershed had 40%, 30%, 20%, and 10% of south (south, southwest, southeast), north (north, northwest, northeast), east, and west facing slopes, respectively (Figure 5).

Table 3. Channel width, bank material, and bank slope for each field site

		Left Bank		Right Bank	
Site	**Channel Width**	**Slope**	**Texture**	**Slope**	**Texture**
I	SC	VS	Sand/Silt	VS	Sand/Silt
II	B	S	Sand	S	Sand
III	B	S	Sand	S	Sand
IV	B	H	Sand	H	Sand
V	B	VS	Sand	VS	Sand
VI	B	H	Sand	VS	Sand
VII	N	S	Sand	S	Sand
M	B	ES	Sand	S	Sand

*SC is semi-confined (0.6-1.2 m), B is broad (1.8-3 m), N is Narrow (1.2-1.8 m), VS is very steep (16%-25%), S is steep (9%-15%), H is hilly (4-8%), and ES is extremely steep (>25%); notation adapted from (VANR, 2004).

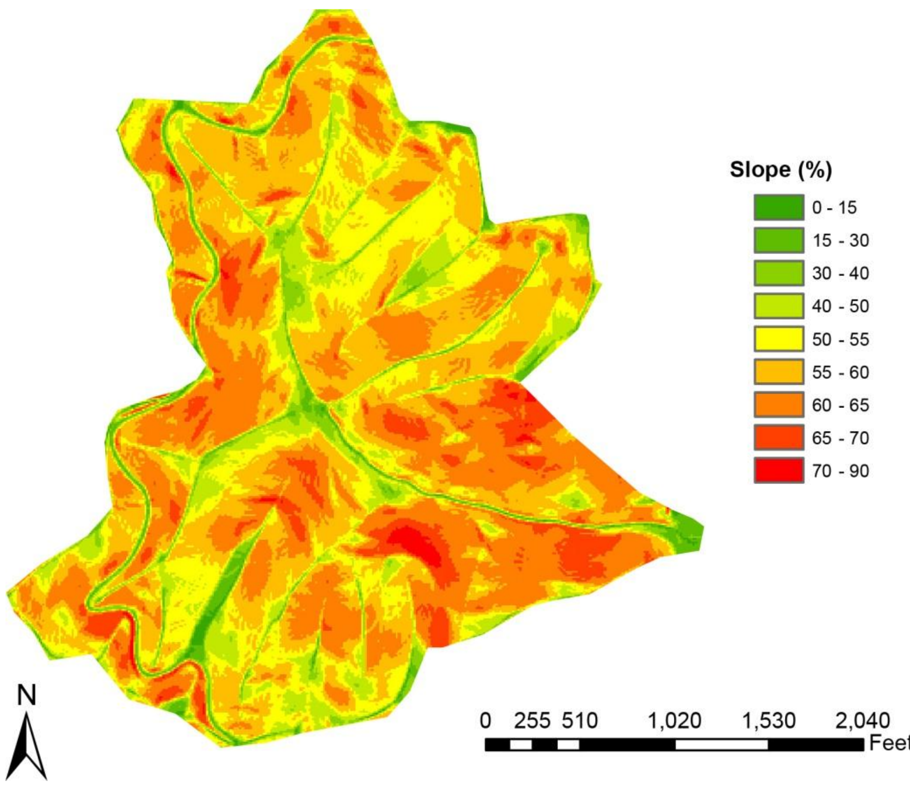

Figure 4. Slope map of Whetstone Branch

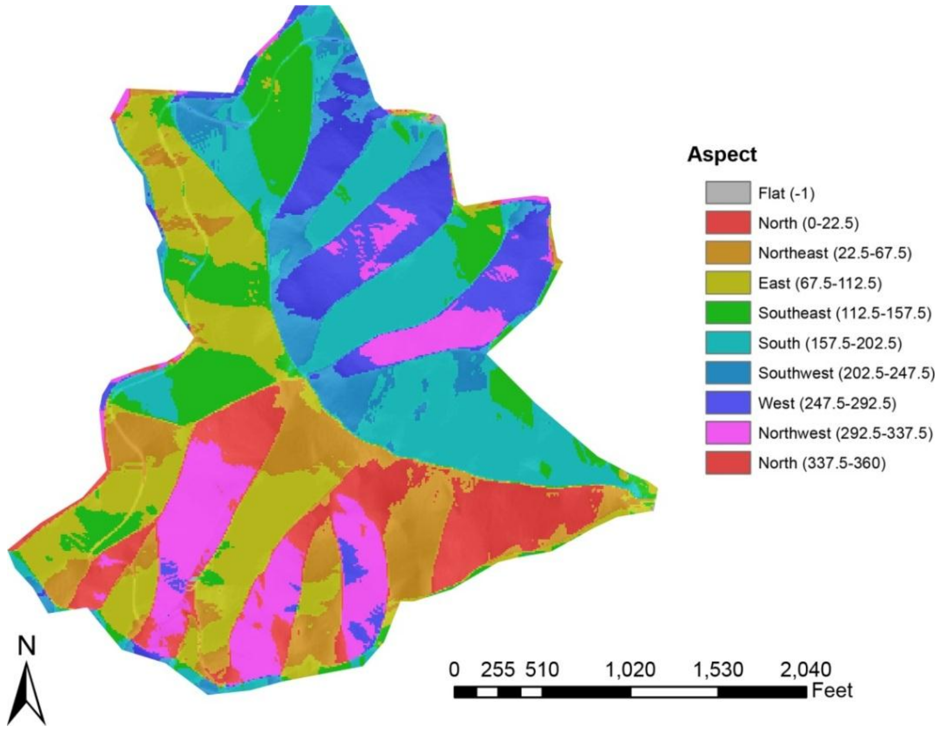

Figure 5. Aspect map of Whetstone Branch

Comparison and Analysis of Design Parameters

Sears et al. (2012) recently designed an alternative valley fill for a site under construction in southern West Virginia. The design applied the geomorphic landform technique and used the design tool Carlson Natural Regrade with GeoFluv^{TM}. Default design parameters that were not specific to West Virginia were utilized in the design process (Table 4).

The measured values quantified in this research varied significantly from the default settings. All observed channels were characterized as colluvial as described by the Montgomery and Buffington (1993) classification system. All channel slopes were greater than 4% for this study and all measured sinuosity values were near one. The measured ridge to head of channel distances were nearly seven times greater than the value utilized in the Sears et al. (2012) design. The default drainage area was less than the measured value; however Sears et al. (2012) allowed a 20% error (6-9 km^{-1}). The experimental watershed value (5.3 km^{-1}) did not fall far outside this range (Table 4).

These reference landform design values are critical to design a system with low erosion rates. Systems designed with a lower than optimum drainage density will likely promote sediment deposition, and systems designed with a greater than optimum drainage density will likely promote erosion, leading to instability. Difference between default and measured parameters noted in this study were somewhat expected. The default design parameters incorporated into the design software were based on semi-arid regions. The geomorphic characteristics in southern West Virginia are a result of the steep slopes, consolidated soil, vegetation, and climatic influences of the region. These characteristics need to be considered for future designs.

Table 4. Comparison of default design parameters to measurements taken from experimental watershed

	Default		Measured	
Max distance from ridgeline to channel's head, m (ft)	24.4	(80.00)	162.8	(534.12)
Slope at mouth of main valley channel, %	2		8	
Drainage density, km^{-1} (ft/ac)	7.5	(100)	5.3	(70)
Upstream slope, %	12		28*	
Downstream slope , %	2		8	
Sinuosity (>-4%)	1.15		1.03*	
Sinuosity (<-4%)	1.48		NA‡	

*represents an average value
‡NA=not applicable

CONCLUSIONS

Because the geomorphic landform approach utilizes a reference landform design method, region specific design parameters are crucial to inform design. This research quantified the complex, steep terrain in southern West Virginia. Results from this study indicate differences between design parameters specific to southern West Virginia and default design parameters utilized in current design tools (i.e. Carlson Natural Regrade with GeoFluv^{TM}). The ridge to head of channel distance, slopes, and drainage density vary from the default values. These region-specific characteristics need to be considered for future designs.

Future work will quantify geomorphic characteristics in additional watersheds in the mining region of southern West Virginia. In addition, surveys of reclaimed sites of varying ages will also provide insight into generating successful designs. Designs will then be created using region specific design values and the differences in each design will be quantified. Ultimately, the research will provide the coal industry and regulators with data to advance watershed reclamation in Central Appalachia.

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