DEVELOPMENTS IN VALLEY-FILL RECLAMATION IN CENTRAL APPALACHIA: THE OF DESIGN STABLE AND SUSTAINABLE LANDFORMS

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Abstract

Surface mining reclamation practices in West Virginia result in stable valley fills with planar slope profiles. Environmental concerns related to these engineered structures include the loss of headwater stream length, increased flooding risk, and elevated conductivity and metal levels. One reclamation technique, geomorphic landform design, may offer opportunities to improve aspects of West Virginia valley-fill design. The approach designs landforms in a steady-state, mature condition and considers long-term climatic conditions, soil types, slopes, and vegetation. There are challenges in applying the method in the steep terrain of the West Virginia coal fields. This work will present recent research accomplishments related to applying geomorphic landform design in southern West Virginia. This research includes the following: i) conceptual geomorphic landform designs completed on a permitted valley fill; ii) the characterization of mature landforms in southern West Virginia to inform landform design processes; iii) a geotechnical slope stability evaluation of geomorphic landform designs for mountainous terrain; iv) an evaluation of differences in groundwater seepage between conventional and geomorphic landform designs; and, v) a comparison of hydrologic response. Ultimately, the research will provide the coal industry and regulators with knowledge to advance reclamation design and techniques.

Introduction

Surface mining and the associated reclamation is the leading source of landuse change in southern West Virginia (Townsend et al., 2009). In surface mining operations, seams are removed and overburden and interburden are placed in valleys. These external dumps are called valley fills and are designed to meet regulations for stability and water control (WVDEP, 1993). This process results in engineered landforms that differ from surrounding topography. In addition, the construction of valley fills result in headwater stream loss and environmental concerns (Hartman et al., 2005; Pond et al., 2008; Petty et al., 2010).

An innovative, alternative reclamation technique has potential to mitigate these impacts: geomorphic landform design. This method has been used in semi-arid regions with documented success (e.g. Toy and Chuse, 2005; Measles and Bugosh, 2007; Martin-Moreno et al., 2008; Bugosh, 2009, Robson et al., 2009; Martin-Duque et al., 2009). This technique designs landforms in an erosional steady state that appear natural (Martin-Duque et al., 2009). Geomorphic landform design has not yet been field tested for valley fills in southern West Virginia as there are several challenges. These challenges include meeting current regulations and creating stable landforms in steep terrain (Michael et al., 2010). Researchers at West Virginia University are working to provide scientific support to field test this technique for WV valley fills. Recent research accomplishments are summarized in this paper.

Current Research Progress

Research has evaluated the potential application of geomorphic landform design in West Virginia by assessing challenges associated with designing in steep terrain as well as considering potential benefits related to hydrologic response, stability, and seepage.

Design Challenges in Central Appalachia

The geomorphic landform method uses a reference landform approach. One challenge in applying geomorphic principles to the Central Appalachia region is that reference landform data (e.g. slopes, drainage density, and ridge to head-of-channel distance) are limited. Current software-published values for critical design criteria are not applicable to WV, and regional values need to be better defined (Sears et al., 2014).

Based on data gathered from field work (three minimally disturbed watersheds in southern West Virginia) and extended GIS analysis, the two critical input parameters were defined: drainage density and ridge to head-of-channel distance. The target drainage density for natural landforms in southern West Virginia was calculated to be 62 ft/ac, 38% less than the value targeted in previous designs. There were also substantial differences for the ridge to head-of-channel distance values. The field measured head-of-channel distance for WV was 400 ft, approximately five times the value used in previous designs. In addition, this field and GIS work characterized hillslope profiles, channel properties, and aspect variability.

A set of preliminary landforms have been completed for an existing valley fill, using the WV specific input parameters. A small scale fill was investigated in this study with the intention of designing a geomorphic landform that shows the practicality of a pilot construction project. The traditional valley fill footprint has an area of 11 ac. The initial designs included separate iterations for preserving the existing stream channel and creating a new stream. Fill volumes were compared to traditional reclamation.

Fill volume percentage as compared to the conventional fill was higher when a new channel was created (99% of volume accounted for in traditional fill) than when the existing channel was preserved (85%). The created channel landforms had a greater proportion of slopes in the low slope ranges suggesting that the landform is more stable than when preserving a channel. The slope stability analysis will be extended to identify critical slopes. In addition, channel properties will be evaluated to determine bed material size needed to support a stable channel. The impacted area will be evaluated to determine if the footprint needs to be increased to support both stable landforms and channels.

Seepage and Slope Stability Analysis

Conceptual two-dimensional profiles of geomorphic designs were analyzed with respect to seepage and slope stability. Results were compared to the seepage and slope stability of a conventional valley fill with a two-dimensional profile in the same location. The modeled two-dimensional profiles ran along the centerline of each fill. Groundwater and slope stability modeling were completed with the finite element method modeling software GeoStudio^{TM}. The SEEP/W module was used to produce groundwater seepage results over a 10 year period. Infiltration functions were created by coupling precipitation data with the surface profile of each fill. Increased infiltration into the conventional fill due to its relatively flat crest created areas of higher storage, hydraulic head, and pore pressures than in the geomorphic fill. Seepage was improved in the geomorphic fill due to lower infiltration volumes (Quaranta et al., 2013; Russell et al., in press).

The results from the seepage analyses served as inputs to a SIGMA/W stress analysis. The SIGMA/W analysis calculated *in situ* stresses within the fill structure. For both fill types, the in situ stress results produced spatially variable areas of increased total hydraulic head and elevated pore pressures. To investigate the effect of variation in stresses on slope stability, SIGMA/W results were used as input parameters for a SLOPE/W stability analysis. Entry and exit points were set to calculate factors of safety against crest, toe, face, and deep foundation failures. For each failure scenario, the geomorphic fill had a higher factor of safety than the conventional fill. This was due to the shallower slope profile associated with the geomorphic design. Additional two-dimensional profiles of the geomorphic fill were modeled to show that certain areas of the generated fill posed a problem with respect to slope stability. This was an area of concern that would have to be addressed in future designs (Quaranta et al., 2013; Russell et al., in press).

This work is currently being expanded to contaminant modeling, focusing on the mobility of selenium. Unsaturated column leaching tests were performed on coal overburden samples from two southern WV surface mines. Duplicate 15.2 cm diameter columns containing each soil were periodically leached with simulated rainwater (1,010 mL) similar in pH (~5.2) to southern WV rainfall. Leachate water was tested for dissolved Se. Saturated jar tests were performed by filling a series of 3.8 L jars with each soil, saturating the jars, and collecting water samples after certain time intervals. The samples were also tested for dissolved Se, and the desorption coefficient was calculated for each soil. Maximum selenium concentrations occurred in the unsaturated tests during the first two pours (0.071-0.185 mg/L). In the saturated test, selenium concentrations increased rapidly within the first day following saturation, reaching a value as high as 0.88 mg/L. The desorption coefficient varied by soil type (10^1-10^2 mL/g) but was consistent between replicated samples. Results from this work will be used in contaminant modeling.

Hydrologic Response

Four conceptual geomorphic landform designs were used to test the potential hydrologic response. These conceptual designs were based on one field site and did not go through an extended stability analysis. The designs were intended to feature potential features that may be included in future work and how they would impact hydrologic response. All designs were based on a permitted surface mine site (1.4 km^2) in southern West Virginia with a traditional valley fill. The tested design iterations included: i) dendritic drainage; ii) retrofit; and, iii) dendritic drainage with valley ponds. The dendritic drainage design applied basic geomorphic design principles to the permit area, adding channels, ridges, and valleys. The retrofit used the same design principles applied to the valley-fill crown. The pond design included three surface storage ponds to promote potential streamflow.

The peak flowrate, time to peak, and runoff volumes were evaluated at three stages of reclamation (during mining, post-mining (< 5 years), and post-mining (> 5 years)) for a range of storm events (1- through 500-year, 24-hour). Results were compared to the response of both the original, undisturbed topography and a conventional valley fill. The hydrologic response of the geomorphic landform design without detention ponds most closely resembled the values obtained for the original watershed. The geomorphic design with detention ponds lowered the peak flowrate, time to peak, and total runoff volume below the values generated by the original watershed. The runoff storage within the detention ponds provides the potential to allow stream flow in excess of ephemeral conditions. However, the ponds need to be properly sized to allow greater runoff storage if intermittent or perennial stream flow is desired. The effectiveness of the retrofit reclamation design was difficult to determine due to changes in watershed area and drainage pattern. These results indicate that geomorphic landform designs could be used to recreate the approximate hydrologic response of the original watershed for reclaimed mountaintop mine sites in southern West Virginia watersheds (Snyder, 2013). This work is being extended to create floodplain maps of the affected area, comparing the alternative to the conventional reclamation.

Summary and Conclusions

This work is addressing challenges associated with applying geomorphic landform design principles to valley-fill reclamation in West Virginia. We have defined geomorphic features specific to southern West Virginia, completed a series of geomorphic designs for individual valley fills, and analyzed designed fills (e.g. fill volumes, landform stability, channel stability, and hydrologic response). Future work will extend to detailed channel design and groundwater and contaminant transport modeling.

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