12-1-2011

EROSION FROM A CROSS COUNTRY GAS PIPELINE IN THE CENTRAL APPALACHIANS

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by

Bridget Harrison

B.S., Southern Illinois University, 2007

A Thesis

Submitted in Partial Fulfillment of the Requirements for the

Master of Science

Department of Forestry

in the Graduate School

Southern Illinois University Carbondale

December 2011

THESIS APPROVAL

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June 29, 2011

AN ABSTRACT OF THE THESIS OF

Bridget Harrison, for the Master of Science degree in Forestry, presented on June 29, 2011, at Southern Illinois University Carbondale.

TITLE: EROSION FROM A CROSS COUNTRY GAS PIPELINE IN THE CENTRAL APPALACHIANS

MAJOR PROFESSOR: Dr. Karl W. J. Williard

Increasing energy demand, coupled with the recent emphasis on domestic production, has resulted in an increase in natural gas exploration and pipeline construction in the central Appalachian region. Very little is known about the effects of natural gas pipeline construction on sediment production. The goals of this project were to measure erosion and examine the effects of vegetation and precipitation characteristics on erosion on a newly constructed pipeline in the Fernow Experimental Forest in West Virginia. The study explored whether seed rate, slope class, or aspect, influenced erosion. The cross country pipeline was buried beneath the surface on study hillslopes ranging from 30-68% and beneath a less steep segment with slopes ranging from 18-26%. A mixture of native herbaceous-plant seeds and straw mulch were applied following construction. Two different seeding rates were applied to compare vegetative recovery and to determine if increasing the seed rate would decrease erosion. A 1-time seed rate, or the normal Forest Service application rate, and a 3-time seed rate (1-time + twice that rate) were tested. Two aspects (northwest-facing and southeast-facing) and four precipitation variables (30-minute maximum intensity, duration, total rainfall amount, and time since last event) were defined. Sediment concentrations were compared for differences between two slopes, two seed rates, and two aspect classes. Precipitation variables were analyzed to identify those that could explain significant amounts of the variability in erosion from the pipeline. The 1-time seed rate sections

produced less sediment than the 3-time seed rate sections, but this was probably more a function of subsurface flow differences associated with the sections seeded with the lighter rate and the water bar construction. Precipitation intensity explained the most variability in erosion. Study sites with gentler slopes produced less sediment than the steeper sections, as expected. As vegetation became established, sediment concentrations decreased for all study sections and reached low and relatively constant levels by approximately the end of August 2009.

ACKNOWLEDGMENTS

I would like to thank my committee for all their support, guidance, and encouragement. I want to thank Dr. Karl Williard for his patience and understanding during this process. I would like to give a special thanks to Dr. Pam Edwards and Freddie Wood for the living accommodations they provided me for the two summers that I worked in WV. Also, I thank them for their constant guidance during my entire masters program. I would like to thank Freddie Wood for tabulating and processing raw data and Robin Quinlivan and Greg Evans for the help they provided both in field sampling and laboratory analyses. I want to thank Stephanie Connolly and Linda Tracy for their assistance and for the information they provided for my study. I also want to thank the Monongahela National Forest in WV for providing the funding for this research. Lastly I want to thank my family and friends, my support and inspiration to make it through to the end.

TABLE OF CONTENTS

LIST OF TABLES

TABLE PAGE

LIST OF FIGURES

FIGURE PAGE

CHAPTER 1

INTRODUCTION

Fossil fuel exploration is essential to supply the United State's current dependency on gas, oil, and coal. Domestic natural gas production is expected to increase from 20.6 trillion cubic feet to 23.3 trillion cubic feet from 2008 to 2035 (EIA, 2009). In the Northeast, natural gas production is expected to rise by 35 percent from 2008 to 2035 (EIA, 2010).This increase in production will necessitate the construction of additional miles of gas pipeline.

Cross county pipelines utilized to transport bulk petroleum products are some of the most energy efficient, safe, and economic means of transporting hydrocarbons (gas, crude oil, and finished product) over long distances (Dey et al. 1996). The economy of a country, like the United States, may be heavily dependent on uninterrupted functionality of these gas pipelines (Dey and Gupta, 2000). Cross country pipelines can be buried or installed above ground. Buried cross country pipelines are installed in trenches along cleared rights-of-way that traverse through a variety of terrain (Dey, 2002).

Gas pipeline construction changes the surface of the land by removing the vegetative layer and exposing mineral soil, at least temporarily. With the mineral soil exposed, an increase in erosion and sedimentation may occur. However, only a limited number of studies have examined the effects of pipeline construction on erosion and sedimentation (Robinson and Yule, 1974; Anderson et al., 1995; Long et al., 1998; Morgan et al., 2003; Reid et al., 2004; Holz, 2009). The study described herein was designed to quantify erosion from portions of a pipeline and identify factors that influence erosion immediately after pipeline construction. Best management practices (BMPs), or techniques used to control nonpoint source pollution, especially erosion, included water bar installation on steep slopes, and seeding with native herbaceous and grass species and straw mulching following re-contouring of the soil surface. Specific objectives of the study included:

1) Quantify sediment loss after pipeline construction for one year.

2) Determine if the amount of eroded sediment was significantly different between two seed application rates, two aspects, or two slope classes.

3) Determine if precipitation amount, duration, intensity, and time between events could explain a significant amount of the variability in erosion.

CHAPTER 2

LITERATURE REVIEW

The three steps of the soil erosion process are detachment, transport and deposition of soil particles. Soil detachment is most probable where mineral soil has been exposed, compaction has occurred, or water has been concentrated (Stuart and Edwards 2006). Particle detachment can occur from either raindrop impact or concentrated flow. The kinetic energy of raindrops can displace soil particles vertically as high as 0.05 m and laterally as far as 1.5 m (Brooks et al., 2003). The shear stress of water must exceed the shear strength of soil for detachment by concentrated flow to occur. Detachment rates increase with increasing flow rates and slope gradients (Zhang et al., 2008). After soil particles have been dislodged, transport can occur from raindrop impact or overland flow, functioning separately or together (Kinnell, 2005). Raindrop splash can transport particles in all directions away from the site of soil detachment.

Sediment transport can occur by sheet flow, interrill, and rill erosion. Sheet flow is an erosion mechanism characterized by a thin flow of water overland. It has the capacity to carry sediment and is the precursor to interrill erosion (Brooks et al., 2003). Interrill soil erosion occurs from soil detachment by raindrop impact and is dependent on the transport capacity of thin sheet flow (Bradford et al., 1987). Interrill erosion can be caused by a complex mixture of the influences of raindrop impact and sheetflow (Bryan, 2000). Rills are formed when concentrated overland flow creates narrow, shallow channels on the ground surface, primarily on sloping terrain (Bryan, 2000). As runoff becomes concentrated in rills and moves down slope, the velocity, intensity, and turbulence of the flow may increase (Brooks et al., 2003). Soil movement by rill erosion can become extensive and eventually turn into gullies.

Deposition occurs when surface runoff slows and its energy is insufficient to keep particles entrained. However, if sediment reaches water bodies by overland flow, sediment can be deposited within their beds during reduced streamflow rates. Sediment deposition in waterways can smother fish eggs and macro-invertebrates, and reduce the quality of aquatic habitats, thus, reducing intolerant aquatic species (Nuttall and Bielby, 1973).

A variety of factors, such as slope steepness, vegetative cover, aspect, and rainfall characteristics can influence the amount of erosion in a watershed. Slope steepness can have a significant effect on erosion because steeper slopes may give rise to greater surface runoff velocity, increasing the potential for sediment detachment and transport. While detachment rates increase only slightly with increasing slope, sediment transport capacity increases greatly on steepened slopes (Ellison 1944; Quansah 1981). Steeper slopes increase erosion from rill development because of increased shear velocities (Chaplot and LeBissonnairs, 2000), which increase the ability for flow to concentrate further and develop additional or larger rills.

The momentum that can be gained by surface runoff on a slope, and the amount of soil that can be lost from the area depends in part on the slope gradient and the length of the unobstructed slope (Brooks et al., 2003). Slope length can influence soil erosion independently from slope steepness; however, slope length may not be an important factor influencing runoff velocity until grades of 8 to 10 percent are reached (Chaplot and LeBissonnais, 2000; Kinnel, 2000). Long contributing lengths on flat surfaces encourage little surface runoff or erosion.

Longer slope lengths may result in higher amounts of soil loss on steep slopes because of the ability to increase surface runoff velocity (Brooks et al. 2003). On less steep slopes, surface runoff reaches its maximum velocity in a short distance, and terminal velocity is relatively low. The terminal velocity and the distance required to reach that velocity increase as slope increases (Chaplot and LeBissonnais, 2000). During simulated rain events in a laboratory experiment, sediment was deposited on slopes of less than 5 percent grade with low rainfall intensities (Huang et al., 1999). As slope steepness and rainfall intensity increased, soil transport became more dominant than soil deposition.

Regardless of slope steepness and slope length, erosion can be reduced with vegetative cover. Soil erosion on steep slopes can be inhibited greatly with dense, self-sustaining vegetative ground cover (Swift, 1984; Freebairn et al., 1986; Zellmer et al., 1991; Quinton et al., 1997; Loch, 2000). However, steep slopes may be difficult to vegetate because seed can be washed off the soil surface (Bochet and Garcia-Fayos 2004). Reid and Anderson (1999) found that erosion from bare soil was an average of three times greater than that from vegetated soil. As vegetation becomes established erosion rates decline (Bethlahmy and Kidd, 1966). At 50 to 60 percent vegetative cover, erosion is substantially reduced (Quinton et al., 1997; Loch, 2000). Plant roots provide physical reinforcement and bind soil particles together so they resist erosion from concentrated flow (Tengbeh, 1993; Gyssles and Poeson, 2003; De Baets et al., 2006). In addition plants reduce the impact of displacement caused by raindrops (Quinton et al., 1997).

In addition to seeding, other soil amendments including mulching have been shown to reduce erosion. Organic mulch, such as straw, can protect bare soil from erosion by preventing raindrop impact (Bethlahmy and Kidd, 1966). Mulch also increases soil moisture retention and the success of vegetation establishment; vegetation provides longer-term protection as mulch decays (Harbor, 1999). Combined cost and erosion-control data indicated that straw mulch applied at a rate of 3.35 t ha^{-1} was economical and effective compared to other erosion control methods (Zellmer et al., 1991). Robinsons and Yule (1974) reported that straw is better suited as mulch than hay. Although no direct reason was provided, it may be that hay contains a mixture of vegetative species and could result in the introduction of invasive plants to the area.

Aspect plays an important role in determining the erosion potential of a hillslope by affecting vegetation establishment. South-facing slopes are generally the driest aspects because they receive the most solar radiation year-round (Churchill, 1982). They also have higher incidences of freeze-thaw cycles, which make permanent vegetation establishment difficult (Hursh 1949; Miller and Buell, 1956). Bochet and Garcia-Fayos (2004), Swift (1984), and Bold et al. (2010) all found poorer vegetation establishment on south-facing road cutbanks. By contrast, north-facing soils receive less solar radiation which decreases soil drying. North-facing soils also experience less frost heaving in the winter (Hursh, 1949; Miller and Buell, 1956), thus, reducing the potential for erosion. Northwest-facing slopes may have an advantage for establishing vegetative cover compared to other aspects. They experience the combined benefits of the afternoon sun and later day warming associated with west-facing slopes, while having lower direct solar radiation and evapotranspirational losses associated with north-facing slopes (Bold et al., 2010).

Rainfall intensity can influence erosion rates (Meyer, 1981) and frequently has been found to be the most important factor influencing erosion (Nichols and Sexton, 1932; Reid et al., 1999; Holz et al., 2009). As rainfall intensity increases so does the kinetic energy of the raindrops, which increases soil detachment and transport (Ellison, 1944; Quansah, 1981). The kinetic energy of a raindrop is influenced by its mass and the velocity; as mass and velocity increase, so does kinetic energy (Stuart and Edwards, 2006).

Sediment from land disturbance from natural gas pipeline construction sites can produce localized, concentrated impacts as well as significant cumulative impacts over longer time periods (Dunne and Leopold 1978; Goldman et al 1986; Marsh 1991; Anderson et al., 1995). Most impacts observed by Anderson et al. (1995) were associated with increased levels of sediment deposition, and were reported to have the highest potential to cause changes to stream community structure.

In addition to impacts of deposition from adjacent construction sites, waterway-crossing construction can have a direct impact on water bodies. Waterway-crossing construction can increase downstream total suspended sediment (TSS) concentrations (Reid and Anderson, 1999) through trench excavation, backfilling, installation of diversion structures, erosion and run-off from adjacent upland worksites, and the discharge of water from hydrostatic pipe testing or trench dewatering (Reid et al., 2004). Reid et al. (2004) examined the waterway crossing construction methods of open cut crossings, flume crossings, and dam and pump. Their research advised that each construction project must be assessed for the best possible method to prevent erosion and sedimentation.

Actions can be taken to prevent or control adverse effects of land use on water quality. Best management practices (BMPs) are techniques that can be applied to control erosion both during and following land-altering and waterway-altering activities. BMPs were established as mitigation measures that are applied to site-specific activities to reduce, prevent, or avoid adverse environmental or social impacts (U.S. Department of Interior, 2009). The design of BMPs is guided by the laws of physics and chemistry. This is manifested in the consideration of potential influences of gravity on erosion of slopes, and the effect of kinetic energy of water on soil detachment (Stuart and Edwards, 2006). BMPs associated with oil and gas development activities in West Virginia have been established for pipeline planning, construction, reclamation, re-vegetation, and maintenance (WV Division of Environmental Protection Office of Oil and Gas, 2009).

CHAPTER 3

METHODS

Study Area

Pipeline Construction and Features

The study area is a natural gas pipeline right-of-way in the Monongahela National Forest. The study sections of the pipeline are located within the Fernow Experimental Forest (Fig. 1). The pipeline is associated with the B800 gas well, which is also on the Fernow.

The Fernow is located in the Allegheny Mountain section of the unglaciated Allegheny Plateau. The mean annual precipitation during the past 30 years (1978-2008) was 148.39 cm (F. Wood, Personal Communication, July 2010). The Fernow is a mixed hardwood forest and the principle overstory species include northern red oak (*Quercus rubra*), sugar maple (*Acer saccharum*), yellow-poplar (*Liriodendron tulipifera*), and red maple (*Acer rubrum*).

Figure 1. The Fernow Experimental Forest in the Monongahela National Forest in West Virginia. The pipeline extends further northwest than shown, but the study was performed on pipeline segments in the portion illustrated.

The B800 pipeline originates in compartment 16A of the Fernow Forest, which also holds the gas well serviced by the pipeline. The pipeline extends cross country northwest through the Fernow, crosses under Elklick Run and up to the ridge of Fork Mountain. It follows along Forest Service Road 709, and goes through the woods and into land administered by the Monongahela National Forest. The pipeline then continues onto private property.

The pipeline is a buried cross country pipeline that was installed in the summer of 2008 and was completed during the spring of 2009 (Table 1). Vegetation was cleared from the right-of-way, and an excavator dug the trench. The pipe was laid in the trench and covered with the excavated soil using a small excavator or a bull dozer.

Table 1. Timeline indicating important dates for construction and study sampling.

Date	Activity
October 2, 2008	Timber removal commenced
April 28, 2009	Water bar installation completed 1-time seed rate applied to pipeline right-of-way 3-time seed rate applied to 6 study sections Mulch applied to pipeline right-of-way
June 12, 2009	Collected pipeline runoff samples (all tanks 1-15)
July 15, 2009	Connected splitters to four installations
July 27, 2009	Vegetation photographs taken
June 10, 2010	Last runoff sample collected

The pipeline is constructed of Polyflow Thermoflex® 3.5-in diameter tubing. It was buried 76 cm below the surface, unless restricted by rock. When it crossed under a Forest Service road, it was buried at approximately 91 cm. The right of way was approximately 9.14-m wide unless it followed adjacent to a Forest Service road – in that case the right-of-way was 4.57-m wide. The narrower right-of-way when following a Forest Service road was possible because machinery and equipment were able to utilize the road for work space.

Water-control features were installed after pipeline installation was complete (Table 1). Out-sloping and crowning were used as the primary water control methods in segments of the pipeline located in flatter ridge-top or bench areas. Water bars were the primary water controls utilized for the steeper sections of the right-of-way. Water bars are mounds of earth consisting of compacted soil built across the right-of-way at an angle (Fig. 2). They are designed to divert runoff in small quantities from sloped land to nearby undisturbed, and usually vegetated or otherwise protected areas, thus, reducing erosion potential. Water bars were installed using a John Deere 120D backhoe, and their spacing was dependent on percent slope of the right-of-way as described by the best management practices for minerals development utilized by the Forest Service (Table 2). The spacing refers to the space from the crest of one water bar to the crest of the following water bar.

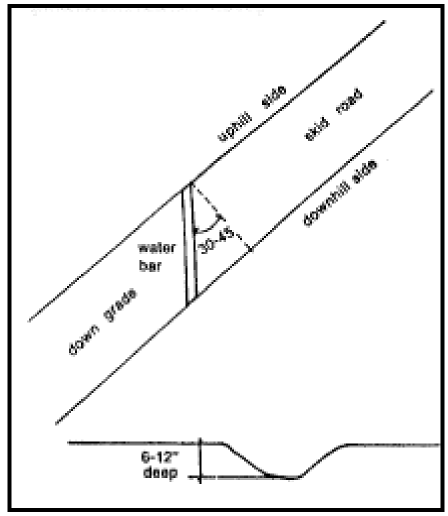

Figure 2. A water bar installed in the field following pipeline installation, and a schematic of a water bar installed on a skid road following WV silvicultural BMPs (WV Division of Forestry, 2005). The method shown for the skid roads is essentially what was used for the pipeline.

Table 2. Water bar spacing requirements associated with hill-side slopes (Thompson, 2008).

Slope (%)	**Distance between water bars (m)**
5-10	30-60
10-15	20-30
15-20	15-20
>20	15

Reclamation measures were applied after the water control features were fully constructed (Table 1). The contractor applied a seed mixture at a standard Forest Service total rate of 50 lb ac^{-1} (hereafter referred to as the 1-time seed rate). The species were a mixture of native grasses and legumes (Table 3). Nurse crops of annual ryegrass, oats, and partridge pea were chosen to serve as establishing plants, to provide a quick vegetative cover, while giving the other more-slowly establishing species an opportunity to grow. Canada milkvetch serves as a nitrogen fixer and is a perennial legume. Along with the Canada milkvetch, a variety of perennial grasses were planted.

As part of the experimental design for this study, a higher seed rate was applied to individual sections of the pipeline, described later. This seeding involved the same seed mixture. Following seeding, the entire pipeline was fertilized (600 lb ac^{-1} of 10-20-10 (N, P, K)), limed (2 tons ac^{-1}), and straw mulched (2 tons ac^{-1}).

Table 3. Species, function, and application rates of seeds used to re-vegetate the entire length of the pipeline.

Common name	**Scientific name**	**Function**	**Seed rate (lb ac^{-1})**
Annual ryegrass	*Lolium mulitflorum*	Nurse crop/ grass	30
Oats	*Avena sativa*	Nurse crop/ grass	3
Partridge pea	*Chamaecrista fasiculate*	Nurse crop/ legume	2
Canada milkvetch	*Astragalus canadensis*	Perennial/ legume	2
Little bluestem	*Andro-pogon scoparius*	Perennial grass	3
Autumm bentgrass	*Agrostis perennans*	Perennial grass	4
Deer tongue	*Panicum clandestinium*	Perennial grass	6
Total			50

Pipeline Study Sections

Erosion monitoring was focused on sections of the pipeline that used water bars to control drainage. Fifteen water-barred sections, defined as the area from the crest of a water bar to the crest of the neighboring water bar, were selected for study.

Based on an initial reconnaissance of the pipeline, six sections on the northwest-facing aspect and six sections on the southeast-facing aspect of the pipeline were selected for study. Sections were selected based on accessibility for equipment installation and sampling, and their associated aspect and slope. Following this initial reconnaissance, a more complete survey of the pipeline sections was conducted using a total station. Each section was surveyed along the crest and base of its water bar, along the edge on each side, and one-third of the way in each direction from the edge. Additionally the pipeline study sections were surveyed anywhere there was a slope break. The survey points were used to calculate the average slope, average contributing lengths, and areas of each section. After selecting the study sections that would receive the additional seed (described below), the survey data were used to determine the amount of additional seed needed. Three less-steeply sloping sections on the northwest-facing aspect also were selected to examine the influence of pipeline gradient on erosion.

The pipeline boundary was surveyed during the summer of 2009 using a TOPCON™ AT-G3 total station. Each total station point represents an X, Y, and Z coordinate that is relative to the location and elevation of the total station itself. Consequently, the shared corner markers for two research compartments located along a road were used as GPS reference points to correct elevations in each survey file and to correctly align the points of each file in space. The elevations for the remaining data in that same total station file were corrected accordingly, and the elevations in all other files were sequentially corrected using temporary benchmarks measured in each set of spatially adjacent files.

These common benchmarks also were used to align individual files properly in space using ArcMap™ 9.1. Files were organized and rotated so the replicate temporary benchmarks measured in adjacent files overlapped. The X-Tools extension was used to assign the correct X and Y coordinates to each point. The result was a point shapefile in ArcMap™ that was used to calculate the aspect, area, mean slope, and mean contributing length of the 15 study sections.

Using ArcMap™, a polygon shapefile was created for each of the pipeline sections using the boundary points of each. With the 3D Analyst extension in ArcMap™, a triangulated irregular network (TIN) for each of the pipeline sections was created. The TINs were restricted to the pipeline section boundaries using the polygon shapefiles. The 3D Analyst extension was used to calculate the surface area of each pipeline section and to produce raster layers from the TINs of the slope of the pipeline.

Changes in elevation were not accounted for using GIS because distances are measured in the horizontal plane; therefore, slope distance was calculated manually using Microsoft® Excel between each pair of points along the surveyed length and width transects of the pipeline segment. A known side of each right triangle was the difference in elevation between the two points, and the other was the horizontal length between the two points. With two known sides, the Pythagorean Theorem was used to calculate the hypotenuse, or the pipeline surface slope distance for each segment. The segment slope length results were summed for each transect of each individual pipeline section. The average slope length for each section was calculated as the mean of all slope length transects for the section. These slope lengths also were used to calculate the pipeline aspect. The points used for calculating aspect included only points on the face of the study section and excluded any water bar points. Pipeline widths were calculated using the same approach used for lengths.

The total area, mean contributing lengths, and average slopes for each section are given in Table 4. Total area ranged from 46.67 to 176.34 m^2 and mean contributing lengths ranged from 4.61 to 25.58 m. The average slope of the less-steep sections (sections 7-9) ranged from 18.6 to 26.8 percent, the steep northwest-facing sections (sections 1-6) ranged from 43.8 to 50.0 percent, and the steep southeast-facing sections (sections 10-15) ranged from 30.2 to 68.4 percent (Table 4, Fig. 3).

Table 4. Surface area, mean slope, aspect, and mean contributing length of each of the 15 study sections. The less-steep sections are sections 7-9.

Section	**Surface area (m^2)**	**Mean slope (%)**	**Mean contributing length (m)**
		Northwest-facing aspect	
1	85.45	50.0	8.51
2	110.72	51.5	10.88
3	111.61	43.8	10.86
4	100.30	45.7	9.95
5	83.08	46.8	7.82
6	102.23	44.4	13.74
7	119.69	26.8	18.94
8	143.32	20.7	25.58
9	110.64	18.6	19.44
		Southeast-facing aspect	
10	148.49	57.0	10.77
11	154.96	57.9	13.72
12	176.34	30.2	19.19
13	95.62	67.6	11.58
14	46.67	68.4	4.61
15	68.01	48.5	7.33

To determine if erosion could be controlled more effectively using a higher seed rate than the standard 1-time seed rate, a 3-time seed rate (i.e., a 2-time seed rate of the same seed mixture was applied in addition to the original 1-time rate, equaling a total seed rate of 150 lb ac^{-1}) was applied to three of the steep sections on each aspect on April 28, 2009 (Fig. 3).

Because the mean contributing lengths of the individual pipeline sections varied, study sections of similar length on the northwest- and southeast-facing aspects were paired. Pairing the sections based on mean contributing length allowed for a more equal comparison of aspects and seed rates. Contributing length rather than total area was used as the pairing factor because surface runoff would occur predominantly along the length vector of the pipeline. The sections for the 3-time seed rate were chosen randomly for the northwest-facing sections, and then applied to the corresponding southeast-facing section (Table 5).

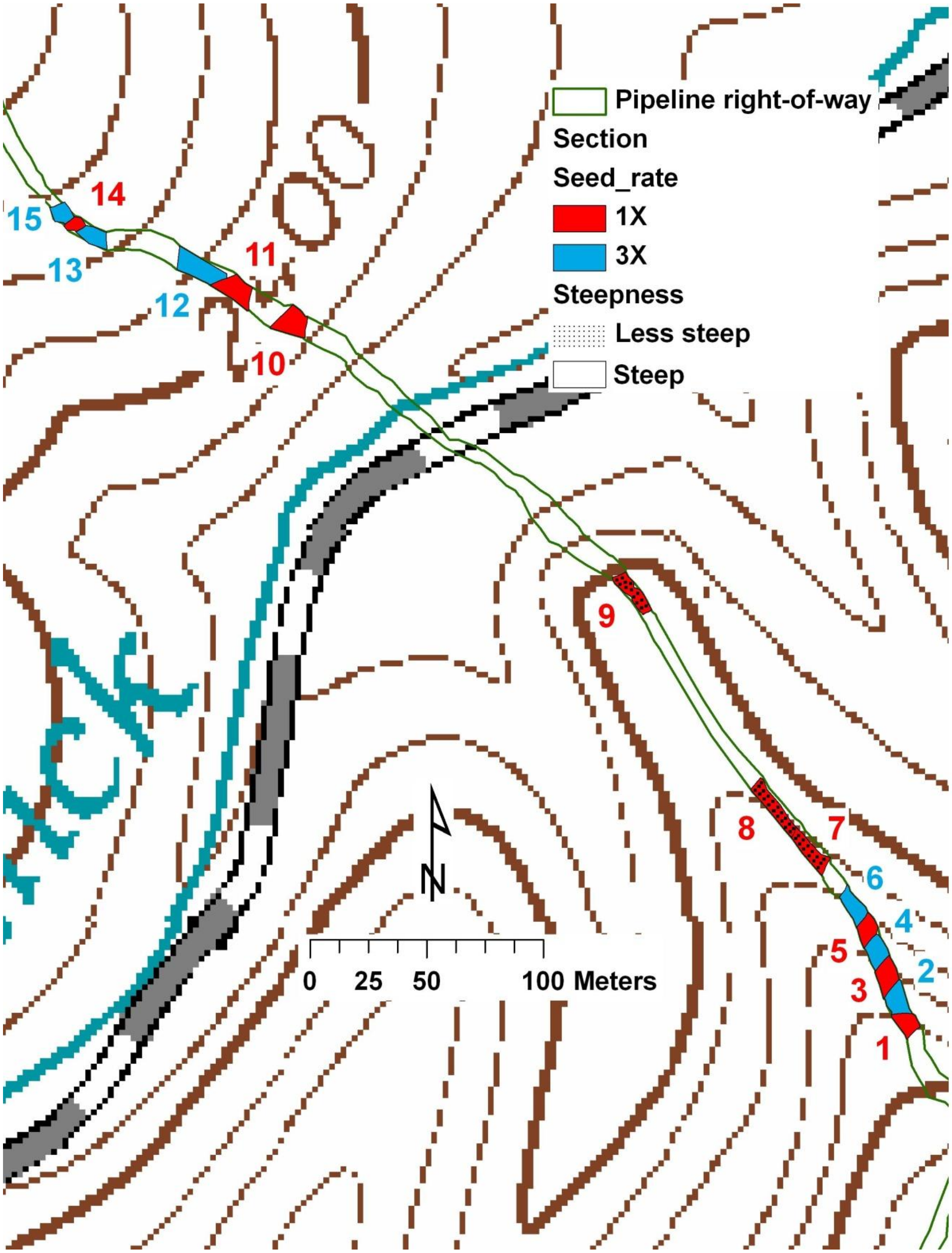

Figure 3. Study section locations indicating seed rates and slope class.

Table 5. Northwest-facing and southeast-facing section pairs and their corresponding seed rates.

Northwest-facing	Paired southeast-facing	Seed rate
1	10	1-time
2	13	3-time
3	11	1-time
4	15	3-time
5	14	1-time
6	12	3-time

To determine if there were differences in the soils on the northwest- and southeast-facing slopes three soil pits were excavated, and Monongahela National Forest Soil Scientist (Stephanie Connolly) characterized the soils (Appendix 1). The pits were excavated immediately adjacent to the pipeline in areas that were considered representative of the sections in that general area. Pit 1 was located on the northwest-facing side near study section 4 to represent the steep sections on that aspect. Pit 2 was excavated on the northwest-facing side near study section 8 to represent the less-steep sections. Pit 3 was located on the southeast-facing side near study section 13 to represent the steep sections on that aspect.

Monongahela National Forest Geologist (Linda Tracy) determined the geology near study section 6, of the steep slope class on the northwest-facing aspect, from visual observations of exposed bedrock along the cutbank of a skid road that existed nearby and parallel to the pipeline. Results of the soil pit excavation and geologic observations are presented later.

Field Equipment

To measure sediment losses, runoff was collected at the down slope water bar of each section (Fig. 4). Field equipment was installed from May through early June 2009 (Table 1). Four pre-fabricated metal 0.61-m H-type flumes and 11 wooden flumes, locally constructed from pressure-treated wood, were used to concentrate and direct surface runoff (Fig. 5). The wooden flumes were built to approximately the same dimensions as the metal flumes, and four coats of varnish were applied to the base and lower half of the side of the wooden flumes to provide a smooth surface on the wood. A bead of silicone caulk was applied to the inside edges where the horizontal and vertical pieces join to prevent water and sediment from leaking through the flumes.

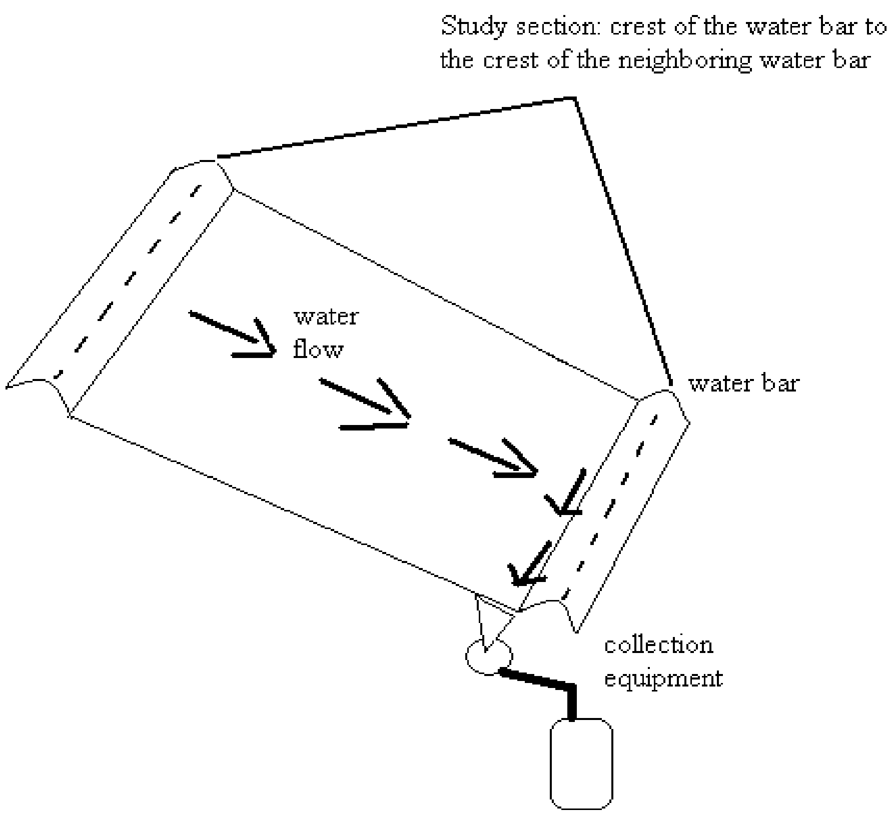

Figure 4. Schematic of a study section in the pipeline.

Figure 5. A pre-fabricated metal flume (left) and a constructed wooden flume (right).

A flume was installed at the outlet of the water bar in each study section. A notch was cut into the soil at the outlet of the water bar wide enough for the back of the flume. A straight cut was made along the edge of the soil where the flume then was positioned up against it, approximately 3 cm below the ground surface. Two wooden stakes (5.0 x 5.0 x 1.2-cm) were driven into the ground on each side of the flume and then fastened to the flume with lag screws to secure the flume in place. The seam between the flume and soil was filled with hydraulic cement to ensure a smooth, hardened connection between the ground surface and the flume.

Twelve pre-fabricated metal pans and three locally-constructed plastic pans (Fig. 6) were used to further divert the runoff toward collection tanks. The metal pans were obtained from Coshocton wheels. The constructed pans were assembled from square buckets cut in half (vertically). A PVC connector was installed a few inches from the bottom of the bucket and a layer of hydraulic cement was poured into the space between the bottom of the bucket and the bottom of the connector. A bead of silicone caulk sealed the edges of the cement to the bucket. A pan was installed below the output of each flume. PVC pipe then was connected to each pan to a collection tank located down slope to allow gravity drainage of runoff to the tank.

Figure 6. A pre-fabricated metal pan (left) and a constructed plastic pan (right). The flume outlet is at the top of each photograph, and the pipe leading to the tanks is shown at the bottom of the left photograph and on the right of the right photograph.

High-density polyethylene holding tanks were used to store collected runoff (Fig. 7). Six 473-L tanks, available from previous studies, had cone-shaped bottoms, and nine 378.5-L tanks procured for this study had flat bottoms. All of the tanks had demarcations in 10-gallon units. To improve the accuracy of the volume measurements taken during sampling (described later), 1-gallon increments were marked on the tanks.

Figure 7. A cone-shaped (left) and flat-bottomed (right) collection tank.

Water Sample Collection

Collection of runoff samples started on May 22, 2009; however, only tank 6 was connected and sampled at the time. On May 27, 2009 tanks 1-5 were installed and samples were collected from tanks 1-6 on May 28, 2009. On June 1, 2009 tanks 7-9 were installed and on June 3, 2009 tanks 13-15 were installed. On June 8, 2009 tanks 1-9 and 13-15 were sampled and tanks 10-12 were installed. All tanks were in place and sampled on June 12, 2009 (Table 1). Sampling continued for one year from that date.

Samples were collected after individual precipitation events when possible; however, a portion of the samples included multiple events, particularly those that occurred on weekends. The date, time and tank volume were recorded at the time the samples were taken. Prior to collection, the contents of the tanks were stirred using a long-handled brush to re-suspend settled solids (Fig. 8). Three 1-L replicate samples were collected from each tank, and the order of the samples collected was noted. The tanks then were emptied. Solids that were present in the flume or in the pans at the time of sample collection were removed and placed into small labeled bags to be included in the total sediment yield for that sample date (described later).

Figure 8. The contents of the tank were re-suspended by stirring prior to sample collection.

Four of the tanks filled to the capacity and/or overflowed during a few of the initial precipitation events. Consequently, splitters manufactured by Oasis Design^{TM} were installed on July 14-15, 2009 (Table 1; Fig. 9). The splitters were placed on concrete bases and leveled. Each splitter was calibrated to determine the actual percentage of water transmitted to each tank. The splitters were recalibrated in the spring of 2010 following the final snowmelt to calculate new calibration values following freeze-thaw of the splitters or concrete pads during the winter or early spring. The initial calibration values were applied to all samples collected prior to January 23, 2010, and the recalibration values were applied to all subsequent sampling periods. This date was selected as the cutoff because prior to January 23, freezing was minimal, but a snowpack and below-freezing temperatures persisted throughout most of the remaining winter.

Figure 9. A splitter (see arrow) installed on section 7, to prevent tank overflows. Splitters were also installed on sections 3, 4, and 6. Approximately one-half of the flow through the pan was delivered to the tank (left PVC pipe in this figure) and the other half was diverted onto the forest floor (right PVC pipe in this figure).

Sediment Sample Processing

Sediment was determined for each of three subsamples collected from each tank at the U.S. Forest Service's Northern Research Station office in Parsons, WV. The U.S. EPA method

160.2 was used to determine the concentration of sediment from the collected samples (Keith, 1991). The first step in the analysis process was to determine the total weight of each sample to obtain its volume. After that, total suspended sediment concentrations were determined. Samples collected soon after pipeline construction contained large sediment masses so most of those samples were initially centrifuged to separate sediment from the water prior to filtering the remaining supernatant. However, as vegetation became established sediment levels declined, making centrifuging unnecessary. Centrifuging was terminated in November 2009.

The solid material remaining in the centrifuged bottles was transferred to one or multiple pre-weighed 70-mm-diameter aluminum weighing dishes. Each bottle was thoroughly rinsed to remove any remaining solids; the rinse water also was transferred to the aluminum dish. The aluminum dishes were oven-dried for 2-6 hours, depending on the amount of water present in the dish.

Following centrifuging, the supernatant was vacuum filtered through Whatman™ GF/C glass microfiber filter papers. Samples that did not require centrifuging also were filtered through GF/C filters. Prior to use, clean filters were oven-dried for two hours and weighed to the nearest microgram. Following filtering, the filters were placed in a drying oven at 100°C for two hours to evaporate the associated water.

The oven-dried weight of the filters and aluminum weighing dishes was recorded, and then the filters and the pans were placed in a muffle furnace for 1 hour at 550° C to combust any associated organic material. After combustion, the filters and aluminum dishes were weighed. The initial clean oven-dried weights of the filters or the aluminum pans were subtracted from the final weight following combustion to determine the final weight of only the inorganic particles in each sample.

The solids collected from the pans and flumes in the field were placed into pre-weighed pans and oven dried. The oven-dried weight was recorded and the material also was combusted in a muffle furnace. The mass of the mineral material remaining in the pan was determined from the difference between the combusted weight and initial weight of only the pan.

The suspended sediment concentration of each pipeline section for each sampling date was calculated using the mass of the three tank samples and the combusted mass of the filtered and pan sediment (solids in flumes and pans). The average mass of the dry sample bottles + lids was subtracted from the total mass of the pre-filtered sample to calculate the mass of the tank sample contents. The total mass of the inorganic suspended sediment was subtracted from the mass of the pre-filtered sample contents to obtain the mass of the water without sediment. Using a 1:1 conversion of grams to milliliters, the mass of the filtered water then was converted to liters. The runoff sediment concentration was calculated by dividing the total mass of the inorganic suspended sediment by the volume of water (Keith 1991). The runoff sediment concentration was multiplied by the total volume of the water in the collection tanks to determine the total mass of sediment produced for each pipeline section for each sampling period.

Precipitation Measurements and Characteristics

Precipitation measurements were taken from a standard rain gauge and a recording rain gauge that were co-located near the study sections on the southeast-facing study section (Fig.10). Total rainfall (mm), 30-minute maximum intensity (mm), precipitation duration (h), and time since the end of the last precipitation event (h) were determined from the recording rain gauge strip charts. Rainfall and precipitation both refer to the total amount of precipitation collected (i.e. rainfall + snow/snowmelt). During the winter season minimal samples were collected due to consistently frozen tanks, however, samples included rainfall, snowfall, and snowmelt. Therefore precipitation and rainfall refer to the collection of both rainfall and snowfall, when applicable.

Corrections had to be made to the chart values using the total precipitation values from the standard rain gauge because the recording rain gauge tended to underestimate rainfall. Total weekly rainfall on the strip chart was adjusted to agree with the standard rain gauge measurements. If a single precipitation event occurred, the total difference was added to the strip chart for that week. If more than one event occurred the adjustments were made to account for the percentage of total precipitation for each event. The corrections were made by dividing the total measured precipitation from the standard rain gauge by the total precipitation from the recording rain gauge chart and then multiplying that ratio by each event on the strip chart. The end result was an adjustment to the precipitation total amount for that recorded event. Each precipitation event was multiplied by that ratio for only that chart. The process was repeated until all adjustments were made. Corrections were made to the nearest millimeter.

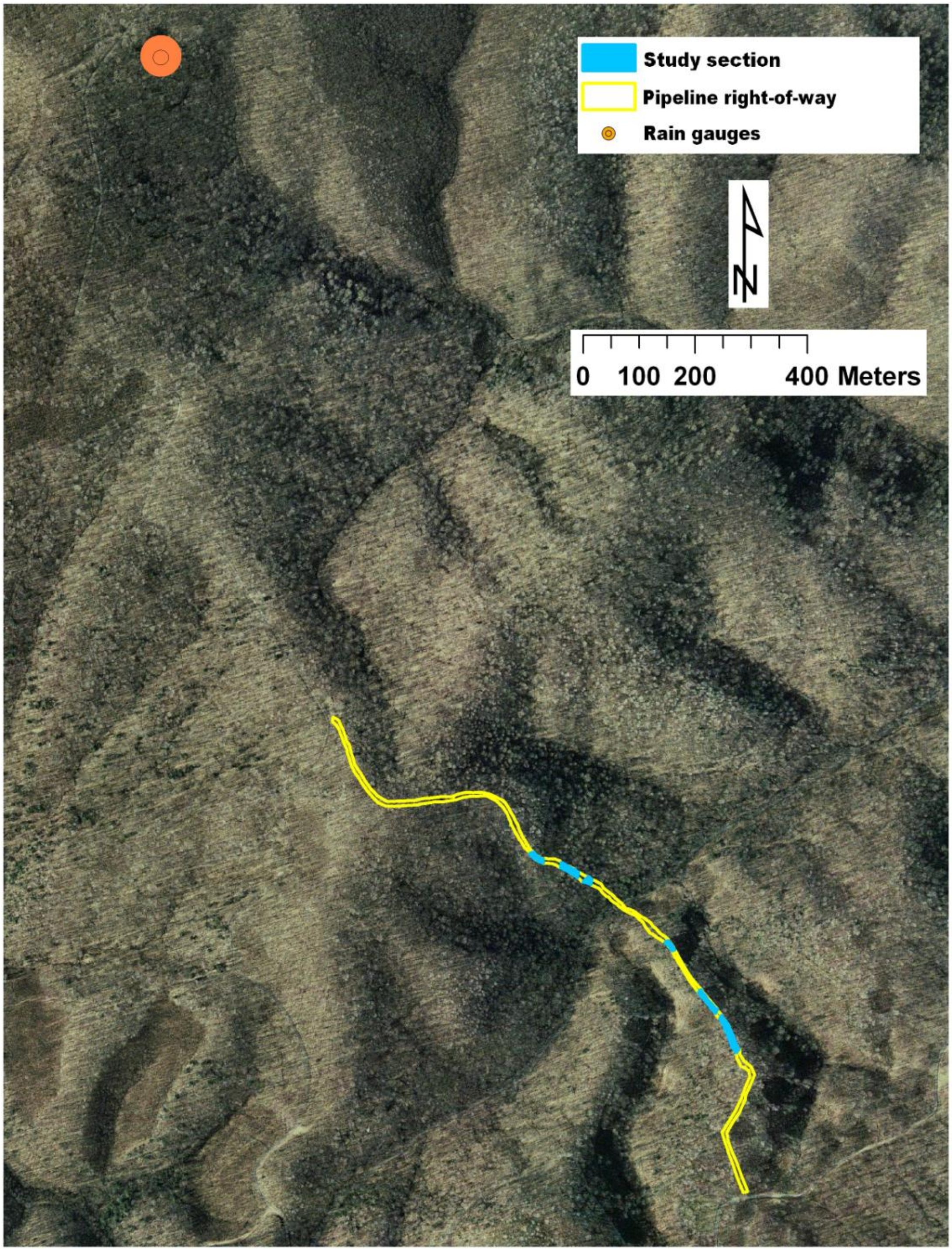

Figure 10. Aerial photograph showing the location of the rain gauges relative to the pipeline study sections.

Total rainfall was calculated as the sum of all precipitation in each sampling period. The 30-min maximum intensity was the maximum intensity during any 30-minute interval in each sampling period. Precipitation duration was the time from the start of each precipitation event to the end, and time since last storm was the time between the events.

Two data sets were developed for the statistical analyses: one containing all precipitation events (36 sampled events) which may have included single or multiple event storms, and one with single precipitation events that yielded 5-mm or more of precipitation (19 sampled events) (Table 6). The objectives for using two separate data sets, respectively, were to determine how precipitation totals influenced erosion from the study sections through each collection period, and to determine how important total precipitation, 30-minute maximum intensity, duration, and time since last storm were for explaining the variability in the sediment loss during individual events.

Table 6. Descriptive data for the 19 individual precipitation events that were used in regression models to determine the precipitation factors that explained the most variability in erosion.

Year	**Month**	**Total precipitation**	**Intensity**	**Duration**	**Time since last event**
		(cm)	**(cm hr^{-1})**	**(hr)**	**(hr)**
2009	June	1.34	0.38	2.50	12.00
2009	June	2.15	1.02	1.50	18.00
2009	July	1.26	0.25	12.00	15.25
2009	July	2.35	0.64	14.75	137.75
2009	July	1.74	1.40	1.25	62.50
2009	July	2.08	1.78	1.00	23.50
2009	July	0.60	0.89	23.00	22.25
2009	August	1.56	1.02	2.50	131.25
2009	August	1.38	0.76	7.50	113.50
2009	August	2.50	1.14	11.00	15.50
2009	September	0.36	0.19	28.50	163.00
2009	October	1.40	1.02	3.50	97.00
2009	October	1.88	0.25	65.50	9.50
2009	October	1.24	0.25	19.00	99.00
2009	November	0.80	0.51	9.00	462.00
2009	December	0.97	0.25	12.50	98.50
2010	May	1.29	0.13	18.50	11.50
2010	June	1.13	0.13	10.50	10.50
2010	June	2.55	0.13	25.75	51.50

Vegetative Cover

Percent vegetative cover was determined for each section using digital photographs. Because the total area of each study section was too large for a single photograph, each study section of the pipeline was divided into multiple subsections that were photographed individually.

Photographs were taken in late July through early August 2009 (Table 1) using a Canon™ Power Shot G2 4.0 megapixel digital camera. The camera was mounted on a swivel bracket on a prism pole positioned at 3.66 m above the ground. The camera was positioned at an angle that was approximately parallel to the slope of each pipeline section. Video output to a portable television allowed the camera image to be seen to correctly position the camera for each photograph. The camera was activated using a remote control. The digital number assigned by the camera to the photograph was recorded with the subsection number of the study section. Access to these subsections was limited prior to photographing in order to avoid damage to the vegetation. The methods for field photography were adapted from Bold et al. (2010).

For each pipeline section, wooden stakes (5.08 x 5.08 x 1.22-cm) were driven into the ground at the edge of the section's water bars. A nylon rope was stretched between the wooden stakes to delineate the outer edges of the pipeline. Each subsection of each study section was defined using a frame constructed of 3.05-m x 1.83-m PVC pipe (Fig. 11). The edge of the frame was positioned along the edge of the pipeline and a photograph was taken. Engineering pins were placed at the inside corners of the frame to identify the location where the frame had been positioned, and then the frame was moved so that the pins on one edge were on the inside edge of the new frame position. This was continued until the entire section was photographed. Where the frame extended over the rope on the other edge of the pipeline, the rope rather than the PVC was used to identify the edge of those photographs. The interior faces of the upper and lower water bar were also photographed. These subsections were delineated with nylon rope for photographs (Fig. 12). The process was completed for all 15 study sections.

Figure 11. PVC frame used to photograph vegetative cover. The camera was mounted at the top of the pole shown in the bottom of this photograph.

Figure 12. Crest and base of water bar delineated for photography.

Image analysis was done by using ArcGIS™ to first outline the segments delineated by the PVC pipe or the nylon rope for each photograph by creating a shapefile for each segment. Total area could be determined from the shapefiles. Erdas Imagine™ software was used to classify the photographs for percent vegetative cover. A signature file was created by closely examining and identifying shades of green, which represented vegetation. This process allowed the program to classify each image into two categories: “green” and “other”. This technique transformed the picture files into growing vegetation versus all other surface objects (i.e., soil, rock, sticks, leaf litter, etc.). The initial signature file was created from a previous project that also analyzed vegetative cover. To ensure the applicability of the file to this study, it was tested for vegetative color recognition using 30 photographs from this project -- two from each study section, selected at random. The photographs were classified and overlaid on the original photographs to ensure that all the green pixels were classified as vegetation. In cases where growing vegetation was classified as other, the signature file was adjusted until no further adjustments would improve the signature file.

The signature file then was used to classify each photograph. The classified photographs were converted to cover shapefiles using the extension Image Analysis for ArcGIS™ raster-to-feature data conversion tool. Each cover shapefile was clipped using its boundary shapefile. This resulted in a thematic shapefile with polygons coded as either vegetation or other for each subsection. The percentage was calculated for vegetation (i.e., “green”) and “other”.

Each photograph was taken from a consistent height; however the elevation changed from section to section so a common scale factor was necessary to determine cover, such as length or width. Photographs were laid out together and the common edges were identified. Using ArcGIS™ the lengths of the PVC frame used to capture a subsection were measured. The adjacent photographs could then be linked by the corresponding portion of the PVC frame, so working from one end or the other of the main part of the section, each photograph had a corrected scale factor applied to the edges. The scale factor was squared before its application to the surrounding edges because the pixel is a square unit. To determine percent vegetative cover, the total number of green pixels in each section was divided by the total number of pixels within the clipped area of each study section, and then multiplied by 100.

Statistical Methods

The experimental design was defined using the characteristics of the pipeline right-of-way (i.e. slope, aspect, and location). The experimental unit for this study was an individual pipeline study section. A total of 15 pipeline study sections were selected for data collection and each varied by the slope, aspect, and seed application rate. The experimental design used repeated measures because, although the sampling dates were independent from one another, the sediment losses were not; if sediment losses from a section were high for one storm, it was likely that they would be high for the next storm, because many of the physical characteristics of each section that contribute to erosion would not be expected to change much over short periods.

A preliminary visual assessment of the sediment data showed that by the end of August 2009 the concentrations of sediment had decreased substantially for all study sections (Fig. 13). Consequently, the data were split into three sets of time periods (separate from the two data sets used in the precipitation model) for analyses to potentially elucidate relationships that may be obscured by combining all of the data together. The time periods employed were: June 12, 2009-June 10, 2010, June 12-Aug. 31 2009, and Sept. 1, 2009-June 10, 2010 (the end of the 1-yr-long study).

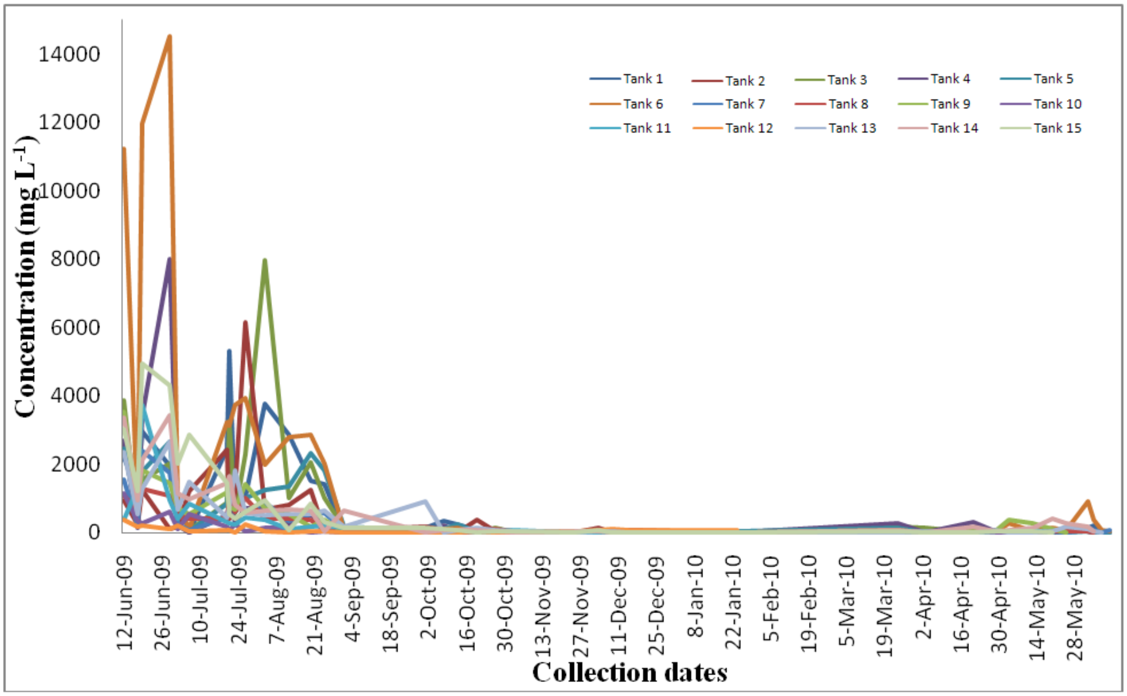

Figure 13. A graph of sediment concentration over time for each tank on each study section. By the end of August 2009, the concentrations of sediment decreased substantially for all study sections; thus, three time periods were used for data analyses.

A model was constructed using maxR stepwise regression with SAS/STAT® software (Yu, 2000) to determine which precipitation characteristics could explain a significant amount of the variability in erosion. The dependent variables were the rainfall characteristics identified previously and the independent variable was sediment concentration (mg L^{-1}). The best fit model was chosen based on the r-square and the C(p) outputs.

One-way analysis of variance models (ANOVA) with repeated measures were used to compare sediment concentrations by seed rate, aspect, or slope class categories (Table 7) at $\alpha = 0.10$ using SAS/STAT® software. The data were not normally distributed, however, repeated measure tests account for the serial correlation between measurements over time on the same subject. The percent vegetative cover data met the assumption of normality using the Shapiro-

Wilk test with a critical value of 0.05.Tukey's studentized range test was used to determine if percent vegetative cover was different between seed rates, aspects, or slope classes at α=0.10.

Table 7.The details of each ANOVA and the time periods that were compared for each ANOVA performed.

ANOVA performed	Time periods compared
Sediment concentrations for 1-time seed rate vs. 3-time seed rate using only steep sections and both aspects	June 2009-June 2010 June-Aug. 2009 Sept. 2009-June 2010
Sediment concentrations for 1-time seed rate vs. 3-time seed rate using only steep sections on the northwest-facing aspect	June 2009-June 2010 June-Aug. 2009 Sept. 2009-June 2010
Sediment concentrations for 1-time seed rate vs. 3-time seed rate using only steep sections on the southeast-facing aspect	June 2009-June 2010 June-Aug. 2009 Sept. 2009-June 2010
Sediment concentrations for steep vs. less steep sections on the northwest-facing aspect using 1-time seed rate	June 2009-June 2010 June-Aug. 2009 Sept. 2009-June 2010
Sediment concentrations for northwest-facing vs. southeast-facing steep sections using 1-time seed rate	June 2009-June 2010 June-Aug. 2009 Sept. 2009-June 2010
Sediment concentrations for northwest-facing vs. southeast-facing steep sections using 3-time seed rate	June 2009-June 2010 June-Aug. 2009 Sept. 2009-June 2010

CHAPTER 4

RESULTS AND DISCUSSION

Runoff Volumes

Runoff from the steep northwest-facing sections totaled 450,081 L ha^{-1}, compared with 65,546 L ha^{-1} from the steep southeast-facing sections. Total tank volumes were consistently greater for the northwest-facing section than the southeast-facing section for all three time periods (Table 8). The volume of runoff was statistically greater for the northwest-facing study sections during all three time periods (Table 9).

Table 8. Total tank volume (L) by section for the three time periods, by aspect.

Northwest-facing sections				**Southeast-facing sections**			
Tank	**Time period**			**Tank**	**Time period**		
	June 2009-June 2010	June 2009-Aug. 2009	Sept. 2009-June 2010		June 2009-June 2010	June 2009-Aug. 2009	Sept. 2009-June 2010
	----------------------(L)------------------				---------------------(L)--------------------		
1	1493.02	442.09	1050.93	10	985.46	192.41	793.05
2	2378.36	1135.27	1243.09	11	619.38	135.56	483.80
3	6997.83	3517.69	3480.14	12	205.10	10.98	194.12
4	7952.70	3369.97	4582.73	13	926.84	404.10	521.85
5	1293.09	247.48	1045.61	14	1184.52	1184.52	996.77
6	6589.51	2699.77	3889.74	15	601.53	172.22	429.31
Total	26707.41	11412.27	15292.23	Total	4523.29	1103.90	3418.90

Table 9. P-values of statistical comparisons of runoff volumes for the tanks on the six steep sections on the northwest-facing side of the pipeline vs. the six on the southeast-facing side.

Time periods	**p-value**
June 2009-June 2010	<0.0001
June-Aug. 2009	<0.0001
Sept. 2009-June 2010	0.0003

There is probably one main factor that contributed to the relatively large differences between the volumes on the two aspects – the northwest-facing aspect has a substantially greater contributing area. Contributing area is the area upslope of a position in a catchment where surface runoff is captured (Lindsay, 2003), therefore, the larger the contributing area, the greater the potential for high runoff volumes. The contributing area on the northwest-facing study aspect was approximately 8.3 ha compared with 1.1 ha on the southeast-facing study aspect (Fig. 14).

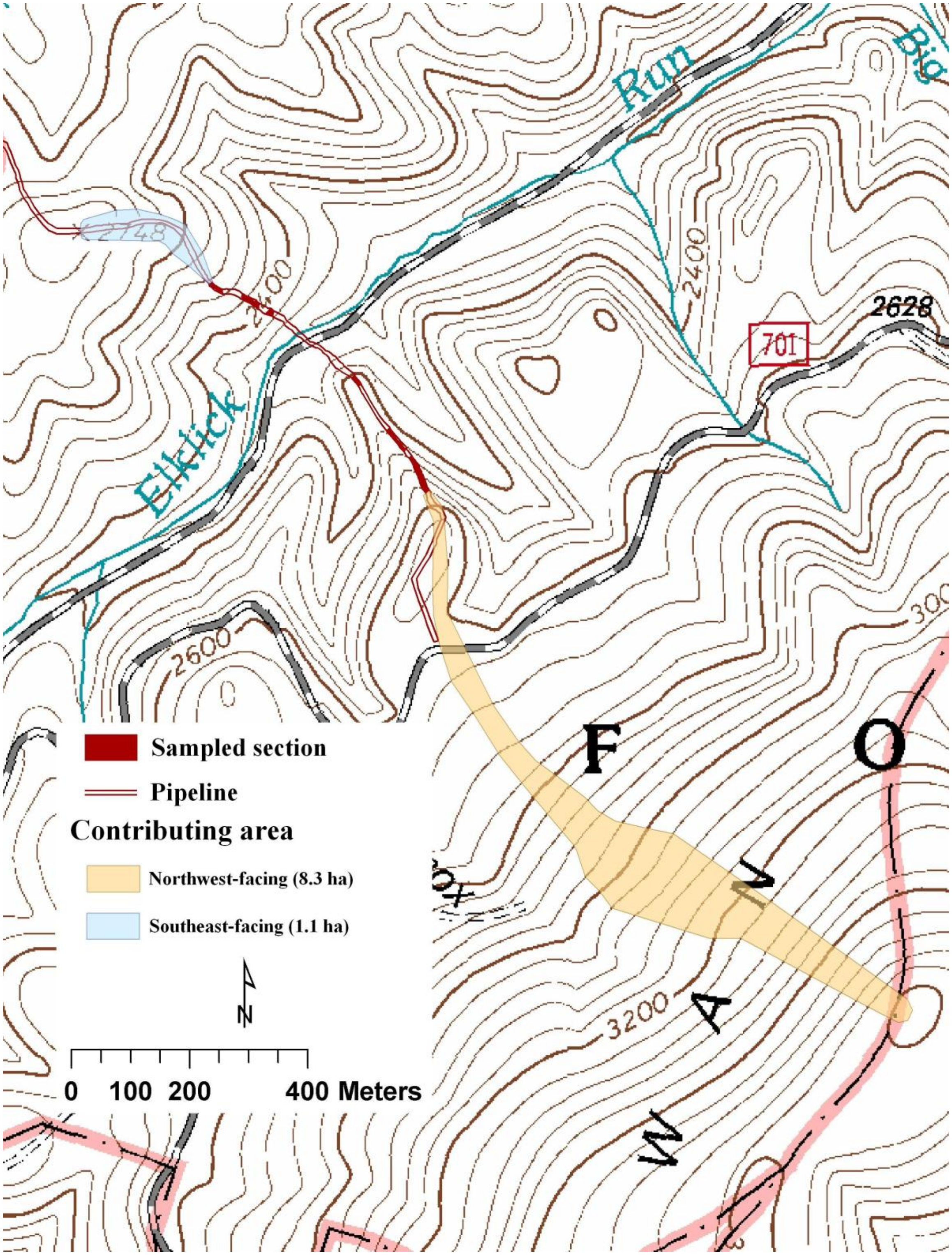

Figure 14. The contributing areas highlighted for each study aspect.

Table 8 also shows that there are substantial differences among runoff values for tanks on only the northwest-facing aspect. Sections 3, 4, and 6 had much greater total runoff than the other three steep pipeline sections on that aspect. The exact cause of this difference is not known, but it is believed to be due to the presence of a discontinuous fragipan on the northwest-facing side that is directing subsurface flow horizontally so the water either is intercepted by the base of those water bars (Fig. 15) or it is diverted onto the face of the pipeline and then captured as surface flow by the water bar. No evidence of overland flow or rilling was present under the mulch, which suggests water became emergent within the base of the water bar.

Soil pit 1 had a fragipan 50-80 cm beneath the surface that was absent in the other pits. A fragipan can have slow to very slow saturated hydraulic connectivity (Grossman and Carlisle, 1969). The spatial extent of the fragipan is not known, but is believed to be discontinuous; if it was continuous, all six of the northwest-facing sections would have been expected to have high runoff values. Results of a study in Pennsylvania also indicated that hillslopes containing fragic properties produced more runoff than soils without fragic properties (Needelman et al., 2004).

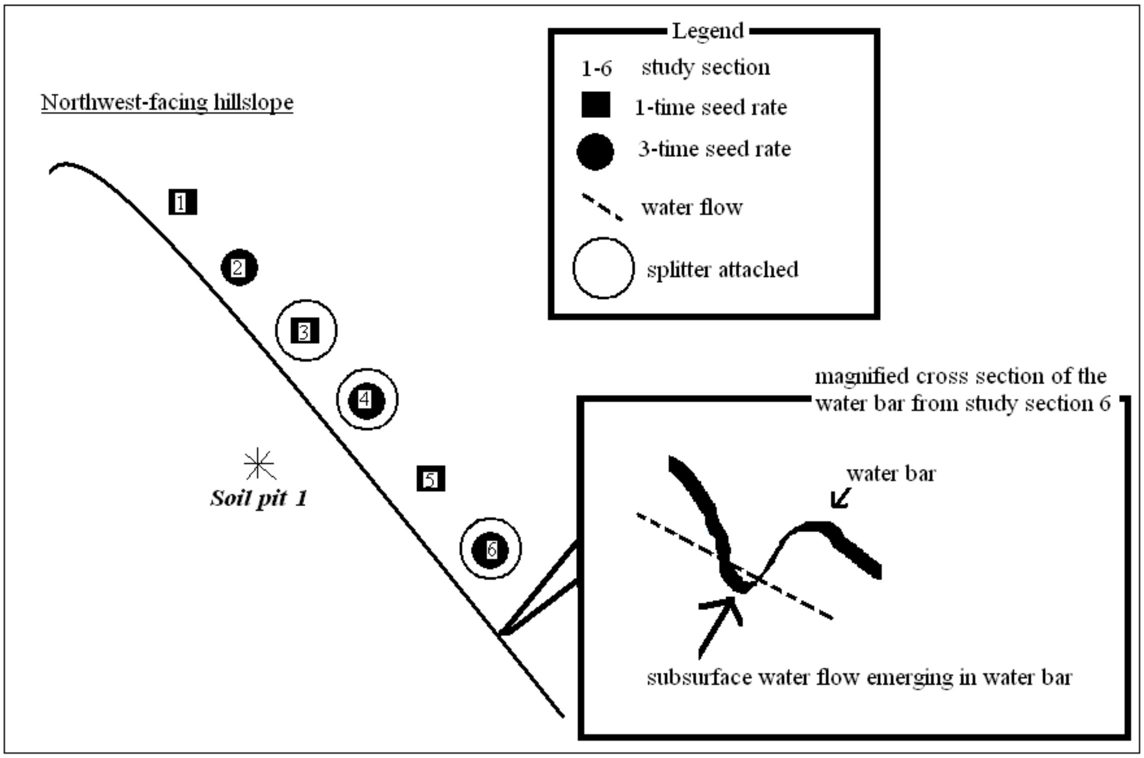

Figure 15. The northwest-facing hillslope with the seed rate and study section depicted with a magnified cross section of the water bar from study section 6 illustrating how subsurface flow emerging in the base of the water bar may have created the high runoff volumes on the sections that required splitters, circled in black.

The northwest-facing sections of the pipeline area were on a scarp slope (Fig. 16) with a dip of about 4 degrees. Normally a scarp slope directs water away from the slope face, but it appears that it is much less important in controlling subsurface flow on this slope than the fragipan. This may be because the dip of the geology is not particularly steep.

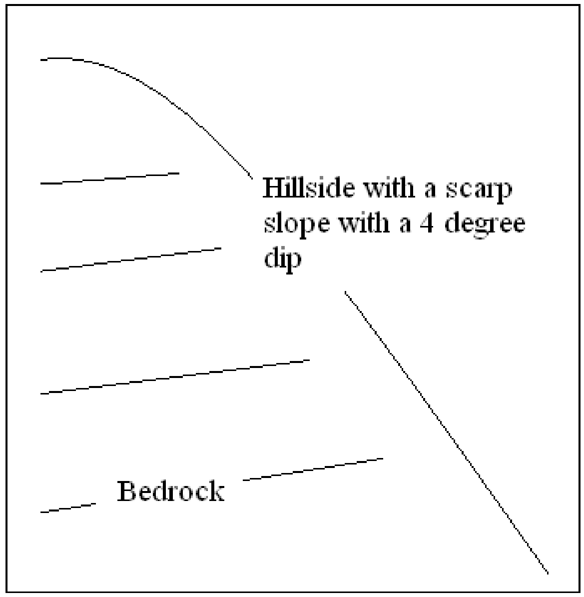

Figure 16. The bedrock beneath the steep northwest-facing study section is dipping at an angle of 4 degrees into the hillslope. Scarp slopes generally divert water away from the surface.

Sediment Loads

A total of 50.38 kg of sediment was collected from the fifteen study sections during the year of monitoring. This equates to 304.04 kg ha^{-1} yr^{-1} of soil loss from sections of the pipeline drained by water bars. This value is greater than sediment losses collected from undisturbed forest plots in the southern Appalachians (Kolka and Smidt, 2004), but it is less than that collected from an in-road pipeline in the central Appalachians (Holz, 2009). Four study sections in Holz's study produced 968.73 kg ha^{-1} yr^{-1} of sediment.

Total loads from the fifteen study sections ranged from 0.045 to 14.32 kg for the duration of the study period (Table 10). The average total load for the steep sections on the northwest-facing side was 6.85 kg ha^{-1} yr^{-1} while on the southeast-facing side the average total was 0.274 kg ha^{-1} yr^{-1}. The average total load for the less steep sections on the northwest-facing side was

2.54 kg ha^{-1} yr^{-1}. The average total loads on the steep sections of southeast-facing study sections were significantly less than that of the steep sections on the northwest-facing side. However, most of this difference is due to the much greater total runoff volumes from sections 3, 4, and 6 (Table 8), because loading calculations are dominated by the volume component of the calculation. The R^2 for the relationship of the sediment concentration to the volume of collected runoff shows a poor linear relationship existed between the two (Fig. 17), indicating that erosion rates did not increase proportionally with the runoff. Consequently, no further statistical analyses of loads were performed and the sediment-related focus of the rest of this thesis is on concentrations, since they are much less influenced by the total runoff volume.

Table 10. Total sediment loads (kg) and sediment loads per area (kg ha^{-1} of pipeline) for each section for the entire study period (June 2009-June 2010).

Northwest-facing sections			**Southeast-facing sections**		
Steeply sloped			**Steeply sloped**		
Pipeline section	**Total load (kg)**	**Total load (kg ha^{-1})**	**Pipeline section**	**Total load (kg)**	**Total load (kg ha^{-1})**
1	3.1964	374.071	10	0.0602	4.057
2	4.1122	371.404	11	0.0858	5.537
3	12.4793	1118.113	12	0.0455	2.578
4	5.9748	595.692	13	0.4684	48.990
5	1.0347	124.545	14	0.3392	72.684
6	14.3159	1400.361	15	0.6470	95.134
Less steeply sloped sections					
7	4.7505	396.898			
8	1.5884	110.831			
9	1.2854	116.183			

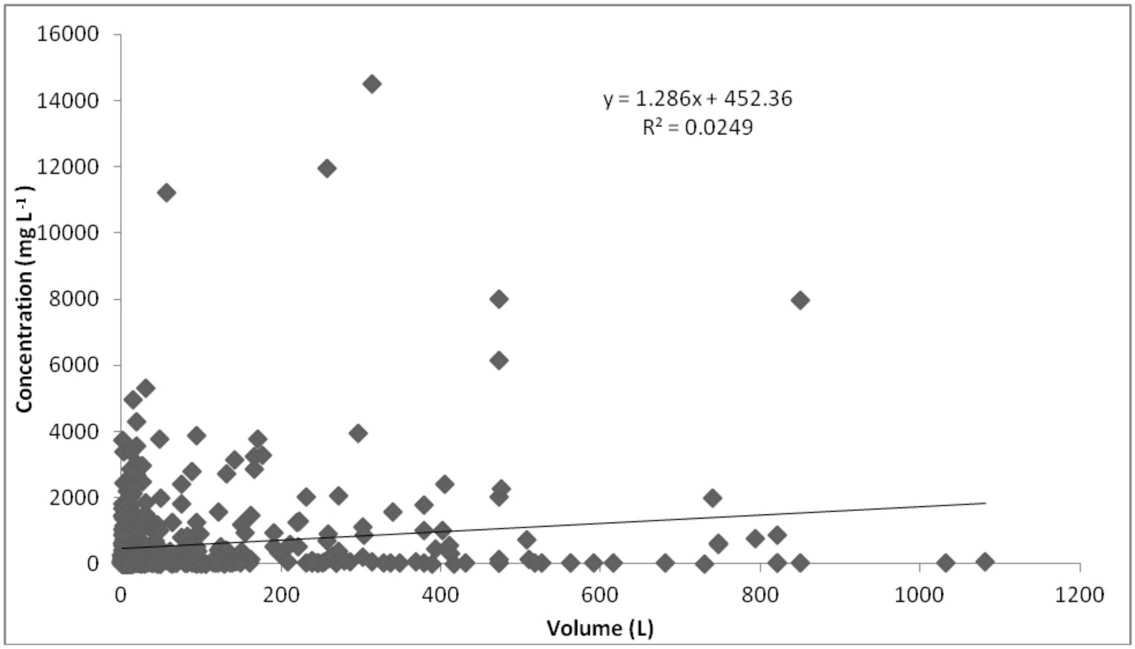

Figure 17. Graph of concentration vs. tank volume indicating that no linear relationship exists between the two variables.

Sediment Concentrations and Vegetation Establishment

At the beginning of the study, sediment concentrations were high but they decreased substantially during the first 3months of the study. Sediment concentrations ranged from 26 to 4500 mg L^{-1}. Concentration graphed against time for all tanks (Fig. 13) indicates an exponential reduction in concentrations from the beginning of the study to the end of August 2009. By contrast, samples taken near the end of August 2009 show that the variability in sediment concentrations as well as the concentrations themselves reached relatively low, consistent levels.

The exponential reduction of sediment concentrations suggests that as vegetation became established, erosion decreased. Other studies have shown that once vegetative cover reached 50 to 60 percent, erosion declined substantially (Bethlahmy and Kidd, 1966; Quinton et al., 1997;

Loch, 2000). In August 2009, the vegetative cover for the pipeline right-of-way for steep sections 1-6 and 10-15, ranged from 55.2 to 79 percent. The September 2009 through June 2010 data set showed no significant differences in sediment concentrations between the 1-time and 3-time seed rate sections suggesting that vegetative cover of at least 50 percent on the study sites provided an effective level of erosion control.

Average percent vegetative cover on the steep 1-time seed rate sections was very similar between the sections on the southeast-facing aspect (55.2%) and the northwest-facing aspect (53.6%). The average percent vegetative cover on the steep 3-time seed rate sections was statistically different ($p = 0.001$) between the northwest-facing aspect (53.2%) and southeast-facing aspect (79%). Although not significantly different ($p = 0.1903$), average vegetative cover on the 1-time seed rate sections (54.4%) was less than that of the 3-time seed rate sections (66.1%) (i.e., disregarding aspect). Vegetative cover on the northwest-facing sections was similar for the 1-time seed rate sections (53.6%) and the 3-time seed rate sections (53.2%). However, vegetative cover on the southeast-facing sections was less, but not statistically less ($p = 0.1414$) for the 1-time seed rate sections (55.2%) than for the 3-time seed rate sections (78.9%). The vegetative cover on the steep sections (53.6%) was significantly greater ($p = 0.0552$) than the less steep sections (34.4%) with the 1-time seed rate on the northwest-facing aspect. The lower amount of established vegetation on the less-steep northwest-facing study sections, compared to the steep sections on the same aspect, can be attributed to the narrow, forested right-of-way that shaded the pipeline during much of the day, coupled with small aspects (slopes ranged from 18-26%), which presumably limited the amount of sunlight reaching the ground.

The northwest-facing study sections had significantly larger sediment losses (mg L^{-1}) for 1-time seed rates during June 2009 – June 2010 ($p = 0.0393$) and June – Aug 2009 ($p = 0.0366$) compared to the southeast facing study sections (Table 11). Similar results are apparent ($p = 0.0848$ and $p = 0.0751$, respectively) for the 3-time seed rate sections. Disregarding aspect and only comparing 1-time seed rate vs. 3-time seed rate for the steep sections, the 3-time seed rate sections had significantly greater ($p = 0.0878$) sediment losses (mg L^{-1}) (Table 11). The 1-time seed rate steep sections had significantly larger sediment losses (mg L^{-1}) than the 1-time seed rate less steep sections on the northwest-facing aspect from June 2009 – June 2010 ($p = 0.0179$) and from June – Aug 2009 ($p = 0.0144$) (Table 11).

Table 11. The statistical comparisons of least square mean sediment concentrations (mg L^{-1}) between aspects for each time period by seed rate, between slope class on the northwest-facing 1-time seed rate sections only, between seed rate for northwest-facing and southeast-facing, and for seed rate only, disregarding aspect.

	June 2009-June 2010		**June-Aug 2009**		**Sept 2009-June 2010**	
	mg L^{-1}	**p-value**	**mg L^{-1}**	**p-value**	**mg L^{-1}**	**p-value**
1-time seed rate						
northwest-facing	683.52		1788.91		66.21	
southeast-facing	376.00		798.75		68.58	
		0.0393		0.0366		0.8682
3-time seed rate						
northwest-facing	966.62		2547.46		74.58	
southeast-facing	509.66		998.03		85.30	
		0.0848		0.0751		0.6716
Northwest-facing						
steep (1-time seed rate)	682.91		1751.67		66.86	
less-steep (1-time seed rate)	340.83		808.76		50.74	
		0.0179		0.0144		0.2595
Northwest-facing						
1-time seed rate	687.99		1744.02		67.88	
3-time seed rate	969.11		2514.49		74.77	
		0.2097		0.2271		0.7122
Southeast-facing						
1-time seed rate	399.88		925.30		66.38	
3-time seed rate	484.17		1161.18		86.03	
		0.5361		0.6312		0.3378
Seed rate only						
1-time seed rate	539.70		1318.00		67.32	
3-time seed rate	751.52		1923.33		80.45	
		0.0878		0.1095		0.3302

Two of the three 3-time seed rate sections on the northwest-facing aspect corresponded to sections believed to be influenced by the fragipan. Consequently, the greater runoff levels may have influenced the erosion rates from the soil primarily in the water bars (Fig. 15). However, the 3-time seed rate sections on the southeast-facing aspect were not influenced by a fragipan and these sections still produced more sediment than the 1-time seeded sections on the southeast-facing aspect (Table 11). Consequently, the additional seed application may not be necessary for controlling erosion because it did not appear to provide a reduction in erosion losses.

Precipitation

Total annual precipitation for 2009 at the Fernow Experimental Forest was 146.95 cm. Mean total annual precipitation for the previous 30 years (1979-2009) was 148.34 cm; consequently, total precipitation was near average during the study period (Table 12).

Table 12. Monthly precipitation totals during the study period. The totals for June 2009 and June 2010 are partial sums because the start and end dates of the study occurred in the middle of those months.

Year	**Month**	**Precipitation (cm)**
2009	June	7.38
2009	July	17.28
2009	August	10.21
2009	September	5.95
2009	October	16.86
2009	November	2.95
2009	December	11.47
2010	January	10.78
2010	February	11.55
2010	March	6.92
2010	April	5.99
2010	May	14.15
2010	June	6.89

Of the precipitation variables examined in the precipitation model, utilizing the precipitation data from the 19 individual events, 30-min maximum intensity explained the greatest variability in sediment concentrations (R^2 = 0.4910 and C(p) = 0.7351). Sediment concentrations versus 30-min. maximum intensity (Fig. 18) for the 19 individual sampled precipitation events illustrate that a significant linear relationship existed between the two variables (p = 0.002). Other studies by Nichols and Sexton (1932), Reid et al. (1999), Holz (2009), and Bold et al. (2010) also found rainfall intensity to be an important factor influencing erosion.

The other precipitation characteristics that were analyzed individually explained much less of the variability in sediment concentrations than intensity. Intensity and duration variables were included in the best two-variable model but could only explain 1.61 percent more variability than then one variable (intensity) model. Intensity, duration, and total precipitation amount combined was the best three variable model but only explained an additional 2.38 percent in variability compared to the one variable model. Consequently, based on the C(p) values for the two and three-variable models the single variable model was the best model for predicting soil losses.

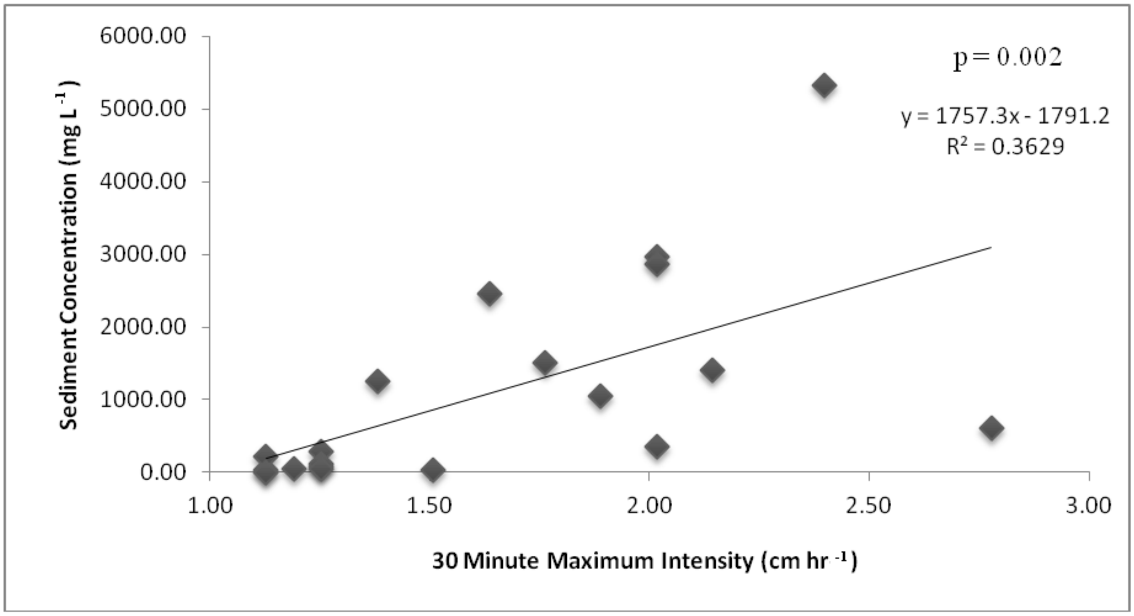

Figure 18. Sediment loss vs. 30-minute maximum intensity based on the 19 individual storm events.

Management Implications

As discussed previously, the excess flow from sections on the northwest-facing side is believed to be attributable to the fragic layer beneath the surface and the water bar construction. Physical characteristics cannot be controlled; however, it may be possible to alter water bar dimensions to reduce the potential for intercepting subsurface flow. Managers may want to consider constructing water bars in a manner that would avoid intercepting less subsurface flow while still controlling drainage. Water bar specifications may include a more shallow depth of the base, with most of the water bar being located on the soil surface. This would require scraping a longer length of soil surface to build each water bar.

The sediment concentrations from the two seed application rates indicated that the 3-time seed rate sections had higher amounts of erosion but the results were almost assuredly affected by the physical characteristics of the study section on the northwest-facing aspect. The vegetative cover was greater for the 3-time seed rate sections (66%) than the 1-time seed rate sections (54%), disregarding aspect. However, removing the influence of greater runoff by focusing only on the southeast-facing sections, the higher seed rate did provide greater vegetative cover (79%) than the 1-time seed rate sections (55%), but it did not result in reducing erosion. Therefore, managers must decide if the cost of establishing greater vegetative cover (in this case by using an additional 100 lb ac^{-1} application) for what ultimately may be simply an improvement in aesthetics is worthwhile.

Rainfall intensity had a strong relationship with erosion rates. Managers cannot control rainfall intensity, but they can control the timing of the construction and the exposure of soil to intense rain events. The summer months in this region hold a greater potential for high intensity storm events than the fall season. Therefore, planning construction to occur during the fall months may reduce the soil erosion potential. However, because of the lower rainfall and extremely limited time to get vegetation established prior to the onset of winter, substantial soil cover in the form of thick mulch or some other material would be necessary to protect the soil prior to seeding in the subsequent spring or early summer.

Future Research

The exploration of natural gas will continue as the nation's dependency on gas, oil, and coal increases. Further research is essential to determine the environmental impacts of natural gas exploration and natural gas pipeline construction. Future research should focus on implementing a study that has similar research objectives to this study. The physical characteristics of the study site like the contributing area, fragic layer, and scarp slope may have influenced the total volume of runoff and sediment that was collected from the study sections on the northwest-facing side. The results for this study may have been masked by the influences of these factors for the vegetative cover, seed application rate, aspect class, and slope class analyses.

Given more time and resources it would have been beneficial to take additional sets of percent vegetative cover photographs to compare sediment losses to percent vegetative cover with the passage of time. The first set would be more useful in this sort of comparison if it captured the cover before it had almost an entire growing season to become established. The second set then could be taken after the first growing season and finally a third set could be useful for after a second growing season had passed. The comparison of vegetative cover and its associated sediment losses would be important in determining how soil is impacted by vegetation recovery over time on this natural gas pipeline right-of-way.

CHAPTER 5

CONCLUSION

Contributing area appeared to influence the amount of runoff in sections with water bars due to interception of the subsurface flow by the water bars. The difference in erosion rates between the two aspects is indicative of the greater runoff. Runoff also seemed to have been augmented by the presence of a fragic soil layer in some pipeline segments. A fragic layer was found in a nearby soil pit, but the variability in the runoff among pipeline sections suggests that the layer may have been discontinuous. The presence of the fragic layer likely allowed substantial subsurface flow to become emergent in the water bars, but in the sections apparently absent of the fragic layer the surface runoff rates were much less.

It is no surprise that erosion rates were strongly affected by the amount of runoff; therefore, methods to control surface runoff or emergence of subsurface flow could be useful. Traditional BMPs like soil amendments (e.g., addition of seed and mulch) and the installation of water bars following construction are used to reduce the amount of sediment losses from pipeline rights-of-ways. However in the current situation, different water bar construction techniques may be useful to reduce the interception of subsurface flow. Water bar specifications may include a more shallow depth of the base, with more water bar fill being placed on the soil surface. This would require scraping a longer length of soil surface to build each water bar.

Initial vegetative establishment was much quicker on the 3-time seed rates sections than the 1-time seed rate sections. However, there was little difference in total erosion and sediment concentrations between study sections with the two different seed rates where the fragic layer influences were not present. In addition, as the first growing season came to an end, the percent vegetative cover establishment was very similar between the study sections of the two seed rates. All of the study sections reached 50 percent vegetative cover which has been shown to be the threshold needed to provide effective erosion control. The exponential reduction of sediment concentrations indicated that once vegetative cover reached 50-60 percent, erosion declined. This highlights the importance of not only establishing adequate vegetation cover as quickly as possible to limit erosion, but also that the 1-time seed rate utilizing native species was adequate in doing so.

REFERENCES

Anderson, P.G., Chandler, T.J., & Fraikin, C.G.J. 1995. Effects of natural gas pipeline constructions on a coldwater stream ecosystem. Prepared for TransCanada Pipelines Limited by B.A.R. Environmental Inc. 86pp.

Bethlahmy, N. & Kidd, W.J. 1966. Controlling soil movement from steep road fills. U.S. Forest Service Research Note INT-45, 4pp.

Bochet, E. & Garcia-Fayos, P. 2004. Factors controlling vegetation establishment and water erosion on motorway slopes in Valencia, Spain. *Restoration Ecology.* 12(2):166-174.

Bold, K. C., Wood, F., Edwards, P. J., Williard, K. W. J., & Schoonover, J. E. 2010. Using photographic image analysis to assess ground cover: a case study of forest road cutbanks. *Environmental Monitoring and Assessment.* 163:685-698.

Bradford, J. M., Ferris, J. E., & Remley, P. A. 1987. Inter-rill soil erosion processes: I. effect of surface sealing on infiltration, runoff, and soil splash detachment. *Soil Science Society of America Journal.* 51(6):1566-1571.

Brooks, K. N., Ffolliot, P. F., Gregersen, H. M., & DeBano, L. F. 2003. Hydrology and the Management of Watersheds: third edition. Blackwell Publishing Company. Ames, IA. 574 pp..

Bryan, R.B. 2000. Soil erodibility and processes of water erosion on hillslopes. *Geomorphology.* 32:385-415.

Chaplot V. & LeBissonnais, Y. 2000. Field measurements of interrill erosion under different slopes and plot sizes. *Earth Surface Processes and Landforms.* 25:145-153.

Churchill, R.R. 1982. Aspect-induced differences in hillslope processes. *Earth Surface Processes and Landforms.* 7: 171-182.

De Baets, S., Poesen, J., Gyssels, G., & Knapen, A. 2006. Effects of grass roots on erodibility of topsoils during concentrated flow. *Geomorphology.* 75:54-67.

Dey, P. K. 2002. An integrated assessment model for cross-country pipelines. *Environmental Impact Assessment Review*. 22:703-721.

Dey, P.K., Tabucanon, M. T., & Ogunland, S. O. 1996. Petroleum pipeline construction planning: a conceptual framework. *International Journal of Project Management.* 14(4):231-240.

Dey, P.K. & Gupta, S.S. 2000. "Analytic hierarchy process boosts risk analysis objectivity." *Pipeline and Gas Industry Journal*. 83(9):69-72.

Dunne, T. & Leopold, L.B. 1978. Water in environmental planning. Freeman, New York. 818pp.

Ellison, W.D. 1944. Studies of raindrop erosion. *Agricultural Engineering.* 25:131-136.

Energy Information Administration Office of Oil and Gas. 2009. Expansion of the U.S. Natural Gas Pipeline Network: Additions in 2008 and Projects through 2011. Online. Cited 2010 July 17. Available from: http://www.eia.gov/.

Energy Information Administration Office of Oil and Gas. 2010. Annual Energy Outlook 2010. Online. Cited 2010 July 17. Available from http://www.eia.gov/oiaf/aeo/pdf/trend_4.pdf.

Freebairn, D.M., Wockner, G.H., & Silburn, D.M. 1986. Effects of catchment management on runoff, water quality and yield potential from vertisols. *Agricultural Water Management.* 12:1-19.

Goldman, S.J., Barfield, B.J., & Hayes, J.C. 1986. Erosion and sediment control handbook. McGraw-Hill, New York.

Grossman, R. B. & Carlisle, F. J. 1969. Fragipan soils of the Eastern United States. *Advances in Agronomy.* 21:237-276.

Gyssels, G. & Poesen, J. 2003. The importance of plant root characteristics in controlling concentrated flow erosion rates. *Earth Surfaces Processes and Landforms.* 28:371-384.

Harbor, J. 1999. Engineering geomorphology at the cutting edge of land disturbance: erosion and sediment control on construction sites. *Geomorphology.* 31:247-263.

Holz, D. 2008. Factors affecting erosion on a natural gas pipeline in the Central Appalachians. M.S. thesis, Department of Forestry, Southern Illinois University Carbondale. 80pp.

Huang, C., Wells, L.K., & Norton, L.D. 1999. Sediment transport capacity and erosion processes: model concepts and reality. *Earth Surface Processes and Landforms.* 24:503-516.

Hursh, C.R. 1949. Climatic factors controlling roadside design and development. In *Proceedings, Highway Research Board, National Research Council.* 9-19pp..

Keith, L. H. (ed.). 1991. Compilation of EPA's sampling and analysis methods. Lewis Publishers Inc. Boca Raton, FL. 803pp..

Kinnell, P.A. 2000. The effect of slope length on sediment concentrations associated with side slope erosion. *Soil Science of America Journal.* 64:1004-1008.

Kinnell, P.A. 2005. Raindrop impact induced erosion processes and prediction: a review. *Hydrological Processes.* 19:2815-2844.

Kolka, R. K., & Smidt, M. F. 2004. Effects of forest road amelioration techniques on soil bulk density, surface runoff, sediment transport, soil moisture and seedling growth. *Forest Ecology and Management.* 202:313-323.

Lindsay, J.B. 2003. A physically based model for calculating contributing area on hillslopes and along valley bottoms. *Water Resources Research.* 32(12):1332.

Loch, R.J. 2000. Effects of vegetation cover on runoff and erosion under simulated rain and overland flow on a rehabilitated site on the Meandu Mine, Tarong, Queensland. *Australian Journal of Soil Research.* 38:299-312.

Long, D., Bender, M. J., Sawatsky, L. F., Anderson, P. & Metikosh, S. 1998. Sediment entrainment during construction of river pipeline crossings: Occurrence, prediction and control. *American Society of Mechanical Engineers.* 2:1045-1050.

Marsh, W.M. 1991. Landscape planning; environmental applications. Wiley, New York. 340pp.

Meyer, L.D. 1981. How rain intensity affects intterrill erosion. *Transactions of the American Society of Agricultural Engineer.* 24(6):1472-1475.

Miller, H.C.E. & Buell, M. 1956. Life-form spectra of contrasting slopes in Itasca Park, Minnesota. *BotanicalGazette (Chicago, Il.).* 117:259-263.

Morgan, R. P. C., Mirtskoulava, T. E., Nadirashvilli, V., Hann, M. J., & Gasca, A. H. 2003. Spacing of berms for erosion control along pipeline rights-of-way. *Biosystems Engineering.* 85:249-259.

Needelman, B.A., Gburek, W.J., Petersen, G.W., Sharpley, A.N., & Kleinman, P.J.A. 2004. Surface runoff along two agricultural hillslpes with contrasting soils. *Soil Science Society of America.* 68:914-923.

Nichols, M. L., & Sexton, H. D. 1932. A method of studying soil erosion. *Agricultural Engineering.* 13:101-103.

Nuttall, P.M. & Bielby, G.H. 1973. The effect of china-clay wastes on stream invertebrates. *Environmental Pollution.* 5:77-86.

Quansah, C. 1981. The effect of soil type, slope, rain intensity, and their interactions on splash detachment and transport. *European Journal of Soil Science.* 32(2):215-224.

Quinton, J.N., Edwards, G.M., & Morgan, R.C. 1997. The influence of vegetation species and plant properties on runoff and soil erosion: results from a rainfall simulation study in south east Spain. *Soil Use and Management.* 13:143-148.

Reid, S.M. & Anderson, P.G. 1999. Effects of sediment released during open-cut pipeline water crossings. *Canadian Water Resources Journal.* 24:23-39.

Reid, S. M., Ade, F., & Metikosh, S. 2004. Sediment entrainment during pipeline water crossing construction: predictive models and crossing method comparison. *Journal of Environmental Engineering and Science.* 3:81-88.

Reid, K. D., Wilcox, B. P., Breshears, D. D., & MacDonald, L. 1999. Runoff and erosion in a Pinon-Juniper woodland: Influence of vegetation patches. *Soil Science Society of America.* 63:1869-1879.

Robinson, L. R., & Yule, P. E. 1974. Erosion control during pipeline construction. In *Proceedings* of the *National Symposium on Urban Rainfall and Runoff and Sediment Control, Lexington. KY*, edited by UKY BU106, 1974.

Stuart, G.W. & Edwards P.J. 2006. Concepts about forests and water. *Northern Journal of Applied Forestry.* 23:11-19.

Swift, L.W. 1984. Gravel and grass surfacing reduces soil loss from mountain roads. *Forest Science.* 30:657-670.

Tengbeh, G.T. 1993. The effect of grass roots on shear strength variations with moisture content. *Soil Technology*. 6:287-295.

Thompson, C. N. 2008. Berry Energy, Inc. B-800 natural gas pipeline project (Decision Memo). WV: U. S. Department of Agriculture, Forest Service.

U.S. Department of the Interior Department of Land Management 2009, BMP Frequently Asked Questions. Retrieved from http://www.blm.gov/. Accessed August 4, 2010.

West Virginia Division of Environmental Protection Office of Oil and Gas. 2009. West Virginia erosion and sediment control field manual. Charleston, W.V.

West Virginia Division of Forestry. 2005. West Virginia silvicultural best management practices for controlling soil erosion and sedimentation from logging operations.

Wood, F., Personal Communication, 20 July 2010. USDA Forest Service, Northern Research Station IT Specialist/Data Manager.

Yu, C. H. 2000. An overview of remedial tools for collinearity in SAS. *Proceedings of 2000 Western Users of SAS Software Conference.* Scottsdale, AZ: WUSS.

Zellmer, S.D., Edgar, D.E., & Isaacson, H.R. 1991. Erosion control on a steeply sloped pipeline right-of-way in southwestern Pennsylvania. Gas Research Institute Final Report, 005832, Chicago, IL.

Zhang, G. H., Liu, G. H., & Zhang, K. M. 2008. Flow detachment of soils under different land uses in the loess plateau of China. *American Society of Agricultural and Biological Engineers.* 51(3):883-890.

APPENDIX

APPENDIX A. Soil pit 1, 2, and 3 field notes and soil description.

Pit #/Location 1/northwest facing side Soil type Calvin (Shouns) File no. SJC
Area Pipeline Erosion Study Date June 3, 2010 Stop no.______
Classification Colluvium over residuum
Location Fernow Exp. Station
N. veg. (or crop) hardwood, red oak, greenbrier Climate mesic
Parent material siltstone/ sandstone Hampshire
Physiography Allegheny Mtns
Relief back slope Drainage mod well Salt or alkali____________
Elevation____________Gr. Water________________Stoniness____________
Slope________________________Moisture__________________
Aspect_______________Root distrib._________________% clay_____________
Erosion___________% Coarse fragments________% Coarser than V.F.S.________
Permeability_________________________________
Additional notes Bt wet water moving thru profile (not argillic horizon but clayskins present in the Bt layer)
Top 50 cm (little rock component) Mixed sands (fine, silt)

		Color				Consistence							
Horizon	Depth	Dry	Moist	Texture	Structure	Dry	Moist	Wet	Reaction	Boundary	Roots	Clay films	Rocks
Oe/ Oa	0-3	O horizon decomposed											
A	3-8		7.5 yr 3/2	Sil	2 fgr			vfr		cw	3vf 2m 3f		10% Gr
BA	8-17		7.5 yr 3/4	Sil	lmsbk/ 2mgr			vfr		cs	3vf 3f 3m		10% Gr
Bw	17-50		7.5 yr 4/4	SiCl	2 msbk			fr		cs	3f 1vf 1m		20% Gr
Bt	50-80		7.5 yr 4/4	SiCl	2 msbk/ 2fsbk			fi		cs	2f 1vf	2 pr on ped faces & rocks	25% Fl 40% Gr 25%Cb
Cr	80-108	Boulder decomposing in place w/ a small amount of									__		90% Bld
BC	108-125		7.5 yr 3/4	SiC	m			vfi		cs	1f		30% Gr
Cr	125	green	siltstone							__	__		

Pit #/Location 2/northwest facing side Soil type Calvin File no. SJC
Area Pipeline Study Fernow Date June 8, 2010 Stop no.______
Classification ______________________________________
Location Fernow Exp. Station
N. veg. (or crop) NRO, PM, SM beech midstory Climate mesic
Parent material Hampshire residuum
Physiography Allegheny Mtns
Relief bench (ridge) Drainage well drained Salt or alkali____________
Elevation____________ Gr. Water________________ Stoniness <0.1%
Slope 10% Moisture__________________
Aspect 289 º W Root distrib._________________ % clay______________
Erosion___________ % Coarse fragments________ % Coarser than V.F.S.________
Permeability__________________________________
Additional notes____

		Color				Consistence							
Horizon	Depth	Dry	Moist	Texture	Structure	Dry	Moist	Wet	Reaction	Boundary	Roots	Clay films	Rocks
Oi	0-3	hardwood leaf											
Oe	3-6	highly decomposing											
Oa	6-11												
A	11-17		7.5 yr 3/1	Sil	2 fgr		vfr				3 vf 3 f		15% gr
BA	17-34		7.5 yr 3/4	Sil	2 fgr lmsbk		fr				3 flc 1vf 2m		15% gr
Bt	34-47		7.5 yr 3/4	L	2 msbk		fr				1f 1vf 2m	1f dis <15%	30% gr
BC	47-57		7.5 yr 4/4	L	m2fsbk		fi				2f		40% gr
C	57-79		5 yr 4/4	L	m		vfi				1f		45% gr
Cr	decomposing shale												

Pit #/Location 3/southeast facing side Soil type Calvin (low base) File no. SJC
Area Pipeline Study Fernow Date June 8, 2010 Stop no.______
Classification ______
Location Fernow Exp. Station
N. veg. (or crop) NRO, SM, chestnut oak beech midstory Climate mesic
Parent material Hampshire residuum
Physiography Allegheny Mtns
Relief backslope Drainage well drained Salt or alkali______
Elevation______ Gr. Water______ Stoniness 1% 3% (flags/Stones covered)
Slope 65% Moisture______
Aspect S 60 ° E Root distrib.______ % clay______
Erosion______ % Coarse fragments______ % Coarser than V.F.S.______
Permeability______
Additional notes pit to the left of the face of the pipeline
<30% rock top 30 cm, increase % rock ~30-50%; fractured bedrock
Bw2 → soil in pockets along rock fractures

		Color				Consistence							
Horizon	Depth	Dry	Moist	Texture	Structure	Dry	Moist	Wet	Reaction	Boundary	Roots	Clay films	Rocks
Oe	0-2	decaying hardwood leaf litter								cs			
A	2-7		10 yr 3/3	Sil	1 fgr		vfr			cw	2vf, f m		15% gr 5% flags
BA	7-22		10 yr 4/4	Sil	1 fgr 1msbk		fr			cw	3f 2m 1vf		5% gr 10% ch 10% fl
Bw1	22-52		7.5 yr 4/3	L	2 msbk		fr			cs	1f		30% fl 30% ch
Bw2	52-115		10 yr 5/4 5 yr 4/3	L	1 msbk		fi			iw			80%fl
Cr	115+	decomposing shale b/w harder rock, crumbles in hand											

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Harrison, B., Williard, K., Edwards, P., & Schoonover, J. "Evaluation of Current Best Management Practices Following Natural Gas Pipeline Construction." American Water Resources Association Conference. Philadelphia, PA, November, 2010.

Thesis Title:

Erosion from a Cross Country Gas Pipeline in the Central Appalachians

Major Professor: Dr. Karl W. J. Williard