A STUDY OF THE FOREST RECLAMATION APPROACH ON HYDROLOGY OF MINE RECLAMATION SITES IN EASTERN KENTUCKY COAL FIELDS

RESEARCH PROPOSAL

A proposal submitted in partial fulfillment of the
Requirements for the degree of Master of Engineering in the
College of Biosystems and Agricultural Engineering
at the University of Kentucky

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Abstract

The environmental impacts from surface coal mining in the Applachian region include increases in downstream flooding and water quality degradation. To mitigate the effects, the Surface Mining Control and Reclamation Act (SMCRA) requires land to be restored to its approximate original contours and hydrologic regime. In practice, the heavy compaction from SMCRA techniques prevents water infiltration and hinders tree growth. The Forest Reclamation Approach (FRA) has been promoted to successfully establish native trees and increase infiltration at these sites. Research is now needed to determine how throughfall, interception and stream discharge are influenced by tree type and age on reclamined mine lands. Throughfall will be measured with randomly spaced tipping buckets on 10-year, 20-year and 100-year tree plots. Stream discharge will be compared across three watersheds: an FRA restored site, an SMCRA restored site, and a 100-year control site. Understanding of the effects of FRA on hydrologic characteristics can be used to model and predict the outcomes of mine reclamation techniques. This could benefit downstream communities by reducing the environmental impacts of surface mining.

Chapter One: Introduction

There are continued efforts to understand the effects of surface coal mining and subsequent restoration on the hydrology of the Appalachian coal region. Surface coal mining is a major industry in Appalachia resulting in environmental damage including deforestation, erosion and altered hydrologic regimes. These damages are seen in downstream communities as increased flooding and degradation of water quality.

Surface mining describes a wide range of mining practices involving deforestation and mountaintop removal to reach the underlying coal seams. Adjacent valleys are filled with the overburden, sometimes permanently and sometimes temporarily, before they can be used to regrade the mining area. This process results in hydrologic changes and significant increases in erosion and sediment loads (Bonta, 2000; Fox, 2009). Griffith et al. (2012) found areas downstream of valley-fills had higher flood occurences than nearby areas with undistubed land upstream. Even with reclamation post-mining, these hydrologic changes persist.

The Surface Mining Control and Reclamation Act (SMCRA) was enacted in 1977 to mitigate the environmental damage caused by surface mining operations. This act requires that hillslopes must be returned to their approximate original contours and hydrologic characteristics, such as peak flow, runoff volume and lag time, must match pre-mine conditions. In practice, peak flow may be the only hydrologic condition that is examined (Taylor et al., 2009a). Spoils are compacted to recreate the contours followed by seeding with aggressive grasses to stabilize the hillslopes.

Unfortunately, these reclamation techniques work against the establishment of native plant species and a return to the natural ecosystem. Compaction of the soil hinders root growth while aggressive species outcompete the native ones preventing the establishment of hardwood forests. Failure to re-establish forests on these sites has significant hydrologic impacts in addition to loss of habitat, carbon storage, and water quality protection (Zipper et al., 2011).

Heavy compaction and lack of canopy cover has a negative impact on the hydrology of the SMCRA restored sites. Heavy compaction creates impervious soils with decreased infiltration rates resulting in high surface runoff (Hoomehr et al., 2015). The volume of runoff is further increased lack of canopy cover reducing interception and evapotranspiration. Sena et al. (2014) found that a lack of forest cover increases overall water yield and heavy compaction is associated with higher flood magnitudes and shorter lag times. The combination of increased quantities of rainfall reaching the surface together with low infiltration rates leads to an overall increase in runoff.

The U.S. Department of the Interior, Office of Surface Mining has promoted the Forest Reclamation Approach (FRA) for mine site restoration with the Forest Reclamation Advisory being published in 2005. FRA is a method based on scientific research to establish forest on reclaimed mine land. This method requires that the best available material be loosely graded and planted with non-competitive ground covers and native tree species using proper tree planting techniques (Jim Burger, 2005). In contrast to the poor establishment of trees on SMCRA plots, studies have shown that trees planted on FRA sites have similar growth rates to trees at unmined sites (Zipper et al., 2011). Hydrologic conditions are restored both through the use of loose spoils themselves and through successful reforestation.

Loose spoils have been shown to increase infiltration rates producing curve numbers at or below mature forest (Taylor et al., 2009a). Additionally, hydrologic parameters are independent of spoil type so there is no need to separate them in the reclamation process (Taylor et al., 2009b). However, Sena et al. (2014) found that there was a difference in tree growth based on spoil type and that these differences were able to account for the seasonal variation in water discharge that was seen in the study. The decreased water discharge seen with better tree growth was attributed to evapotranspiration effects.

Interception and evapotranspiration plays an important role in the hydrology of a forest (Bryant et al., 2005). Helvey and Patric (1965) found interception losses to be approximately 15% with litter losses up to 5% for eastern forests. A study of northern hardwoods found interception losses to be 19% of total precipitation (Carlyle-Moses and Price, 1999).

Few studies have been done, due to the age of FRA plots, quantifying the effects of evapotranspiration on the growing forests of reclaimed mine sites. Furthermore, while it has been established that loose spoils are effective at increasing water infiltration, studies are needed to show if this impact is long term. Zipper et al. (2011) questions whether gravity will eventually consolidate surface soils or if this will be counteracted by forest establishment and root growth.

The Forest Reclamation Approach has proven successful at establishing forests on reclaimed mine sites. Preliminary studies have been done showing improved hydrology and water quality due to loose spoils. However, few studies have shown the long-term effects of reforestation on the hydrology of these sites. Watershed scale studies of hydrology are also needed for a FRA restored site as hydrologic studies to date have focused on small scale plots with bare soil or young growth trees.

Chapter Two: Objectives

Surface mining has a negative impact on the hydrology and water quality of the Appalachian coalfields. Hydrologic changes caused by deforestation and soil compaction, even with standard reclamation techniques, have resulted in increased peak flows and runoff. The Forest Reclamation Approach has been successful at establishing native trees and increasing infiltration at the mine sites, but data is needed on the hydrologic effect of this approach.

To quantify the effects of tree type and age, throughfall, interception and tree canopy characteristics will be measured based on age of reclamation and vegetation type: decidious, coniferous or grassland. The plots will be compared to mature forest control plots of deciduous and coniferous trees.

Daily flows will be measured in three watersheds; a FRA site, a SMCRA site and a control site. This will compare the effects of reforestation on daily and peak discharge from the watersheds.

While we know the hydrology of the SMCRA sites has not returned to original conditions, there is little information on the long term effects of FRA. If FRA sites show a hydrologic change towards pre-mine conditions, we will be able to demonstrate that reclamed mine sites can be restored not just visually (with native tree species) but functionally (with improved water quality and hydrologic function). This will benefit downstream communities by demonstrating the best techniques to minimize downstream impacts such as poor water quality and increased frequency and magnitude of floods.

Chapter Three: Methods

Study Plots:

Four study plots, of different tree types and ages, were selected for this study. Four of the study plots are reclaimed mine sites. Two are 20-year, un-compacted plots; one of white oak and the other pine. Two are 10-year FRA reclaimed plots of oak and pine. These four plots are flat compared to typical watersheds in this region. An additional plot of compacted grassland will be used to compare the FRA plots to a site without established forest.

Two plots are control sites in the Little Millseat branch of Robinson Forest. Both are characterized by over 100-year old growth with one site containing hemlock and the other containing white oak. These sites have the steep slopes characteristic of this region and it was not possible to use flat plots.

Three complete watersheds will be used to examine the hydrology of complete restoration sites. Guy Cove has been restored using the FRA technique and has significant tree growth throughout. Rattlesnake is a compacted site that has been reclaimed as grassland. Lastly, Little Millseat is an old growth forest that will be used as a control.

Site location has been recorded. Plot perimeters will be 30x30 feet with a buffer of at least 2 trees between the end of the plot and a change in tree type or topography. Plots will be as flat as possible with a survey to determine elevation differences between the gauges.

Meteorological Data:

To record base meteorological information three rain gauges will be placed in open fields within 900 meters from the test plots as was done by Bryant et al. (2005). This will provide site specific rainfall measurements to minimize errors from localized storms. Rainfall depth, intensity and duration will be recorded with Davis Rain Collector II tipping buckets and HOBO Rain Gauge data loggers. Temperature, wind speed, daily mean solar radiation and relative humidity will be recorded at nearby weather stations. Wind speed is an important component as rainfall can be underestimated due to evaporation losses due to the wind (Crockford and Richardson, 2000).

Interception and Throughfall:

Throughfall will be measured using funnels over tipping buckets dispersed randomly throughout each plot. Troughs have been used in some studies to integrate uneven rainfall over the area. However, results are inconclusive as to whether they are more accurate than funnels, possibly due to increased splash effects and evaporation (Helvey and Patric, 1965; Levia and Frost, 2006). Tipping buckets were chosen since they have a more robust design that will interfere less with the native species.

12 tipping buckets will be used per site and placement will be randomly determined for each site based on the location of obstacles such as trees and large rocks. Helvey and Patric (1965) determined that no less than 13 funnels per site should be used, however, plot sizes were not specified. Bryant et al. (2005) divided plots into four sampling grids of 10m x 10m with 4 gages per plot. Levia and Frost (2006) recommends 15 per plot to reduce error but did not specify the plot size. Research suggests gages be relocated after each precipitation event as this provides more accurate results with fewer gages (Bryant et al., 2005; Levia and Frost, 2006). The rocky nature of our sites will make relocation of the tipping buckets difficult. To address this the tipping buckets will be rotated around a stand by 90 degrees at the same interval as the data collection.

In addition to the tipping buckets in the trial plots, one tipping bucket per region (the plots are spaced across three regions) will be used in an open area to collect total or gross rainfall.

Data collection is suggested to take place weekly, biweekly or after each precipitation event for at least one year due to seasonal variations (Levia and Frost, 2006). Data will be collected continuously through data loggers, however frequent site visits are required to ensure the functioning of the equipment and to relocate the gages. This study will use a biweekly data collection method on the same schedule as the rotation of the buckets.

Interception and Evapotranspiration will be calculated based on the net throughfall subtracted from gross rainfall that is collected from the open field rain gauges.

Canopy Cover:

Canopy cover and characteristics will need to be measured seasonally. A Model-A spherical densitometer will be used to measure the canopy cover once per season.

Watershed Hydrology:

Canopy effects have been shown to have significant impact on the hydraulics of forest ecosystems by increasing interception and evapotranspiration (Griffith et al., 2012). Additionally, it is suspected that a forest ecosystem could impact infiltration rates and groundwater storage. Daily flow will be collected for two restored watersheds (one FRA and one SMCRA) and one control watershed to determine the effects of tree type and age on watershed discharge. Daily water level will be recorded using Solinst levelloggers and barologgers placed in the stilling wells at flume sites for the streams. Guy Cove, the FRA stream, has three flumes along its length which will all be monitored. Rattlesnake, the SMCRA site, and Little Millseat, the control site, have one flume each that will be monitored. Water level and air pressure information along with flume dimensions will be used to calculate discharge. Hydrographs will be produced based on rainfall data collected at the nearby weather stations.

References

Bonta, J. V. 2000. IMPACT OF COAL SURFACE MINING AND RECLAMATION ON SUSPENDED SEDIMENT IN THREE OHIO WATERSHEDS1. *JAWRA Journal of the American Water Resources Association* 36(4):869-887.

Bryant, M. L., S. Bhat, and J. M. Jacobs. 2005. Measurements and modeling of throughfall variability for five forest communities in the southeastern US. *Journal of Hydrology* 312(1–4):95-108.

Carlyle-Moses, D. E., and A. G. Price. 1999. An evaluation of the Gash interception model in a northern hardwood stand. *Journal of Hydrology* 214(1–4):103-110.

Crockford, R. H., and D. P. Richardson. 2000. Partitioning of rainfall into throughfall, stemflow and interception: effect of forest type, ground cover and climate. *Hydrological Processes* 14(16-17):2903-2920.

Fox, J. F. 2009. Identification of Sediment Sources in Forested Watersheds With Surface Coal Mining Disturbance Using Carbon and Nitrogen Isotopes1. *JAWRA Journal of the American Water Resources Association* 45(5):1273-1289.

Griffith, M. B., S. B. Norton, L. C. Alexander, A. I. Pollard, and S. D. LeDuc. 2012. The effects of mountaintop mines and valley fills on the physicochemical quality of stream ecosystems in the central Appalachians: A review. *Science of The Total Environment* 417–418:1-12.

Helvey, J. D., and J. H. Patric. 1965. Canopy and litter interception of rainfall by hardwoods of eastern United States. *Water Resources Research* 1(2):193-206.

Hoomehr, S., J. S. Schwartz, D. Yoder, E. C. Drumm, and W. Wright. 2015. Erodibility of low-compaction steep-sloped reclaimed surface mine lands in the southern Appalachian region, USA. *Hydrological Processes* 29(3):321-338.

Jim Burger, D. G., Patrick Angel, Vic Davis, Carl Zipper. 2005. Forest Reclamation Advisory No. 2. *The Appalachian Regional Reforestation Initiative*.

Levia, D. F., Jr., and E. E. Frost. 2006. Variability of throughfall volume and solute inputs in wooded ecosystems. *Progress in Physical Geography* 30(5):605-632.

Sena, K., C. Barton, P. Angel, C. Agouridis, and R. Warner. 2014. Influence of Spoil Type on Chemistry and Hydrology of Interflow on a Surface Coal Mine in the Eastern US Coalfield. *Water, Air, & Soil Pollution* 225(11):2171.

Taylor, T. J., C. T. Agouridis, R. C. Warner, and C. D. Barton. 2009a. Runoff curve numbers for loose-dumped spoil in the Cumberland Plateau of eastern Kentucky. *International Journal of Mining, Reclamation and Environment* 23(2):103-120.

Taylor, T. J., C. T. Agouridis, R. C. Warner, C. D. Barton, and P. N. Angel. 2009b. Hydrologic characteristics of Appalachian loose-dumped spoil in the Cumberland Plateau of eastern Kentucky. *Hydrological Processes* 23(23):3372-3381.

Zipper, C. E., J. A. Burger, J. G. Skousen, P. N. Angel, C. D. Barton, V. Davis, and J. A. Franklin. 2011. Restoring Forests and Associated Ecosystem Services on Appalachian Coal Surface Mines. *Environmental Management* 47(5):751-765.

Appendix 1: Budget

1. Direct Costs			Year 1	Year 2	Total
	A. Salaries and Wages				
		Graduate Researcher	$16,000.00	$16,000.00	
		Total Salaries and Wages	**$16,000.00**	**$16,000.00**	$32,000.00
	B. Fringe Benefits				
		Graduate Researcher	$1,416.00	$1,416.00	
		Total Fringe Benefits	**$1,416.00**	**$1,416.00**	$2,832.00
	C. Travel				
		(1) ASABE meeting	$1,337.00		
		(2) Gas to research site	$1,650.00	$1,650.00	
		Total Travel	**$2,987.00**	**$1,650.00**	$4,637.00
	D. Materials and Supplies				
		(1) Wire fencing	$50.00		
		(1) Rebar	$50.00		
		Total Materials and Supplies	**$100.00**	**$0.00**	$100.00
	E. Equipment				
		(1) Davis II Rain Gauge	$1,216.00		
		(2) HOBO Pendant	$2,520.00		
		(3) HOBO Shuttle	$249.00		
		(4) HOBO Base Station	$124.00		
		(5) HOBOware Pro	$75.00		
		Total Equipment	**$4,184.00**	**$0.00**	$4,184.00
	F. Other Direct Costs				
		(1) Publication costs	$1,000.00		
		(2) Tuition and fees	$14,190.00		
		Total Other Direct Costs	**$15,190.00**	**$0.00**	$15,190.00
	G. Modified Total Direct Costs		**$39,877.00**	**$19,066.00**	**$58,943.00**
2. Indirect Costs			**$19,938.50**	**$9,533.00**	**$29,471.50**
3. Total Costs			**$59,815.50**	**$28,599.00**	**$88,414.50**

Budget Justification:

1. Direct Costs
   A. Salaries and Wages
      (1) Based on current departmental stipend of $16,000/year for a MS Research Assistant.
   B. Fringe Benefits
      (1) Current University of Kentucky fringe benefit rate for graduate students is 8.85%
   C. Travel
      (1) Attendance at 2017 International Meeting of ASABE. Air fare estimated as $514, three days' lodging and per diem at $99 + $64 per day and meeting registration of $334.
      (2) 30 round trips from Lexington to Robinson Forest at 220 miles per round trip and a standard mileage rate of $0.50/mile.
   D. Materials and Supplies
      (1) Wire Fencing to construct elk fences around the equipment.
      (2) support measurement equipment and elk fences.
   E. Equipment
      (1) Davis II Rain Gauge
      (2) HOBO Pendant
      (3) HOBO Shuttle
      (4) HOBO Base Station
      (5) HOBOware Pro

      Equipment to construct tipping buckets and measurement system.
   F. Other Direct Costs
      (1) Estimated 10-page article to be published in *Transactions of the ASABE* at $100/page.
   G. Modified Total Direct Costs. As per University of Kentucky guidance, calculated as Total Direct Cost less graduate tuition and equipment.

2. Indirect Costs. Calculated as 50% of Modified Total Direct Costs as per University of Kentucky Office of Sponsored Projects Administration.

Appendix 2: Research Plan

Milestones:

Completed:

9/24/16: Completed GIS Tutorial

10/14/16: Identify Sampling Sites and obtain GPS Coordinates

3/14/17: Installation of tipping buckets

To-do:

5/2/14: Install flume and levellogger at Rattlesnake

4/1/18: End data collection

4/30/18: End statistical analysis

5/1/18: Complete final report